State of California
Air Resources Board

Response to Notice of Availability of Modified Text and Availability of Additional Documents Released on September 23, 2009

SUPPLEMENTAL DECLARATION OF JAMES MICHAEL LYONS ON THE EXECUTIVE OFFICER'S CANE ETHANOL PATHWAY ANALYSIS

I, James Michael Lyons, declare as follows:

1. On August 19, 2009, I provided a Declaration in this proceeding that addressed, among other subjects, the Executive Officer's proposed modifications and additions to the cane ethanol pathways for proposed section 95486 of title 17, California Code of Regulations. The purpose of this Supplemental Declaration is to address certain aspects of the additions to the rulemaking file relevant to the cane ethanol pathway in the Executive Officer's Notice of Modified Text and Availability of Additional Documents released on September 23, 2009. My qualifications to address this subject are presented in my August 19, 2009, Declaration and Appendix A thereto. I could and would testify as to the facts and opinions set forth in this Declaration if called upon to do so.

2. Subsequent to the April Board Hearing at which the LCFS regulations were adopted, the Executive Officer published a documented entitled "Detailed California-Modified GREET Pathways for Brazilian Sugarcane Ethanol: Average Brazilian Ethanol, With Mechanized Harvesting and Electricity Co-product Credit, With Electricity Co-product Credit," dated July 20, 2009. According to the Second Notice of Public Availability of Modified Text and Availability of Additional Documents and Information, the staff of the California Air Resources Board ("CARB") has made "minor changes" to the Brazilian Ethanol Pathway (and others) to "correct slight calculation errors, rounding errors, and errors that occurred when outputs from the California-modified GREET model were transferred into the applicable supporting pathway documents." CARB staff also released another version of the Brazilian Ethanol Pathway document dated September 23, 2009.

3. The September 23 version of the Brazilian Ethanol Pathway document does not indicate explicitly any of the changes made to the June 20, 2009 version. I have therefore obtained a version of the Brazilian Ethanol Pathway document that attempts to show (as accurately as possible based on the use of commercial document comparison software), in CARB's traditional strike out and underline format, the additions and deletions reflected in the September 23, 2009 version relative to the July 20, 2009 version. This document is attached as Appendix A. As it shows, there are numerous changes to tabulated values throughout the document. Both the direction of numerical changes and the magnitude of the changes vary considerably from value to value. There are still obvious errors in the September 23, 2009 version. For example, summation of the values presented in either column of Table M does not yield the values for "Total GHG Emission" presented in Table M.

4. The CARB staff's updated analysis still fails to address a number of flawed assumptions that led to an underestimation of the carbon intensity ("CI") values for Brazilian Ethanol. An important example of this can be seen in CARB's assessment of GHG emissions due to transport of Brazilian ethanol to the California. As stated on page 11 of the September 23, 2009 version of the Brazilian Ethanol Pathway document, CARB assumes that "[a] significant fraction of ethanol imported into the U.S. is processed as hydrated ethanol (5% water) in the Caribbean where denaturant is also added. This delivery mode is not modeled in CA-GREET so the pathway based on delivering anhydrous ethanol to California is shown here." This CA-GREET modeled pathway is used in the determination of the CI values for Brazilian ethanol.

5. CARB's use of the CA-GREET pathway based on delivery of anhydrous ethanol, instead of a Life-Cycle Analysis (LCA) that accurately reflects CARB's understanding of the transport and processing of hydrated ethanol from Brazil in the Caribbean, leads to an underestimation of the CI value for Brazilian ethanol.

6. Hydrous ethanol has a somewhat higher density and somewhat lower energy content than anhydrous ethanol. The difference in density is approximately 2%; the difference in energy content on an equivalent volume basis is about 3%. Proper accounting for those factors, particularly during transport of ethanol inside Brazil and by tanker from Brazil, will increase the GHG emission estimates for Brazilian ethanol.

7. Energy is required to dehydrate cane ethanol to the anhydrous form used in the United States. There is no indication that the GHG emissions associated with the production of the energy required for this process have been accounted for in CA-GREET. Molecular sieve technology is reported to have an energy requirement of approximately 6,000 btu per gallon of hydrous ethanol that is dehydrated.[1] Assuming that this process energy requirement is met using steam from an 80% efficient Diesel-fueled industrial boiler (which appears to be a reasonable assumption based on comments submitted to U.S. EPA by Caribbean Basin Ethanol Producers Group[2]), and using the CA-GREET-based GHG emission factor for such a boiler of 78,298 gCO_2eq emissions per million btu of energy input and a value of 80.53 MJ/gal for anhydrous ethanol, the GHG emissions associated with dehydration amount to approximately 7.29 gCO_2eq/MJ.[3] Addition of this value to the CARB CI value for the Baseline Brazilian Ethanol pathway in the September 23, 2009 version increases the CI value by about 20% to 34.7 gCO_2eq/MJ; the percentage increases for the other two CARB Brazilian Ethanol pathways are even larger.

[1] Personal communication with Erin Heupel, POET LLC, September 16, 2009.
[2] Comments submitted to DOCKET NO EPA-HQ-OAR-2005-0161 by Caribbean Basin Ethanol Producers Group by George Fitch September 15, 2009, attached hereto as Appendix B.
[3] The net energy input per gallon is 7500 btu (6000/.8), which is divided by 1,000,000 and then multiplied by 78298 to yield 587 gCO2eq emissions per gallon dehydrated. That result is then divided by the value of 80.53 MJ per gallon of anhydrous ethanol contained in the CARB LCFS regulation.

8. CA-GREET assumes that the 150,000 DWT tankers will be used for Brazilian ethanol shipment. Tankers of this size have volumes 50 to 70% greater than the largest tankers that can pass through the Panama Canal (so-called "Panamax" tankers). Given this, Brazilian ethanol processed in the Caribbean would likely need to be transported in smaller and likely less energy efficient tankers through the Panama canal to California, with the result being greater GHG emissions than is estimated by CA-GREET.

9. The value of the CI credit provided to Brazilian Ethanol produced using mechanized harvesting was decreased slightly from the June 20, 2009 to the September 23, 2009 versions of the CARB Pathway document. However, this revised value does not accurately reflect the GHG emissions impacts associated with additional Diesel fuel use and process energy required for mechanized harvesting. These emissions are ignored by the CARB staff in arriving at the value of the CI credit for mechanized harvesting. Although there is no single approach to mechanized harvesting,[4,5] factors related to increased Diesel fuel use and additional energy requirements for cane and trash processing must be accounted for in assessing the GHG emissions associated with Brazilian sugarcane ethanol. This is acknowledged by Wang *et al*., who note that there could be differences in energy use and therefore GHG emissions between the two harvesting methods that are not accounted for in GREET or CA-GREET. [6]

10. In contrast to the CI credit for mechanized harvesting, the Executive Officer has not revised the CI credit provided to Brazilian ethanol produced in plants that generate surplus electricity. The value of that credit continues to be based on the assumption that **all** of the surplus electricity generated from ethanol production displaces natural gas based electricity generation. The source of the data used is reported to be "M. Wang, *et al*.: WTW Energy Used and GHG Emissions of Brazilian Sugarcane Ethanol – July 2007." Although this incomplete reference precludes definitive identification of the source of the data used by the CARB staff, it appears to be from a paper submitted for consideration by the International Journal of Life Cycle Assessment, which is dated July 20, 2007, with a submission date to the journal of July 23, 2007.[7] The following quotation from this reference highlights the speculative nature of the value of electricity co-product credit, which was also included in the 2008 publication by Wang *et al*. (Appendix E to this Declaration): "We assumed in our analysis that the exported electricity from sugarcane ethanol plants will displace electricity generated in natural gas electric power plants, which are believed to be the marginal electric power plants in

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[4] "Green cane impact on sugar processing," ISSCT Process Workshop, Saint Denis, Reunion Island, October 2008 http://issct.intnet.mu/processreport08.htm, attached hereto as Appendix C.

[5] "Biomass power generation: Sugar cane bagasse and trash," Published by PNUD and CTC, 2005 attached hereto as Appendix D.

[6] Wang, M., et al., "Life-cycle energy use and greenhouse gas emission implications of Brazilian sugarcane ethanol simulated with the GREET model," International Sugar Journal, Vol. 110, No. 1317, September 2008, attached hereto as Appendix E.

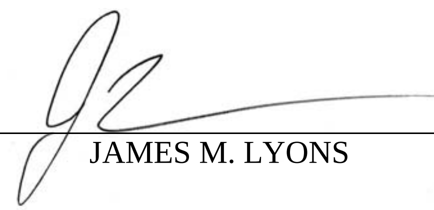
[7] Wang, M., et al., "Life-cycle energy use and greenhouse gas emission implications of Brazilian sugarcane ethanol simulated with the GREET model", Paper to be submitted to the International Journal of Life Cycle Assessment, July 20, 2007, attached hereto as Appendix F.

Brazil. On the other hand, if the exported electricity displaces the average electricity in Brazil (83% of which is from hydro-power), GHG emission benefits of sugarcane ethanol are reduced by up to 8 percentage points."

11. In addition, the assumption that all surplus electricity from ethanol production will displace natural gas based generation is not supported by other sources, including the U.S. Department of Energy. These sources indicate that rather than relying solely on increased natural gas based electricity generation capacity, Brazil plans to rely mainly on expanded hydro-power and nuclear power generating capacity.[8,9] Obviously, to the extent that surplus electricity from ethanol production displaces other sources that do not have associated GHG emissions, there should be no GHG emission reduction credit provided to sugarcane ethanol.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Executed this 8th day of October, 2009 at Dearborn, Michigan.



JAMES M. LYONS

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[8] Duff A. and Hirch R., "Power Struggle, the future contribution of the cane sector to Brazil's Electricity Supply," Rabobank, 2007; excerpt attached hereto as Appendix G.

[9] See *http://www.eia.doe.gov/emeu/cabs/Brazil/Full.html*, attached hereto as Appendix H.

APPENDIX A

California Environmental Protection Agency

Air Resources Board

Detailed California-Modified GREET Pathways for Brazilian Sugarcane Ethanol: Average Brazilian Ethanol, With Mechanized Harvesting and Electricity Co-product Credit, With Electricity Co-product Credit

Stationary Source Division

Release Date: ~~July 20,~~September 23, 2009

Version ~~2.2~~2.3

The Staff of the Air Resources Board developed this preliminary draft version as part of the Low Carbon Fuel Standard regulatory process

The ARB acknowledges contributions from Life Cycle Associates (under contract with the California Energy Commission) during the development of this document

When reviewing this document, please submit comments directly to:
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These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner.

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SUMMARY

CA-GREET Model Pathway for Brazil Sugarcane Ethanol

A Well-To-Tank (WTT) life cycle analysis of a fuel (or blending component of fuel) pathway includes all steps from feedstock production to final finished product. Tank-ToWheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together WTT and TTW analysis are combined together to provide a total WellTo-Wheel (WTW) analysis.

A life cycle analysis model called the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET)[1] developed by Argonne National Laboratory has been used to estimate the energy use and greenhouse gas (GHG) emissions associated with the entire pathway of producing ethanol from Brazilian sugarcane, transporting it via ocean tanker to a California port, distributed and finally used in a light-duty vehicle in California. The original Argonne model was modified to include California specific values and factors and this model, the CA-GREET model was published on the Low Carbon Fuel Standard website in February 2009 (http://www.arb.ca.gov/fuels/lcfs/lcfs. htm).

The original pathway document for sugarcane ethanol published in February 2009 was for baseline ethanol produced in Brazil, transported to and used in California. For this document, this original pathway termed 'baseline' pathway in this document is identical in all aspects to the pathway published in February 2009. However, the Board directed staff to analyze two additional scenarios for sugarcane ethanol to account for improved harvesting practices and the export of electricity from sugarcane ethanol plants in Brazil using energy from bagasse. Therefore, this document adds the two additional scenarios for ethanol from sugarcane in Brazil. These two are not to be considered average for all of Brazilian ethanol but specific cases when such practices are adopted in Brazil.

The first additional scenario (labeled Scenario 1) added here includes:

a) mechanized harvesting of cane which is gradually replacing the traditional practice of burning straw before harvesting cane and;
b) export of electricity (co-generated) from power plants that are capable of exporting additional energy beyond that required for processing in the plant (co-product credit).

The second additional scenario (labeled Scenario 2) added here is by considering only the export of electricity (co-product) from power plants capable of producing the additional electricity for export.

For the results presented in this document, none of the assumptions or values have been changed for the baseline pathway published in February 2009.

[1] GREET Model: Argonne National Laboratory: http://www.transportation.anl.gov/modeling simulation/GREET/index.html

Figure 1 below outlines the discrete components that comprise the baseline sugarcane ethanol pathway. The baseline pathway does not include impacts from the components corresponding to the dashed arrows which are for the two additional scenarios presented in this document.

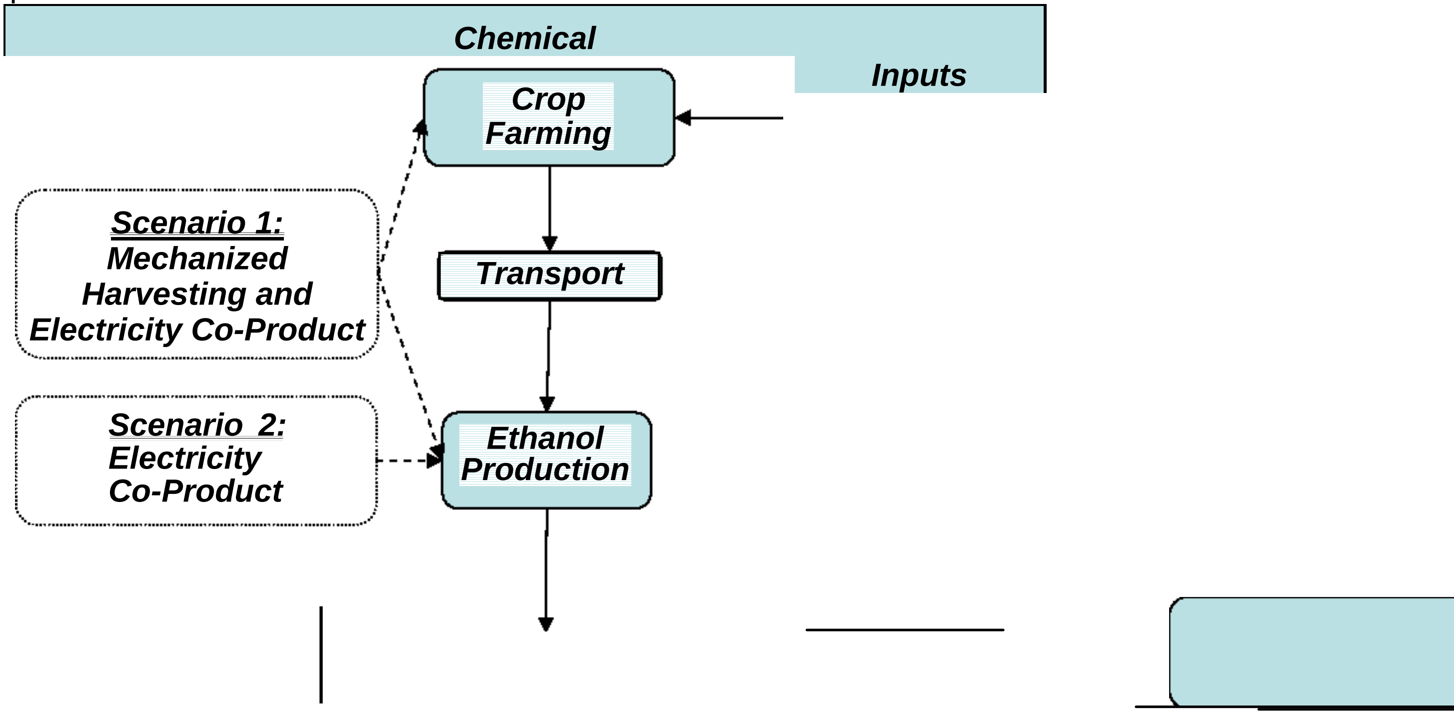

Figure 1. WTW Components for Sugarcane Ethanol Produced in Brazil and Transported for Use in CA

Several general descriptions and clarification of terminology used throughout this document are:

- CA-GREET employs a recursive methodology to calculate energy consumption and emissions. To calculate WTT energy and emissions, the values being calculated are often utilized in the calculation. For example, crude oil is used as a process fuel to recover crude oil. The total crude oil recovery energy consumption includes the direct crude oil consumption AND the energy associated with crude recovery (which is the value being calculated).

- Btu/mmBtu is the energy input necessary in Btu to produce one million Btu of a finished (or intermediate) product. This description is used consistently in CA-GREET for all energy calculations.

- gCO_2e/MJ provides the total greenhouse gas emissions on a CO_2 equivalent basis per unit of energy (MJ) for a given fuel. Methane (CH_4) and nitrous oxide (N_2O) are converted to a CO_2 equivalent basis using IPCC Global Warming Potential (GWP) values and included in the total.

- CA-GREET assumes that VOC and CO are converted to CO_2 in the atmosphere and includes these pollutants in the total CO_2 value using ratios of the appropriate molecular weights. This method is also used by the IPCC.
- Process Efficiency for any step in CA-GREET is defined as:

  Efficiency = energy output / (energy output + energy consumed)

- Note that rounding of values has not been performed in several tables in this document. This is to allow stakeholders executing runs with the GREET model to compare actual output values from the CA-modified model with values in this document.

Table A provides a summary of the WTW GHG emissions for the baseline pathway and the two additional scenarios described in this document.

Table A. Summary of Baseline Pathway and Two Additional Scenarios

Pathway Description	WTW GHG* Emissions (gCO2e/MJ)
Baseline Pathway Brazilian sugarcane using average production processes	27.40
Scenario 1 Brazilian sugarcane with average production process, mechanized harvesting and electricity co-product credit	~~12.20~~12.40
Scenario 2 Brazilian sugarcane with average production process and electricity co-product credit	20.40

*These values do not include contributions from Land Use Change. This analysis is available in the staff report titled "Proposed Regulation to Implement the Low Carbon Fuel Standard - Initial Statement of Reasons (ISOR)" from the website: www.arb.ca.gov/fuels/lcfs/lcfs.htm.

Results provided in this section are for all the three pathways: baseline and the two additional scenarios. All the components and values of the baseline pathway are applicable to the two additional scenarios presented in this document. Only certain components that provide GHG credits to the baseline pathway form the additional components for scenarios 1 and 2.

Table B summarizes the fuel cycle energy inputs by stage (Btu/mmBtu) and Table C summarizes the major GHG emission categories and intensities (gCO_2e/MJ) for the baseline pathway. This is same as the document published in February 2009 for the Brazilian sugarcane ethanol pathway (see Appendix A1 for further details on energy use and emissions). Figure 2 shows the percentage energy contributions from the various components of the baseline ethanol pathway. From an energy viewpoint, ethanol production (48.6%) and carbon in fuel (44.4%) components dominate the baseline sugarcane ethanol pathway. Figure 3 shows the GHG contributions from the various components of this pathway. From a GHG viewpoint, sugarcane farming impacts (37.2%) and production and use of agricultural chemicals (32.7%) components are the major contributors to the sugarcane ethanol pathway. Complete details of all energy inputs and GHG emissions for the baseline pathway are provided in Appendix A1. For the two additional scenarios provided in this document, details are provided in Appendix A2. A list of all input values is provided in Appendix B.

Note: Since all the ethanol is produced from sugarcane which consists of CO_2 fixed via photosynthesis, the tailpipe emissions from combustion of ethanol is considered to be zero. This is because the CO_2 release from combustion was actually removed from the atmosphere by the feedstock. The addition of denaturant, however, does lead to contributions to CO_2 during combustion which is proportional to the amount of denaturant added to anhydrous ethanol. This value is not shown below in Table C under TTW category since the values are shown for anhydrous ethanol. The discussion and calculations are presented in Appendix A1. Since the use of anhydrous ethanol as a stand alone fuel is not permitted in California, this document does not include tailpipe emissions of CH_4 and N_2O. An accompanying document for CaRFG[2] (containing ethanol as an oxygenate in CARBOB) provides combined effects including tailpipe emissions of using reformulated gasoline in a light-duty vehicle.

Table B. Summary of Energy Use for the Baseline Sugarcane Ethanol Pathway

Sugarcane Ethanol Components	**Energy Use (Btu/mmBtu) (Anhydrous)**	**% Energy Contribution**
Sugarcane Farming	~~26,407~~**26,219**	1.2%
Energy Inputs for Ag Chemicals	~~59,616~~**59,562**	~~2.7~~**2.6**%
Sugarcane Transportation	~~25,722~~**25,344**	1.1%
Ethanol Production	~~1,093,376~~**1,093,320**	48.6%
Ethanol T&D	~~44,442~~**43,795**	~~2~~**1.9**%
Total Well-to-Tank	**1,249,563**	**~~55.6~~55.5%**
Carbon in Fuel	1,000,000	~~44.4~~**44.6**%
Total Tank-to-Wheel	**1,000,000**	**~~44.4~~44.6%**
Total Well-to-Wheel	**~~2,249,563~~2,248,240**	**100%**

2 See this CaRFG document published 02/2009 by ARB: http://www.arb.ca.gov/fuels/lcfs/022709lcfs carfg.pdf

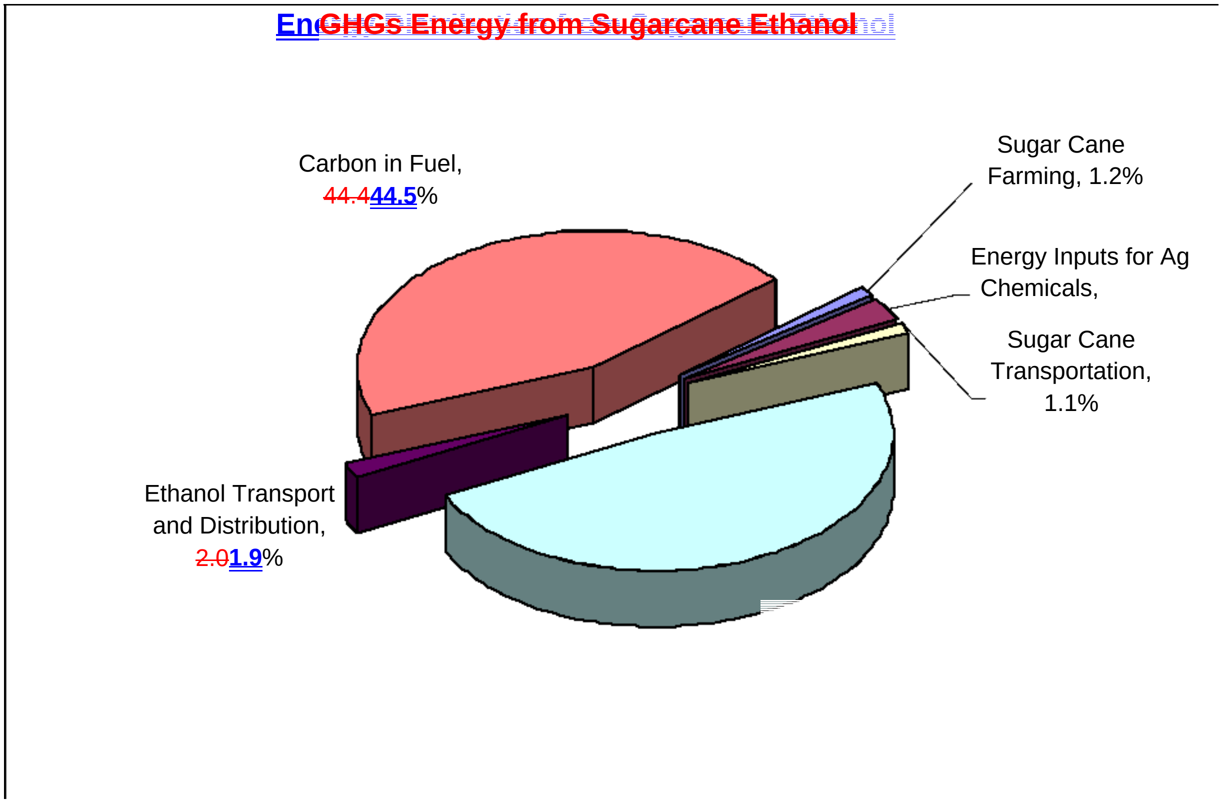

Figure 2. Percent Energy Contribution from WTW Analysis for Sugarcane Ethanol

Table C. GHG Emissions Summary for Sugarcane Ethanol

Sugarcane Ethanol Components	**GHG Emissions (gCO2e/MJ)**	**% Emission Contribution**
Sugarcane Farming *(incl. straw burning)*	~~9.9~~**9.8**	37.2%
Ag Chemicals Production and Use Impacts	~~8.7~~**9.2**	32.7%
Sugarcane Transportation	2.0	7.5%
Ethanol Production	~~1.9~~**2.1**	7.1%
Ethanol T&D	~~4.1~~**3.5**	15.4%
Total Well-to-Tank	26.6	100%
Total Tank-to-~~w~~Wheel	0	0%
Total Well-to-Wheel	**26.6***	**100%**

*Note: The value of **26.6 gCO2e/MJ** does not include contributions from CH_4 and N_2O when ethanol is blended with CARBOB and used as Reformulated Gasoline in a light-duty gasoline engine. The total GHG value including tailpipe contributions for sugarcane ethanol is **27.40 gCO_2e/MJ** when blended with CARBOB (approximately 10% by volume ethanol). Details of this calculation are available in the CaRFG document available on the LCFS website (www.arb.ca.gov/fuels/lcfs/lcfs.htm).

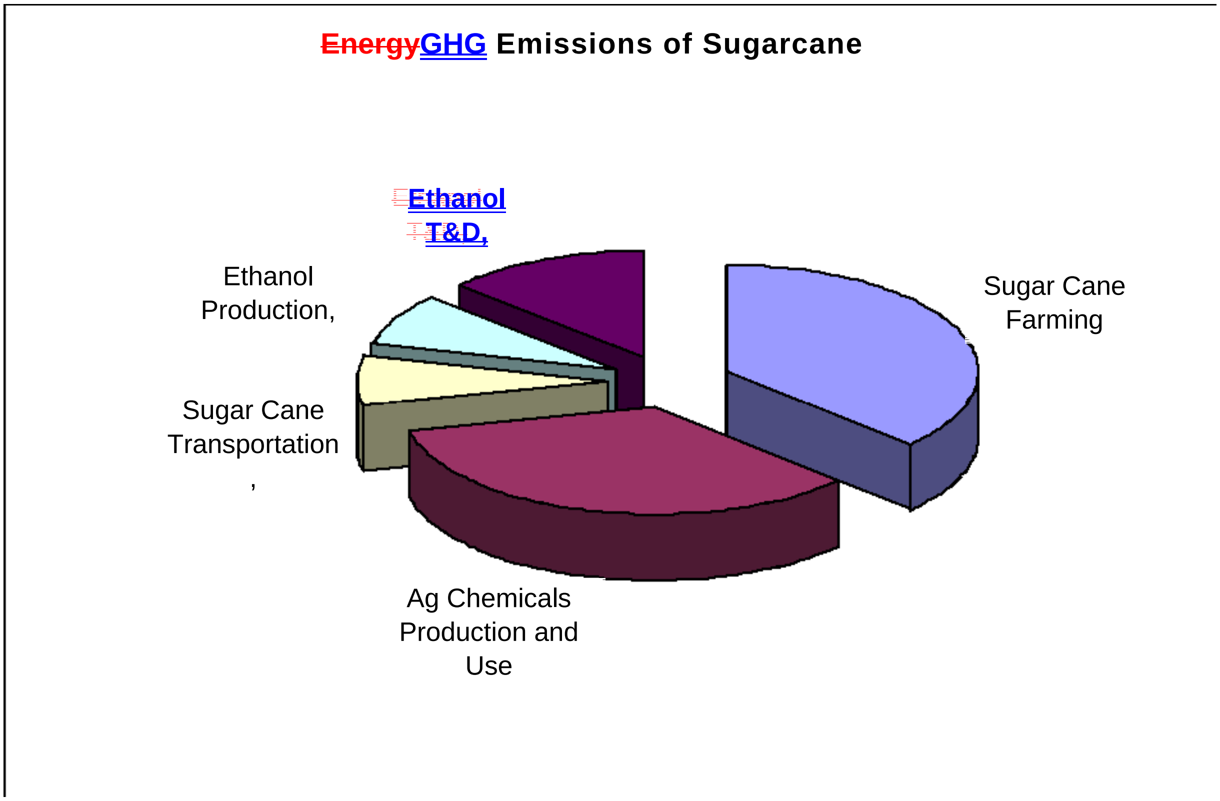

Figure 3. Percent GHG Emissions from WTW Sugarcane Ethanol

This section provides additional details of the energy and related GHG emissions for all the various baseline pathway components for sugarcane ethanol. Complete details including calculations, equations, etc. are provided in Appendices A1 and A2.

Additional Details of the Sugarcane Ethanol Pathways

The first part of this section provides results for the energy use and GHG emissions for the baseline sugarcane ethanol pathway. These values are identical for the two additional scenarios modeled here. Later in this section, details pertaining to the impacts of the two additional scenarios on the baseline pathway GHG emissions are provided.

SUGARCANE FARMING

Table D provides a breakdown of energy input from each fuel type used in sugarcane farming activities. Table E provides information on GHG emissions related to sugarcane farming. Additional details are provided in Appendix A1.

Table D. Total Energy Input by Fuel Use for Sugarcane Farmin

Fuel Type	**Total Energy Use**
Diesel fuel (Btu/mmBtu)	~~10,247~~**10,113**
Gasoline (Btu/mmBtu)	~~3,401~~**3,357**
Natural gas (Btu/mmBtu)	~~5,213~~**5,221**
Liquefied petroleum gas (Btu/mmBtu)	~~4,790~~**4,768**
Electricity (Btu/mmBtu)	~~2,756~~**2,760**
Total Energy for Sugarcane Farming ~~(Btu/mmBtu)~~	**~~26,407~~26,219**

Table E. GHG Emissions from Sugarcane Farming and Straw Burnin

Emission Species	**GHG Emissions of Farming**	**GHG Emissions of Straw Burning**
CH_4 (gCO_2e/MJ)	~~< 0.01~~**0.1**	6.6
N_2O (gCO_2e/MJ)	0.01	2.1
VOC (gCO_2e/MJ)	< 0.01	2.2
CO (gCO_2e/MJ)	< 0.01	~~14.4~~**14.2**
CO_2 (gCO_2e/MJ)	~~1.69~~**1.8**	163.20
Biogenic CO_2 credit (gCO_2e/MJ)	n/a	(-180.31)
GHG Emissions (gCO_2e/MJ)	**~~1.74~~1.8**	**~~8.2~~8.0**
Total GHG Emissions ~~**(gCO_2e/MJ)**~~		**~~9.9~~9.8**

INPUTS FOR AGRICULTURAL CHEMICALS

Table F provides details the energy inputs required to produce chemicals used in agricultural operations related to sugarcane farming. This includes fertilizers such as nitrogen, phosphorus, potassium (potash), and calcium carbonate (lime) as well as herbicides and insecticides. Table G provides details of the associated GHG emissions related to the production of these chemicals as well as their use in sugarcane farming. N_2O and CO_2 emissions from the soil are based on the amount of fertilizer and lime applied respectively. Complete details are provided in Appendix A1.

Table F. Energy Inputs for Agricultural Chemicals for Sugarcane Farmin

Chemical Type **(Btu/mmBtu)**	**Total Energy Use**
Nitrogen Fertilizer	~~31,054~~**31,076**
Phosphate	~~880~~**878**
Potash ~~(Btu/mmBtu)~~	~~885~~**889**
Lime ~~(Btu/mmBtu)~~	~~22,354~~**22,467**
Herbicide ~~(Btu/mmBtu)~~	~~3,853~~**3,875**
Insecticide ~~(Btu/mmBtu)~~	~~375~~**377**
Total Energy Use (Btu/mmBtu)	~~**59,616**~~**59,562**

Table G. Total GHG Emissions from Agricultural Chemical Use in Sugarcane Farmin

~~**Ethanol Pathway**~~	~~**Agricultural Chemicals**~~			~~**Soil N_2O and NO**~~	~~**CO_2 from Application of Lime**~~	~~**Total**~~
	~~**Fertilizers**~~	~~**Herbicide**~~	~~**Pesticide**~~			
~~**GHGs (gCO_2e/MJ)**~~	~~3.7~~	~~0.3~~	~~0.03~~	~~3.5~~	~~1.2~~	~~**8.7**~~

GHG Emissions	**GHG Emissions from Agricultural Chemicals**			**GHG Emissions from Soil N_2O and NO**	**GHG Emissions from CO_2 from Application of Lime**	**Total GHG Emissions**
	Fertilizers	**Herbicide**	**Pesticide**			
GHGs (gCO_2e/MJ)	**4.18**	**0.3**	**0.03**	**3.5**	**1.2**	**9.2**

SUGARCANE TRANSPORT

Table H details the energy inputs required to transport sugarcane from the farm to the ethanol production plant using heavy duty trucks. Table I provides details of the associated GHG emissions related to transportation of sugarcane from the farm to the ethanol plant. Complete details are provided in Appendix A1.

Table H. Sugarcane Transport Energ

Transport Mode	Energy Consumption
Total Energy Use for Sugarcane Transport (Btu/mmBtu)	**~~25,722~~25,344**

Table I. Sugarcane Transport – Total GHG Emissions

GHG Species	GHG Emissions
VOC (gCO_2e/MJ)	**≤ 0.01**
CO (gCO_2e/MJ)	**≤ 0.01**
CH_4 (gCO_2e/MJ)	**0.05**
N_2O (gCO_2e/MJ)	**0.01**
CO_2 (gCO_2e/MJ)	**1.88**
Total GHG Emissions	**2.0**

~~GHG Species~~	~~GHG Emissions~~
~~VOC (gCO_2e/MJ)~~	~~<0.01~~
~~CH_4 (gCO_2e/MJ)~~	~~<0.01~~
~~N_2O (gCO_2e/MJ)~~	~~<0.01~~
~~CO (gCO_2e/MJ)~~	~~<0.01~~
~~CO_2 (gCO_2e/MJ)~~	~~2.0~~
~~**Total GHG Emissions (gCO_2e/MJ)**~~	~~**2.0**~~

ETHANOL PRODUCTION

Table J details the energy inputs required to produce ethanol from sugarcane for the baseline pathway. Table K provides details of the associated GHG emissions related to production of ethanol. Complete details are provided in Appendix A1.

Table J. Ethanol Production Ener^gy Use

Fuel Type	Total Energy Use
From Residual Oil (Btu/gal)	~~284~~279
From Bagasse (Btu/gal)	83,132
Total Energy Input for Ethanol Production (Btu/gal)	~~83,415~~83,411

Total Energy Input for Ethanol Production (Btu/mmBtu)	~~**1,093,743**~~**1,093,320**

Table K. GHG Emissions for Ethanol Production

GHG Species (gCO2e/MJ)	GHG Emissions
~~CO_2 from~~ Residual Oil (gCO2e/MJ)	0.03
~~CO_2~~GHG from Bagasse ~~B~~burning	~~124.9~~124.93
~~CO_2 credit~~Credit for Bagasse burning	-~~122.97~~122.9
~~CH_4 (gCO_2e/MJ)~~	~~< 0.01~~
~~N_2O (gCO_2e/MJ)~~	~~< 0.01~~
~~VOC from Residual Oil (gCO_2e/MJ)~~	~~< 0.01~~
~~VOC from Bagasse Burning (gCO_2e/MJ)~~	~~0.02~~
~~VOC from non-combustion source (gCO_2e/MJ)~~	~~0.09~~
~~CO from Residual Oil (gCO_2e/MJ)~~	~~< 0.01~~
~~CO from Bagasse Burning (gCO_2e/MJ)~~	~~0.12~~
Total GHG Emissions (gCO2e/MJ)	~~1.9~~2.1

ETHANOL TRANSPORT AND DISTRIBUTION

Ethanol is transported within Brazil by rail or pipeline. It is then shipped to the US by ocean tanker. Several different denaturant blending options can apply to Brazilian ethanol. A significant fraction of ethanol imported to the U.S. is processed as hydrated ethanol (5% water) in the Caribbean where denaturant is also added. This delivery mode is not modeled in CA-GREET so the pathway based on delivering anhydrous ethanol to California is shown here. Once in California, it is blended with CARBOB and transported and distributed by heavy duty trucks. Table L details the energy inputs required to transport ethanol. Table M provides details of the associated GHG emissions related to ethanol transport and distribution. Additional details are provided in Appendix A1.

Table L. Energy Use for Ethanol Transport and Distribution

Transport Mode	Total Energy Use
Transportation within Brazil and to US Port	
By Ocean Tanker (Btu/mmBtu)	~~21,510~~21,6
By Rail (Btu/mmBtu)	~~4,614~~4,638
By Pipeline (Btu/mmBtu)	~~3,056~~3,069
Transportation within U.S	
By Heavy Duty Truck (Btu/mmBtu)	~~10,251~~10,3
Distribution within US	
By Heavy Duty Truck (Btu/mmBtu)	~~2,460~~4,122
Total Ethanol T&D Energy Use (Btu/mmBtu)	~~44~~43 ,~~442~~795

Table M. GHG Emissions Related to Ethanol Transport and Distribution

Transport Mode	GHG Emissions (gCO2e/mmBtu)	GHG Emissions (gCO2e/MJ)
Transportation within Brazil and to US Port		
By Ocean Tanker	~~1.81~~1,901	1.81
By Rail ~~(gCO2e/MJ)~~	~~0.72~~755	0.72
By Pipeline ~~(gCO2e/MJ)~~	~~0.45~~468	0.45
Transportation within U.S		
By Heavy Duty Truck ~~(gCO2e/MJ)~~	~~0.81~~839	0.81
Distribution within US		
By Heavy Duty Truck ~~(gCO2e/MJ)~~	~~0.32~~419	0.32
Total GHG Emissions (gCO2e/MJ)	**~~4.1~~3,687**	**3.5**

Since the CO_2 released from ethanol combustion is the carbon fixed during crop growth, the CO_2 emissions are not counted in the Life Cycle Analysis of sugarcane ethanol. Also, since ethanol is not used as a fuel but as an oxygenate in CaRFG, tailpipe emissions from use of anhydrous ethanol is not discussed in this document. Staff has provided a CaRFG (California Reformulated Gasoline) document which details the blending of ethanol into CARBOB for use as CaRFG and emissions from use of CaRFG (www.arb.ca.gov/fuels/lcfs/lcfs.htm).

Details for Additional Scenarios 1 and 2 Modeled here

FOR SCENARIO 1, WITH MECHANIZED HARVESTING AND EXPORT OF CO-PRODUCT ELECTRICITY

Table N provides a summary of the WTW GHG emissions for scenario 1. Complete details are provided in Appendix A2.

Table N. WTW GHG Emissions for Scenario 1

Description	GHG Emissions
Baseline Pathway Emissions (gCO2e/MJ)	27.40
Credit from Mechanized Harvest (gCO2e/MJ)	-~~8.2~~8.0
Electricity Co-product Credit (gCO2e/MJ)	-7.0
Total GHG Emissions for Scenario 1 (gCO2e/MJ)	**~~12.20~~12.40**

FOR SCENARIO 2 WITH EXPORT OF CO-PRODUCT ELECTRICITY

Table O provides a summary of the WTW GHG emissions for scenario 2. Complete details are provided in Appendix A2.

Table O. WTW GHG Emissions for Scenario 2

Description	GHG Emissions ~~(gCO2e/MJ)~~
Baseline Pathway Emissions **(gCO2e/MJ)**	27.40
Electricity Co-product Credit **(gCO2e/MJ)**	-7.0
Total GHG Emissions for Scenario 2 (gCO2e/MJ)	**20.40**

APPENDIX A1 (BASELINE PATHWAY)

AVERAGE BRAZILIAN SUGARCANE ETHANOL

SECTION 1. SUGARCANE FARMING

1.1 Energy Use for Sugarcane Farming

This section presents the direct energy inputs for sugarcane farming. For farming, the CA-GREET model calculates energy and emissions based on the quantity of fuel (Btu) and chemicals used per tonne of sugarcane, rather than using energy efficiencies, as the petroleum pathways do in CA-GREET. The total input energy per metric tonne of sugarcane is **41,592** Btu (CA-GREET default) using a mix of fuel types shown in Table 1.01.

The Brazilian sugarcane ethanol pathway uses three different electricity mixes: Brazilian average, Brazilian marginal and U.S. average mix. The electricity mix used for sugarcane farming is the Brazilian average mix[3], and U.S. electricity is the assumed input for fertilizer production (see Sections 2.1 and 2.2 in this Appendix). Marginal Brazilian electricity (natural gas) is the assumed electricity mix displaced by bagasse-fired exported electricity produced at the ethanol plant. Table 1.02 below shows generation shares of the three electricity mixes used in this fuel pathway.

Table 1.01 Primary Energy Inputs by Fuel/Energy Input Type for Farm

Fuel Type	Fuel Share	Equation	Primary Energy Input (Btu/tonne)	Primary Energy Input (Btu/mmBtu)
Diesel Fuel	38.3%	41,592*38.3%	15,930	9,858
Gasoline	12.3%	41,592*12.3%	5,116	3,166
Natural Gas	21.5%	41,592*21.5%	8,942	5,534
Liquefied Petroleum Gas	18.8%	41,592*18.8%	7,819	4,839
Electricity	9%	41,592*9%	3,743	2,316
Direct Energy Consumption for Sugarcane Cultivation (unadjusted)			**41,592**	**22,704**

Note: To convert Btu/tonne (metric tonne) into the standard units of Btu/mmBtu, we use the following convention for anhydrous ethanol:
41,592 (Btu/tonne)/(24 (gallons/tonne)*76,330 Btu/gal) * 10^6 = 22,704 Bru/mmBtu
where :
41,592 is a calculated value in Table 1.01
24 (gallons/tonne) = sugarcane EtOH yield (CA-GREET default)
76,330 Btu/gal = Low Heating Value of anhydrous ethanol (CA-GREET default)

[3] Brazilian Average Electricity Mix: http://www.eia.doe.gov/emeu/cabs/Brazil/Full.html

Table 1.02 General Shares of Electricity Mix in Brazil

Fuel	Brazilian Average Mix	U.S. Average Mix	Brazilian Marginal Mix
Petroleum	1.2%	2.7%	0.0%
NG	5.0%	18.9%	100.0%
Coal	1.7%	50.7%	0.0%
Biomass	4.2%	1.3%	0.0%
Nuclear	3.0%	18.7%	0.0%
Hydro	82.9%	(Included in "Others")	0.0%
Others	2.0%	7.7%	0.0%

The primary energy inputs do not include the upstream energy associated with the fuels. For example, the amount of energy associated with diesel does not include the energy and emissions associated with the making of the diesel fuel. CA-GREET accounts for the ‘upstream’ energy associated with fuels by multiplying with appropriate factors. Calculations are shown in Table 1.03. The factors A, B, etc. used in table 1.03 are defined in Table 1.04. Table 1.05 provides additional details for values used in Table 1.04.

Table 1.03 Calculating Total Energy Input by Fuel for Sugarcane Farming

Fuel Type	Equation	Total Energy (Btu/tonne)	Total Energy (Btu/mmBtu)
Diesel fuel	$A*[1+((B*C)+D/10^6)]$	~~18,803~~**18,527**	~~10,247~~**10,112**
Gasoline	$E*[1 +((B*F)+G/10^6)]$	~~6,240.4~~**6,150**	~~3,400.8~~**3,35**
Natural gas	$H*(1+I)/10^6$	~~9,565.2~~**9,565**	~~5,212.7~~**5,22**
LPG	$(J)*(K)*(1+(I*L+M)/10^6 +$ $(J)*(N)*(1 +(P*O+Q)/10^6$	~~8,789.3~~**8,735**	~~4,789.9~~**4,768**
Electricity	$R*S/$~~10^6~~**10^6**	~~5,057.8~~**5,055**	~~2,756.3~~**2,760**
Total Energy for Sugarcane Cultivation		~~**48,456**~~**48,032**	~~**26,407**~~**26,210**

Note: Brazilian average electricity mix used. No energy inputs are included for agricultural machinery.

Table 1.04 Values Used in Table 1.03

Factor	Description	Value	Reference
A	Direct Diesel Input	15,930 Btu/tonne	calculated in Table 1.01
B	Crude Energy	~~31,657~~**39,213**	CA-GREET calculated
C	Diesel Loss Factor	1.00004	CA-GREET default value
D	Diesel Energy	~~125,303~~**123,805**	CA-GREET calculated
E	Direct Gasoline Input	5,116 Btu/tonne	calculated in Table 1.01
F	Gasoline Loss Factor	1.00081	CA-GREET default
G	Gasoline Energy	~~169,676~~**162,914**	CA-GREET calculated
H	Direct NG Input	8,942 Btu/tonne	calculated in Table 1.01
I	NG Stationary Energy	~~72,626~~**69,596**	CA-GREET calculated
J	Direct LPG Input	7,819 Btu/tonne	calculated in Table 1.01
K	NG for LPG Production Share	60%	CA-GREET default
L	NG to LPG Loss Factor	1.00006	CA-GREET default
M	NG to LPG Fuel Stage Energy	~~48,835~~**48,896** Btu/mmBtu	CA-GREET calculated
N	Petroleum for LPG Production Share	40%	CA-GREET default
O	Petroleum to LPG Loss Factor	1.00012	CA-GREET calculated
P	Petroleum to LPG Fuel Crude Energy	~~31,657~~**39,213** Btu/mmBtu	CA-GREET calculated
Q	Petroleum to LPG Fuel Energy	~~75,622~~**75,862** Btu/mmBtu	CA-GREET calculated
R	Direct Electricity Input	3,743 Btu/tonne	calculated in Table 1.01
S	Stationary Electricity Feedstock Production	~~1,347,391~~**1,350,521** Btu/mmBtu	CA-GREET calculated

The factors listed in Table 1.04 are derived from the energy contributions of all other fuels that were used in processing these fuels. Those fuels are shown in Table 1.05 below, in two components: WTT energy (E) and Specific Energy (S) for each fuel type.

Table 1.05 Energy Consumption in the WTT Process and Specific Energ

Factor/Operation /Fuel	WTT energy (Btu input/mmBtu product)	S: Specific Energy (Btu input/Btu product)
Crude Recovery	$WTT_{Crude\ Recovery}$ = ~~44,499~~**28,285**	$S_{Crude\ Recovery} = 1+WTT_{Crude\ Recovery}/10^6 = 1.028$
B	$WTT_{Crude} = WTT_{Crude\ Recovery} * LF_{T\&D} + WTT_{Crude\ T\&D} + WTT_{Crude\ Storage}$ = ~~28,249~~**28,285***1.00006 +~~3,406~~**10,925** = [illegible]	$LF_{T\&D}$ = Loss Factor for Transport and Distribution = 1.00006 (CA-GREET default) $WTT_{Crude\ T\&D}$ = ~~3,406~~**10,925** (CA-GREET calculated) $WTT_{Crude\ Storage}$ = 0.0 (CA-GREET default)
Residual Oil	$WTT_{Res\ Oil}$ = ~~55,561~~**74,239** (CA-GREET calculated)	$S_{Res\ Oil} = 1 + (WTT_{Crude} * LF_{Crude} + WTT_{Res\ Oil}) / 10^6$ ~~= 1.106~~ **= 1.113**
D	WTT_{diesel} = ~~124,812~~**123,805** (CA-GREET calculated)	$S_{diesel} = 1 + (WTT_{Crude} * LF_{diesel} + WTT_{diesel}) / 10^6$ = ~~1.157,~~**1.163.** LF_{diesel} = 1.00004 (CA-GREET default)
G	$WTT_{gasoline}$ = ~~164,227~~**162,914** (CA-GREET calculated)	$S_{gasoline} = 1 + (WTT_{Crude} * \text{Loss Factor}_{gasoline} + WTT_{gasoline}) / 10^6$ = ~~1.201~~**1.202** $LF_{gasoline}$ = 1.00081 (CA-GREET default)
I	$WTT_{NG} = (WTT_{NG\ Recovery} * LF_{processing} + WTT_{NG\ Process}) * LF_{T\&D} + WTT_{T\&D}$ = ~~69,664~~**69,596** (CA-GREET calculated)	$S_{NG} = 1+WTT_{NG}/10^6 = 1.073$ Natural Gas recovery, Process and T&D includes $WTT_{NG\ Recovery}$ = ~~31,125,~~**31,148,** $WTT_{NG\ Process}$ = ~~31,843,~~**31,854,** $LF_{Processing}$ = 1.00148 and $WTT_{NG\ T\&D}$ = ~~9,381.~~**6,498.**
S	$WTT_{electricity}$ = ~~1,347,391~~**1,350,521**	$S_{Electricity}$ = **1 +** (WTT ~~feedstock + WTT fuel~~**electricity**)/ 10^6 = ~~2,347~~**2,351**

Note: $WTT_{Crude\ Recovery}$: WTT energy for crude oil recovery, of self use of crude oil at the well, and does not include T&D. $WTT_{Crude\ Storage}$: WTT energy of crude storage

1.2 GHG Emissions from Sugarcane Farming

CA-GREET calculates carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions for each component of the pathway and uses IPCC[4] **G**lobal **W**arming **P**otentials (GWP) to calculate CO_2 equivalent values for CH_4 and N_2O (see Table 1.06). For VOC and CO, CA-GREET uses a carbon ratio to calculate CO_2 equivalent values which are detailed in a note below Table 1.06. These are based on the oxidation of CO and VOC to CO_2 in the atmosphere.

Table 1.06 Global Warming Potentials for Gases

GHG Species	GWP (relative to CO2)
CO_2	1
CH_4	25
N_2O	298

Carbon ratio of VOC = 0.85 grams CO_2/MJ so grams VOC*(0.85)*(44/12) = 3.1
Carbon ratio of CO = 0.43 grams CO_2/MJ so grams CO/mm Btu*(0.43)*(44/1 2) = 1.6

4 Intergovernmental Panel on Climate Change a scientific intergovernmental body tasked to evaluate the risk of climate change caused by human activity established by United Nations in 1988.

The GHG emissions for farm energy use are determined separately for CO_2, CH_4 and N_2O in CA-GREET using the direct energy inputs presented in Section 1.1 (Btu/tonne) and the combustion and upstream emissions for the energy inputs. CA-GREET calculates the emissions for each fossil fuel input by multiplying fuel input (Btu/tonne) by the total emissions from combustion, crude production and fuel production. The electricity emissions are calculated by multiplying the electricity input (Btu/tonne) by the total (feedstock plus fuel) emissions associated with the chosen electricity mix (from the "*Electricity*" tab in CA-GREET). Note that U. S. average emission factors are used for Brazilian fuel use and electricity generation. Table 1.07 below shows equations and calculated values by fuel type for sugarcane farming CO_2 emissions. Equations and values for CH_4 and N_2O are not shown, but use the same structure. Table 1.08 provides values for parameters used in equations shown in Table 1.07.

Table 1.07 CA-GREET Calculations for CO_2 Emissions from Sugarcane

Fuel	Equations	CO_2 Emissions (g/tonne)	CO_2 Emissions (g/mmBtu)
Diesel	[(A)*[(B)*(C) + (D)*(E)+(F)*(G)+ (H)*(I)+(J)*(K)+(L)]]/10^6	~~1,435~~**1,441**	~~782~~**787**
Gasoline	[(M)*[(N)+ (J)*(O)+(P)]]/10^6	~~466~~**335**	~~254~~**183**
Natural Gas	[(Q)*[(R)*(S) + (T)*(U)+(V) *(W)+(X)*(Y)+(Z)]]/10^6	552	301
LPG	[(AA)*[(BB)+((J)*(CC)+(DD)+(EE)*(FF) +(GG))/2]]/1 0^6	~~599~~**601**	~~326~~**328**
Electricity	[(H H)*(I I)]/1 ^{06}	~~69~~**70**	38
Total CO_2 Emissions		~~**3,120**~~**2,999**	~~**1,701**~~**1,637**

To convert from g/tonne to g/mmBtu use:
~~3,120~~**2,999** (g/tonne)/(24 (gallons/tonne)*76,330 Btu/gal) * 10^6 =
~~1,701~~**1,637** g/mmBtu where:
24 (gallons/tonne) = sugarcane EtOH yield (CA-GREET default)
76,330 Btu/gal = Low Heating Value of anhydrous ethanol (CA-GREET default)
10^6 is to convert to mmBtu.

Table 1.08 Input Values for Calculations in Table 1.06

	Relevant Parameters*	**Reference**
A	= Diesel input = 15,930 Btu/tonne	Table 1.01
B	= % Fuel share diesel boiler = 0%	CA-GREET default
C	= Boiler CO_2 emissions = 78,167 g/mmBtu	CA-GREET default
D	= % Fuel share diesel stationary engine = 0%	CA-GREET default
E	= IC Engine CO_2 Emissions =77,401 g/mmBtu	CA-GREET default
F	= % Fuel share diesel turbine = 0%	CA-GREET default
G	= Turbine CO_2 emissions 78,179 g/mmBtu	CA-GREET default
H	= % Fuel share diesel tractor = 100%	CA-GREET default
I	= Tractor CO_2 emissions = 77,411 g/mmBtu	CA-GREET default
J	= Crude production CO_2 emissions = 3,260 g/mmBtu	CA-GREET calculation
K	= Diesel loss factor = 1.00004	CA-GREET default
L	= Diesel production CO_2 emissions = 9,387 g/mmBtu	CA-GREET default
M	= Gasoline input = 5,116 Btu/tonne	Table 1.01
N	= Farming tractor CO_2 emission factor = 75,645 g/mmBtu	CA-GREET default
O	= Gasoline loss factor = 1.00081	CA-GREET default
P	= Gasoline production CO_2 emissions = 12,122 g/mmBtu	CA-GREET calculation
Q	= NG input = 8,942 Btu/tonne	Table 1.01
R	= % Fuel share NG engine = 100%	CA-GREET default
S	= Engine CO_2 emission factor = 56,551 g/mmBtu	CA-GREET default
T	= % Fuel share NG large turbine = 0%	CA-GREET default
U	= Turbine CO_2 emission factor = 58,179 g/mmBtu	CA-GREET default
V	= % Fuel share NG large boiler = 0%	CA-GREET default
W	= Large boiler CO_2 emission factor = 58,198 g/mmBtu	CA-GREET default
X	= % Fuel share small NG boiler = 0%	CA-GREET default
Y	= Small boiler CO_2 emission factor = 58,176 g/mmBtu	CA-GREET default
Z	= WTT stationary NG CO_2 emissions = 5,218 g/mmBtu	CA-GREET calculation
AA	= LPG input = 7,819 Btu/tonne	Table 1.01
BB	= Commercial boiler CO_2 emission factor = 68,036 g/mmBtu	CA-GREET default
CC	= LPG loss factor = 1.00012	CA-GREET default
DD	= LPG production CO_2 emissions = 5,708 g/mmBtu	CA-GREET calculation
EE	= LNG feedstock CO_2 emissions = 4,882 g/mmBtu	CA-GREET calculation
FF	= NG to LPG loss factor = 1.00006	CA-GREET default
GG	= NG to LPG fuel CO_2 emissions = 3,162 g/mmBtu	CA-GREET calculation
HH	= Electricity input = 3,743 Btu/tonne	Table 1.01
II	= Electricity CO_2 emissions = 18,504 g/mmBtu	CA-GREET calculation

Other GHGs, including VOC, CO, CH_4, and N_2O emissions are calculated with the same equations, energy input, and loss factors as CO_2 emissions calculations shown in Tables 1.07 and 1.08, but with different VOC, CO, CH_4, and N_2O emission factors. Table 1.09 shows the results of the calculations of VOC, CO, CH_4, and N_2O in (g/tonne) then converted to g/mmBtu. The conversion is performed as shown in the note below Table 1.07.

Table 1.09 GHG Emissions from Sugarcane Farmin

Emission Species	Emissions [1] (g/ton	GHGs (gCO2e/mm Btu)	GHGs (gCO2e/MJ)
CH_4	~~7.82~~7.85	~~106.5~~107	0.1
N_2O	0.08	~~11.9~~13	0.01
CO_2	~~3,035~~3,163	~~1,654~~1,726	~~1.57~~1.6
Total GHG Emissions		**1,772**	~~1.7~~1.8

[1]Emissions in grams of gaseous species per tonne. To convert all VOC, CO, CH_4 and N_2O (g/tonne) to (g/mmBtu) = (g/tonne)/(Ethanol Yield (gal/tonne) * LHV of Anhydrous Ethanol (Btu/gal))*10^6. Note that non-CO_2 gases expressed as GHG in gCO_2e/mmBtu were converted to CO_2e

1.3 GHG Emissions from Straw Burning in Field

The sugarcane field is burned prior to manual harvesting. The fire removes dry leaves and straw and kills any pests present while leaving the wet, sugar-rich stalks undamaged. The CA-GREET model uses assumptions shown below in Table 1.10 and emission factors presented in Table 1.11 to calculate emissions from field burning. An emission credit is also calculated in grams of CO_2/tonne cane, assuming that all carbon in burned residue is converted to CO_2.

Table 1.10 Inputs for Calculating Field Burning Emissions

Sugarcane Straw Burning Input Parameters	Straw Yield (Dry tonne straw/tonne cane)	Straw C Ratio (% by weight)
	0.190	50.%

Table 1.11 Sugarcane Straw Burning Emission Factors

Emission Species	CO_2 EF	VOC EF	CO EF	CH_4 EF	N_2O EF
Emission Factor (g/kg straw burned)	1,660	7.0	92.0	2.7	0.07

The straw burning emissions for CO_2 are calculated as follows:

(1,660 g CO_2/kg straw)(0.190 dry tonne straw/tonne cane)(1,000 kg/tonne) =
315,973 g/tonne cane

The CO_2 emission credit is calculated as follows:
-(0.190 dry tonne straw/tonne cane)*(50.0% C content by wt.)*(1 ,000 kg/tonne)*(1,000 g/Kg)*(44/12) = **-349,067 g/tonne cane**
Table 1.12 shows all emission species calculated the same way as CO_2 example above.

Table 1.12 Su^g^arcane Straw Burnin^g^ Emissions

Emission Species	**Emissions (g/tonne cane)**	**GHG Emissions (gCO2e/~~m mBtu~~mmBtu)**	**GHG Emissions (gCO2e/MJ)**
VOC	1,332.80	~~2,287~~**2,264**	2.2
CO	17,516.80	~~15,204~~**15,001**	~~14.4~~**14.2**
CH_4	514.1	~~7,003.90~~**7,004**	6.6
N_2O	13.3	~~2,164.50~~**2,164**	2.1
CO_2	315,973	172,195	163.2
Biogenic CO_2 Credit	-349,067	-190,230	-180.3
Total GHG Emissions		23,226	
Total GHG Emissions (gCO2e/MJ)			**~~8.2~~8.0**

The same notes under Table 1.09 apply for this table.

Total GHG emissions from sugarcane farming and straw burning is therefore **~~1.74~~ 1.8+ ~~8.2~~8.0 = ~~9.9~~9.8 gCO2e/MJ.**

SECTION 2. INPUTS FOR AGRICULTURAL CHEMICALS

2.1 Energy Calculations for Production of Chemical Inputs

Chemical inputs, including fertilizer, herbicide and insecticide, are input on a g-nutrient/tonne (fertilizer) or g-product/tonne (herbicide and pesticide) basis. Table 2.01 below presents the CA-GREET chemical inputs per metric tonne of sugarcane, the total energy required to produce the chemical product and the calculated upstream energy required to produce a bushel of sugarcane using these inputs. Both chemical input values and product energy values are CA-GREET defaults.

Table 2.01 Sugarcane Farming Chemical Inputs

Chemical Type	Chemical Input (Btu/g)	Product Input Factors (g/tonne)	Total Energy Use (Btu/tonne)	Total Energy Use (Btu/mmBtu)
Nitrogen Fertilizer	~~45.9~~**52.2**	1,091.7	~~50,133~~**56,930**	~~31,054~~**31,076**
Phosphate Fertilizer	13.3	120.8	~~1,604~~**1,608**	~~880~~**878**
Potash	8.4	193.6	~~1,624~~**1,629**	~~892~~**889**
Lime	7.7	5,337.7	~~41,019~~**41,158**	~~22,512~~**22,467**
Herbicide (average)	~~262.8~~**263.9**	26.9	~~7,070~~**7,098**	~~3,898~~**3,875**
Insecticide (average)	~~311.3~~**312.4**	2.21	~~688~~**690**	~~379~~**377**
Total				~~**59,616**~~**59,562**

Note: Ethanol yields for sugarcane ethanol are assumed to be 24 gal/tonne in CA-GREET. The WTT energy = chemical input (g/tonne)* product input energy (Btu/g).

Example Calculation:

For Nitrogen Fertilizer: WTT Energy (Btu/tonne) = ~~45.9~~**52.2** (Btu/g) * ~~1,092~~**1,091.7** (g/tonne) = ~~**50,133**~~**56,930** **Btu/tonne**

To convert Btu/tonne into the standard units of Btu/mmBtu, we use the following:

(~~50,133~~**56,930** Btu/tonne)/((24 gallons/tonne)*76,330 Btu/gal) * 10^6 = ~~**59,616**~~**31,076** **Btu/mmBtu** where :
50,133 is a calculated value in Table 2.01
24 gallons/tonne = sugarcane EtOH yield (CA-GREET default)
76,330 Btu/gal = Lower Heating Value of anhydrous ethanol (CA-GREET default)

CA-GREET models nitrogen fertilizer as a weighted average of ammonia (70.7%), urea (21.1%) and ammonium nitrate (8.2%) fertilizers. As Table 2.01 shows, nitrogen fertilizer input accounts for more than half of total chemical energy input. The herbicide production energy is a weighted average of four types of herbicides used: atrazine (31.2%), metolachlor (28.1%), acetochlor (23.6%) and cyanazine (17.1%). The insecticide inputs represent an "average" insecticide, rather than an explicitly weighted average of specific insecticides. The energy required to produce nitrogen fertilizers, herbicides or pesticides does not vary significantly by category, attesting to the validity of using average energy inputs.

2.2 GHG Calculation from Production and Use of Agricultural Chemicals

This component includes all of the upstream emissions related to the manufacturing of agricultural chemical products. It also includes impacts from the use of agricultural chemicals in farming. Upstream emissions are calculated in CA-GREET per metric tonne of product, including the production, process and transportation emissions associated with manufacturing chemicals; these intermediate calculations take place in the "*Ag _Inputs"* sheet. These values are converted to emissions per tonne of nutrient using the ratio of nutrient to product.

Nitrogen fertilizer greenhouse emissions are modeled as a weighted average of 3 types of N-fertilizers modeled in CA-GREET. Energy and emissions are converted to Btu or grams greenhouse gases per g of nutrient (fertilizer) or product (herbicide and pesticide). Average emissions for herbicides are calculated using a weighted average of 4 types of herbicides while pesticide emissions are based on a single pesticide type. Table 2.02 below shows the greenhouse emissions for agricultural chemicals in grams per gram of nutrient for fertilizers and per gram of product for herbicides and pesticides. The equations are complex and not shown here since agricultural inputs apply to large variety of crop cultivation and are not specific to sugarcane cultivation.

Table 2.02 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

GHG Type	Nitrogen (weighted average)	P_2O_5	K_2O	$CaCO_3$	Herbicide (weighted average)	Pesticide
VOC	≤0.01	≤0.01	≤0.01	≤0.01	≤0.01	≤0.01
CO	≤0.01	≤0.01	≤0.01	≤0.01	0.01	0.02
CH_4	<0.01	<0.01	<0.01	<0.01	0.03	0.03
N_2O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CO_2	~~2.39~~1.81	0.98	0.66	0.60	~~20.53~~20.63	~~23.87~~23.9
Convert to GHG (g/g)	**~~2.9~~2.8**	**1.0**	**0.7**	**0.6**	**~~21.3~~21.4**	**~~24.84~~24.9**

The greenhouse emissions of agricultural inputs are multiplied by chemical input factors (g/tonne) in the "*Ethanol"* tab and a loss factor from the "*Ag_Inputs"* tab to yield fertilizer emissions in grams per bushel of sugarcane produced. Table 2.03 below shows the calculations for CO_2 emissions associated with the use of chemical inputs in g/tonne of sugarcane produced. Table 2.04 details the values used in calculations in Table 2.03. The equations for CH_4 and N_2O are analogous to these calculations and are not shown.

Table 2.05 shows the emission results for all greenhouse gases for chemical use, based on the calculations shown in Table 2.03.

Table 2.03 Calculated CO_2 Emissions Associated with Production of Agricultural Chemicals

Chemical Product	**Equation**	**CO_2 Emissions**		
		(g/~~ton~~ ~~ne~~tonne)	**(g/~~mm Btu~~mmBtu)**	**(gCO₂e/MJ)**
Nitrogen (weighted average)	(A)*(B)*(C)	~~2,971~~3,431	~~1,619~~1,870	
P_2O_5	(D)*(E)*(F)	~~118~~119	~~64~~65	
K_2O	(G)*(H)*(I)	~~127~~128	~~69~~70	
$CaCO_3$	(J)*(K)*(L)	~~3,210~~3,224	~~1,749~~1,757	
Herbicide	(M)*(N)*(O)	~~552~~555	~~301~~302	
Pesticide	(P)*(Q)*(R)	53	29	
Total CO_2 emissions (gCO_2e/MJ)		**~~7,031~~7,509**	**~~3,832~~4,092**	**~~3.63~~3.88**

Table 2.04 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

Variables	Relevant Parameters	Reference
A	Nitrogen input = 1,091.7 g/tonne	CA-GREET default
B	Nitrogen chemical cycle emissions = 2.39 g/g	Table 2.02
C	Nitrogen loss factor = 1.0 (during transport, distribution...)	CA-GREET default
D	P_2O_5 input = 120.8 g/tonne	CA-GREET default
E	P_2O_5 chemical cycle emissions = 0.98 g/g	Table 2.02
F	P_2O_5 loss factor = 1.0 (during transport, distribution...)	CA-GREET default
G	K_2O input = 193.6 g/tonne	CA-GREET default
H	K_2O chemical cycle emissions = 0.66 g/g	Table 2.02
I	K_2O loss factor = 1.0 (during transport, distribution...)	CA-GREET default
J	$CaCO_3$ input = 5,337.7 g/tonne	CA-GREET default
K	$CaCO_3$ chemical cycle emissions = 0.60 g/g	Table 2.02
L	$CaCO_3$ loss factor = 1.0 (during transport, distribution...)	CA-GREET default
M	Herbicide input = 26.9 g/tonne	CA-GREET default
N	Herbicide chemical cycle emissions = 20.53 g/g	Table 2.02
O	Herbicide loss factor = 1.0	CA-GREET default
P	Pesticide input = 2.21 g/tonne	CA-GREET default
Q	Pesticide chemical cycle emissions = 23.87 g/g	Table 2.02
R	Pesticide loss factor = 1.0	CA-GREET default

Table 2.05 shows the emission results (g/tonne) for all GHG emissions for production of chemicals used in agriculture based on the calculations shown in Table 2.03. The CH_4 and N_2O emissions results shown in Table 2.05 are calculated with the same equations as CO_2 emission calculations, except that CO_2 emission factors are replaced by CH_4 and N_2O emission factors. Table 2.05 also shows the WTT emissions on an energy basis. Note that converting from g/tonne to g/mmBtu is shown in a note below Table 2.05. To convert from g/mmBtu to gCO_2e/mmBtu, non-CO_2 gasses are adjusted using their respective GWPs.

Table 2.05 Calculated GHG Emissions from Production of Agricultural Chemicals

GHG Type (g/tonne)	Nitrogen (weighted average)	P_2O_5	K_2O	$CaCO_3$	Total Fert.	Herbicide (weighted average)	Pesticide	Total
VOC	6.86	0.04	0.02	0.42		0.07	0.01	7.43
CO	6.94	0.14	0.12	2.80		0.39	0.05	10.45
CH_4 ~~(g/tonne)~~	~~3.1~~2.99	~~0.2~~0.17	~~0.2~~0.17	~~4.9~~4.23		~~0.8~~0.70	~~0.1~~0.07	~~9.3~~8.32
N_2O ~~(g/tonne)~~	~~1.8~~3.23	< 0.01	< 0.01	~~0.05~~0.03		< 0.01	< 0.01	~~1.8~~3.27
CO_2 ~~(g/tonne)~~	~~2,971~~3,431	~~118~~119	~~127~~128	~~3,210~~3,2		~~552~~555	53	~~6,743.4~~7,
GHGs ~~(g/tonne)~~	~~3,579~~4,500	124	133	3,344		574	55	~~7524.2~~8,
GHGs (g/mmBtu)	**~~1,951~~2,453**	**~~68~~67**	72	1,822	**~~3,913~~4,415**	313	30	**~~4,256~~4,758**
Total GHG Emissions (gCO2e!MJ)	**~~1.85~~2.33**	**0.06**	**0.07**	**1.73**	**~~3.70~~4.18**	**0.30**	**0.03**	**~~4.03~~4.5**

Note: To convert (g/tonne) to (g/mmBtu) = (g/tonne)/(Ethanol Yield (gal/tonne) * LHV of Anhydrous Ethanol (Btu/gal))*10^6. LHV of denatured ethanol is 76,330 Btu/gal and ethanol yield is assumed to be 24 gal/tonne.

Impact of soil N_2O emissions resulting from nitrogen fertilizer use on WTT GHG emissions

CA-GREET also calculates direct field and downstream N_2O emissions resulting from nitrogen fertilizer input. Table 2.06 below shows the two main inputs: fertilizer input (g/tonne) and percent conversion of N-input to N_2O. The table shows the N_2O emissions on an energy basis. CA-GREET v1 .8b assumes 1.3% of fertilizer-N is ultimately converted to N_2O. The calculation also uses the mass ratio of N_2O to N_2 (44/28). Table 2.06 provides total GHG impacts from soil N_2O emissions.

Table 2.06 Inputs and Calculated Emissions for Soil NO and N2O from Sugarcane Farmin

	~~g~~ Fertilizer N input	Percent conversion to N_2O-N	N_2O formed! N_2O-N (g!g)	N Converted (g!tonne)	N_2O or NO Emissions (g!tonne)	GHG Emissions (g!mmBtu)	GHG Emissions (gCO_{2e}!MJ)
N_2O	1,091.7	1.3%	44/28	14.5	22.7	3,691	**3.5**

Note: Soil N2O emissions = (1,091.8 g N/tonne)(1 .3%)(44 g N2O/28 g N2) = 22.7 g N2O/tonne
N2O Emissions: N in N2O as % of N in N fertilizer and biomass: CA-GREET default of 1.3%

Effect of Lime ($CaCO_3$) added to soil on GHG emissions

CA-GREET assumes that all of the carbon in added lime is emitted as CO_2. This results in the following CO_2 emission: Soil CO_2 emissions = (5,337.7 g CaCOgCaCO$_3$/tonne)*(44 g CO_2/1 00 g CaCOgCaCO$_3$) = 2,349 g COgCO$_2$/tonne = 1,282 g COgCO$_2$/mmBtu = **1.2** g CO**gCO$_2$e/MJ.**

Tables 2.05, 2.06 and emissions from adding lime to soil are combined to provide the total GHG emissions from the use of Agricultural Chemicals and is detailed in Table 2.07.

Table 2.07 Total GHG Emissions from Agricultural Chemical Use for Sugarcane Ethanol

Ethanol Pathway	Fertilizers	Herbicide	Pesticide	Soil N_2O and NO	CO_2 from $CaCO_3$	Total (gCO_2e/MJ)
GHGs (gCO_2e/MJ)	3.7**4.18**	0.3	0.03	3.5	1.2	**8.79.2**

SECTION 3. SUGARCANE TRANSPORT

3.1 Energy for Sugarcane Transportation

CA-GREET calculates the total energy needed (Btu/tonne) to transport sugarcane from the field to the ethanol production facility using heavy duty trucks. Table 3.01 below shows the sugarcane transportation distance and energy inputs. The calculations are based on heavy duty truck capacities of 17 tonnes. The default transport distance modeled is 12 miles. CA-GREET calculates the diesel energy per tonne mile based on the cargo capacity of the truck and its fuel economy and assumes that truck trips carrying sugarcane and returning empty use the same energy. All values are CA-GREET default values.

Table 3.01 Sugarcane Transport Inputs

Transport Mode	Energy Intensity (Btu/tonne-mile)	Distance from Origin to Destination	Capacity (tonnes)	Fuel ~~Consumption~~ Cons. (mi/gal)	Energy ~~Consumption of~~ Cons. of Truck	Share of Diesel Used
Field to Ethanol Plant	1,511	12	17	5	25,690	100%

The calculated sugarcane transport energy on a Btu per tonne of sugarcane basis is shown below in Table 3.02 using the values in Table 3.01.

Table 3.02 Sugarcane Transport Energ

Transport Mode	Energy Consumption (Btu/ton)
Field to Ethanol Plant	(12 miles one-way distance)*(1 ,511 Btu/~~tonmile~~ton-mile origin to destination + 1,511 Btu/ton-mile back-haul)*(Diesel share ~~1 00~~100%)*(1 +Diesel WTT Energy 0.157 Btu/Btu) /0.907
Total Energy Used (Btu/tonne)	~~47,200~~46,506
Total Energy Used (Btu/mmBtu)	~~25,722~~25,344

Note: To convert (Btu/ton) to (Btu/mmBtu) = (Btu/ton)/(0.907 tonnes/ton)/(Ethanol Yield (gal/tonne) * LHV of Anhydrous Ethanol (Btu/gal))*1 0^6. Diesel WTT energy is a CA-GREET calculation

3.2 GHG Calculations from Sugarcane Transportation

GHG emissions from sugarcane transportation are calculated from section 3.1 above with the same transportation mode, miles traveled, etc. as indicated by Table 3.01 above. Table 3.03 below details key assumptions of calculating GHG from sugarcane transportation. All values used in calculations are CA-GREET default values.

Table 3.03 Key Assumptions in Calculating GHG Emissions from Sugarcane

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	CO_2 Emission Factors of Truck (g/mi)	WTT Transport Diesel Emissions (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
Sugarcane to plant by heavy duty truck	1,511	12	1,999 (2,002)*	12,647	77,809 (77,913)*

Note: *values in parenthesis are for the return trips.

Sugarcane transport emissions are first calculated on a g/ton basis and then finally converted to g/mmBtu as shown in Table 3.04 below.

Table 3.04 Sugarcane Transport - CO_2 Emissions

Transport Mode	CO_2 Emission (g/tonne)	CO_2 Emissions (g/mmBtu)
Sugarcane to Ethanol Plant by Heavy Duty Truck	~~3,701~~**3,644**	~~2,017~~**1,986**
Total CO_2 Emissions (gCO$_2$e/MJ)		~~**2.0**~~**1.88**

Note: Example formula to calculate CO_2 emission of Heavy Duty Truck above:
[((77,809 g/mmBtu)~(12,647 g/mmBtu)*(100% diesel used))*(1 ,51 1 Btu/ton-mile)~ ((77,913 g/mmBtu)~(1 2,647 g/mmBtu)*(1 00% diesel used))*1 ,51 1 Btu/ton-mile]*1 2 miles/0.907 ton/tonne/(10^6 mmBtu/Btu) = 3,701 g/tonne.
To convert (g/tonne) to (g/mmBtu) = (g/tonne)/(Ethanol Yield (gal/tonne) * LHV of Anhydrous Ethanol (Btu/gal))*10^6.

Similarly, CH_4, N_2O, VOC, and CO are calculated the same way (with different emission factors for each species) and shown in Table 3.05. All emissions are converted to a CO_2 equivalent-basis. The emissions are shown on an anhydrous ethanol basis.

Table 3.05 Sugarcane Transport –Total GHG Emissions

GHG Emissions	CH_4	N_2O	VOC	CO	CO_2	GHG Emissions
(g/tonne)	~~4.078~~3.98	~~0.088~~0.09	~~1.493~~1.53	~~6.553~~6.83	~~3,701~~3,644	
(g/mmBtu)	~~2.222~~54.27	~~0.048~~14.62	~~0.814~~2.60	~~3.571~~5.84	~~2,017~~1,986	2,087
Total GHG ~~Emisisons~~Emissions	**~~<0.01~~0.05**	**~~<~~0.01**	**<0.01**	**<0.01**	**~~2.0~~1.88**	**2.0**

SECTION 4. ETHANOL PRODUCTION

4.1 Ethanol Production

Similar to the sugarcane farming energy calculations, CA-GREET uses energy input values for sugarcane ethanol in Btu/gallon of anhydrous ethanol and uses fuel shares to allocate this direct energy input to process fuels. Part of the bagasse, the fibrous residue remaining after squeezing the juice of the plant, is currently burned at the mill to provide heat for distillation and electricity to run machinery at the plant. This allows ethanol plants to be energetically self-sufficient and even sell surplus electricity to utilities in some cases.

A major portion of the energy used in sugarcane ethanol plant in Brazil is from bagasse (a fiber material of the sugarcane plant). Sucrose accounts for little more than 30% of the chemical energy stored in the mature plant; 35% is in the leaves and stem tips, which are left in the fields during harvest, and 35% are in the fibrous residue (bagasse).

Table 4.01 shows the ethanol production fuel shares and energy inputs per gallon of anhydrous ethanol. The electricity input is represented in Btu/gal and added to the process fuel consumption to determine the fuel shares. Additional details are shown in Table 4.02.

Table 4.01 Sugarcane Ethanol Fuel Shares and Primary Energy Inputs

Fuel Type	Fuel Share	Primary Energy Input (Btu/gallon)
Bagasse	99.65%	83,132
Residual Oil	0.35%	278
Total	**100%**	**83,409**

Note:
For Bagasse: 0.00642 US ton of dry bagasse/gal ethanol *12,947,318 (Btu/US ton) LHV = **83,132 Btu/gal**
For Residual oil: Oil use in sugarcane ethanol plants is from lubricant use. For CO_2 calculation, it is assumed that 10% of lubricants are burned.

Tables 4.02 and 4.03 show the CA-GREET equations, parameters and energy inputs for ethanol production. The tables show the total input energy per mmBtu of anhydrous ethanol. For this document, ethanol transported from Brazil is considered as anhydrous which is subsequently blended to make denatured ethanol in California.

Table 4.02 Sugarcane Ethanol Production Parameters and Total Energy Use

Fuel Type	Formula	Relevant Parameters	Total Energy
Bagasse	Dry tonne bagasse/gal ethanol *Bagasse LHV	Dry tonne bagasse/gal ethanol = 0.00642 tonne/gal	83,132 (Btu/gal)
		Bagasse LHV = 12,947,318 Btu/tonne (CA-GREET default)	
Residual Oil	(Direct Residual Oil Input)* (1+(WTT Crude Oil Energy*Loss Factor + WTT of residual oil)/1 0^6)	Direct residual oil input = 251 Btu/gal	~~284~~**279** (Btu/gal)
		WTT crude oil energy = ~~31,657~~**39,213** Btu/mmBtu	
		Loss Factor = 1.001	
		WTT of residual oil = ~~74,001~~	
Total energy input for ethanol production (Btu/gal)			~~83,415~~**83,4**
Total energy input for ethanol production (Btu/mmBtu)		~~83,415~~**83,411** Btu/gal / (76,330 Btu/gal) *10^6*1.001	~~1,093,376~~**1,093,320**

Note: 1.001 is the loss factor by CA-GREET default

4.2 GHG Emissions from Ethanol Production

Sugarcane mill ethanol production in Brazil is assumed here to use dry bagasse as fuel for small boilers (99.65%). A relatively small amount of residual oil is also utilized in the process (about 0.35%). GHG from ethanol production by burning bagasse is calculated based on the assumptions in Table 4.03 and the results are shown in Table 4.04. The CO_2 emissions shown in Table 4.03 include the direct boiler emissions (118,834 g/mmBtu) of bagasse; residual oil emissions include emissions from an industrial boiler (85,045 g/mmBtu) and direct WTT residual oil use in the boiler. CO_2 is credited to the ethanol production process resulting from biomass (bagasse) burning.

Table 4.03 Process Shares and Emission Factors (EF) for Ethanol Production

EtOH Production Equipment and Fuel Used	% Shares of Equip. Usage	CO_2 EF (g/mmBtu of fuel burned)	VOC EF	CO EF	CH_4 EF	N_2O EF	Assumed % of Fuels used at the EtOH Plant	Direct Energy Use (Btu/gal)
Small industrial boiler (1 0-100mmBtu/hr input) to burn bagasse	100%	118,834	5.34	76.8	31.6	4.2	~~99.65~~**99.7** %	83,132
Residual oil industrial boiler	10%	85,045	0.9	15.8	3.2	0.4	~~0.35~~**0.30**%	~~284~~**251**

Table 4.04 Calculated GHG Emissions for Ethanol Production Using CO_2 Factors from Table 4.03

Calculations CO_2 in g/gal			Conversion to g/mmBtu	Conversion to g- COto gCO_2e/	gCO_2e/ MJ
Bagasse burning in EtOH Production					
CO_2 Small industrial boiler	(Direct energy use of bagasse, Btu/gal) *(1 18,834 g/mmBtu)*1 .001/10^6	9,8819,879	9,8819,879 g/gal/(76,330 Btu/gal)*1 06 10^6	129,519129,423	122.67
CO_2 credit from bagasse burning	Bagasse burning = -(0.00642 tonne/gal *46.3% carbon content *2000 lbs/tonne*454 g/lbs)*44/1 2	-9,897	-9,897 g/gal/(76,330 Btu/gal)*$10^6$1 06	- 129,732129,667	-122.9
EtOH ProductionCH_4	Bagasse burning = 0.00642 tonne/gal*(31 .6 g/mmBtu* 12,947,318 Btu/ton/10^6)	2.63	2.634 g/gal/(76,330 Btu/gal)*1 06	862	0.82
N_2O	Bagasse burning = 0.00642 tonne/gal* (4.2 g/mmBtu *12,947,318 Btu/gal/10^6)	0.35	0.351 g/gal/(76,330 Btu/gal)*1 06	1,370	1.3
CH_4VOC	Bagasse burning = 0.00642 tonne/gal* (31 .65.34 g/mmBtu * 12,947,318 Btu/gal/ 10^6)	2.6340.44	2.6340.44 g/gal/(76,330 Btu/gal)*10^6 = 06	963.518	0.02
N_2OCO	Bagasse burning = 0.00642 tonne/gal* (4.276.8 g/mmBtu* 12,947 ,318 *12,947,318	0.3516.3	0.351 6.3 g/gal/(76,330 Btu/gal)*10^6 = 06	1,395131	0.12
Residual Oil					
CO_2 of small industrial boiler	(Direct energy use of residual oil, Btu/gal) *10%* (85,045	2.12.10	(2.1 g/gal) /(76,330 Btu/gal)*1	28.028	0.03
CO_2 for WTT of crude oil	(Direct energy use of residual oil, Btu/gal) *10%*	0.10.10	(0.1 g/gal) /(76,330 Btu/gal)*1	1.1	≤0.01
CO_2 for WTT of residual oil	(Direct energy use of residual oil, Btu/gal) *10%*	0.10.10	(0.16 g/gal) /(76,330 Btu/gal)*10^6	1.8	≤0.01
VOCCH_4	(Direct energy use of residual oil, Btu/gal) *(0.910%* [(3.24 g/mmBtu)~ (90.166 g/1 06 mmBtu)*1.000 ~ 4.94	< 0.01	(<0.010.002 g/gal) / (76,330 Btu/gal)*(3.1)	<0.010.8	≤0.01
CON_2O	(Direct energy use of residual oil, Btu/gal) * (15.810%* [(0.36 g/mmBtu)~ (0.65 g/mmBtu)*1.000 ~ 0.54	< 0.01	(<0.01 0.00 g/gal) / (76,330 Btu/gal)*(1 06 10^6	0.08≤ 0.01	≤0.01
Total GHGs for ethanol production (gCO_2e/mmBtu)				2,021	
Total GHGs for ethanol production (gCO_2e/MJ)				1.9	

VOC	(Direct energy use of residual oil, Btu/gal)*(0.9 g/mmBtu)/10^6	≤0.01	(≤0.01 g/gal)/(76,330 Btu/gal)*(3.1)*10^6	≤ 0.01	≤0.01
CO	(Direct energy use of residual oil, Btu/gal) * (15.8 g/mmBtu)/10^6	≤0.01	(≤0.01 g/gal)/(76,330 Btu/gal)*(1.6)*1	0.02	≤0.01
Total GHGs for ethanol production (gCO2e/mmBtu)				2,169	
Total GHGs for ethanol production (gCO2e/MJ)					2.1

Note: Feed Loss Factor is assumed at 1.000. Small amounts of CH_4 and N_2O are negligible.
Carbon ratio of bagasse is 46.3% by CA-GREET default.
The 10% allocation of residual oil to ethanol is a CA-GREET default value. The 10% is to account for lubricating oil that is used not as a combustion source but is lost during the operation of the machinery involved in ethanol production. For this document, the lubricating oil is modeled as residual oil and its WTT emissions are used as a surrogate for lubricating oil. (Numbers may not add up, due to rounding)

SECTION 5. ETHANOL TRANSPORT AND DISTRIBUTION

5.1 Energy for Ethanol Transportation and Distribution

For the CA-GREET sugarcane ethanol pathway modeled here, the default sugarcane ethanol transport and distribution (T&D) from Brazil to the U.S is divided as follows:

- From ethanol plant in Brazil to U.S ports:
  - Inside Brazil: 50% by rail (500 miles) and 50% by pipeline (500 miles)
  - From Brazilian ports to U.S ports by ocean tanker (7,416 miles)
- From U.S ports to distribution centers inside U.S
  - 100% by Heavy Duty Truck (100 miles)
- For distribution within U.S
  - 80% by truck (50 miles)
  - 20% directly from ports to blending terminals

Instead of calculating the WTT values on a per tonne basis as CA-GREET does for the sugarcane transport component, CA-GREET calculates WTT energy required per mmBtu of fuel (anhydrous ethanol) transported. Table 5.01 below shows the major inputs used in calculating transport energy and Table 5.02 presents the CA-GREET formulas used to calculate the ethanol transport energy for each transport mode.

Table 5.01 Inputs and Calculated Energy Requirements for Ethanol Transport to Bulk Terminals

Transport	**Mode**	**Energy Intensity** (Btu/tonne-mile)	**Distance from Origin to Destination** (mi)	**Capacity** (tonnes)	**Fuel Used** (mi/gal)	**Energy Used** (Btu/mi for truck) (Btu/hp hr for ship)	**Shares of Diesel Used**	**% Fuel Transported by Mode**
Brazil Plant to Brazil port	Pipeline	253	500	110	n/a	n/a	20%	50%
	Rail	370	500	n/a	n/a	n/a	100%	50%
Brazil port to U.S port	Ocean Tanker	32	7,416	150,000	19	4,620	100%	100%
		29	7,416	150,000	19	4,691	100%	100%
U.S port to distribution center inside U.S	Heavy Duty Truck	1,028	100	33	5	25,690	100%	100%
Distribution to blending terminal inside U.S	Heavy Duty Truck	1,028	50	33	5	25,690	100%	80%

Note: Pipeline use 20% diesel, 6% electricity, 24% natural gas, the remaining 50% is residual oil. Ocean tanker travel from origin and back has different energy consumption. For ethanol distributed in the U.S, 20% ethanol is directly transported to blending terminal by CA-GREET default.

Table 5.02 Calculations for Ethanol Transport Energy by Transport Mode

Transport Mode	CA-GREET Formula	Relevant Parameters	Btu/mmBtu
Transport Pipeline within Brazil	- 6% electricity use: (1 06/A)*B)/((g/lb)*(lb/tonne)*(C)*(D)*[6%*(H)*~~100~~1 00%] ~~= 440~~ - 20% diesel use: (106/A)*B)/((g/lb)*(lb/tonne)*(C)*(D)* [20%*1 00%*(1 ~(F)] ~~= 1,260~~ - 50% residual oil: (106/A)*B)/((g/lb)*(lb/tonne)*(C)*(D)* [50%*100%*(1~(G)] ~~= 3,010~~ - 24% NG Use: 1 06/A)*B)/((g/lb)*(lb/tonne)*(C)*(D)* [24%*~~100~~1 00%*(1 ~(K)] ~~=~~	A = Ethanol LHV = 76,330 Btu/gal B = Ethanol density = 2,988 g/gal C = Mi traveled = 500 miles D = Energy intensity = 253 (Btu/tonne-mile) E = %Diesel Share = 20% F = Diesel energy = ~~0.157~~**0.163** Btu/Btu G = Residual oil energy = ~~0.106~~**0.113** Btu/Btu H = Electricity Energy ~~in Brazil = 1.347 Btu/Btu~~**(U.S. Average) = 2.647**	~~6,202~~**3,069**
Transport Rail within Brazil	100% diesel use: ~~10^6~~ **1 0^6**/A*B/((g/lb)*(lb/tonne)*I*K*[E*(1 ~F)] ***50%**	I = Mi traveled = 500 miles J = % Electricity share = 0% K = Rail energy intensity = 370 Btu/tonne-mile	~~9,414~~**4,638**
Transport Ocean Tanker to U.S ports	106/A*B((g/lb)*(lb/tonne)*(L*(M~N)*100 %(1 ~G)	L = Mi traveled = 7,416 miles M = energy intensity from origin = 32 Btu/tonne-mile N = energy intensity from destination = 29 Btu/tonne-mile	~~21,992~~**21,6 61**
Total EtOH Transportation used in Brazil = 50%~~*6,202 +~~ by pipeline, 50%~~*9,414 +~~			~~29,800~~**29,3**
Transport Within U.S	1 0^6/A*B((g/lb)*(lb/tonne)*(O*(P~P)*1 00 %(1~F)	O = Mi traveled = 100 miles P = energy intensity = 1,028	~~10,459~~**10,3 05**
Total EtOH Transportation			~~**40,259**~~**39,6**
Distribution	1 0^6/A*B((g/lb)*(lb/tonne)*(Q*(P~P)*1 00 %(1 ~F)*80%	Q = Mi traveled = 50 miles 80% = shares of truck travel	~~4,183~~**4,122**
T&D Total (Btu/mmBtu)			~~**44,442**~~**43,7**

Note: The energy intensity for heavy duty trucks is multiplied by 2 to account for return trip.

5.2 GHG Calculations from Ethanol Transportation and Distribution (T&D)

Similar to sugarcane T&D, ethanol T&D to bulk terminal is assumed in CA-GREET model by rail and pipeline inside Brazil, then ocean tanker from Brazilian ports to U.S ports, and finally from trucks to terminal within U.S. All the assumptions are the same as sugarcane T&D's and are shown in Table 5.03. The values in this table do not reflect the mode shares.

Table 5.03 Assumptions in Calculating GHG Emissions from EtOH Transportation

Transport Mode	Transport Fuel	1-way Energy Intensity (Btu/tonne-mile)	Distance from Origin to Destination (mi)	WTT Fuel CO_2 Emissions of transportation fuels (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
50% Rail	Diesel	370	500	12,647	77,623
50% Pipeline	Electricity	253	500	18,504	-
	Diesel			12,647	Turbine: 78,179 Reciprocating Engine: 77,337
	Residual Oil			8,867	Turbine: 85,061 Reciprocating Engine: 84,219
	Natural Gas			5,218	Turbine: 58,044 Reciprocating Engine: 56,013
100% Ocean Tanker	Residual Oil	32 (29)	7,416	8,867	84,102
100% Heavy Duty Truck	Diesel	1,713	100	12,647	77,809 (77,913)
80% Heavy Duty Truck	Diesel	1,713	~~30~~50	12,647	77,809 (77,913)

Note: It is assumed that all locomotives use diesel. Values in parenthesis are for the return trips

The results are shown in Table 5.04. The WTT emissions shown in the Table for each GHG species is calculated in the "*T&D"* tab of CA-GREET model. The equation for CO_2 from rail is shown below and the calculations for the other transport modes and GHG gases are done similarly. VOC and CO emissions are not shown in Table 5.04, which contribute 8.7 g/mmBtu and 18.6 g/mmBtu (on a CO_2-equivalent basis), respectively. CA-GREET also includes 19.7 g/mmBtu VOC fugitive emissions (62 g/mmBtu CO_2-equivalent). Note that only one-way rail emissions are counted, whereas an extra term exists in the calculation for truck transport to account for the return truck trip; emissions from the return trip are assumed to be equal to emissions for the trip from the origin to destination.

Table 5.04 GHG Emissions from EtOH Transport and Distribution

Transport Mode	CO_2 Emissions, Excluding VOC and CO (g/mm Btu)	CH_4 Emissions (g/mmBtu)		N_2O Emissions (g/mmBtu)		CO_2e[1] (g/mmBtu)
		actual	as CO_2e	actual	as CO_2e	
Transported by Pipeline*	~~449~~223.5	~~0.77~~0.76	~~0.77~~0.76*25/2=~~19~~	0.01	0.01*298~~=~~/~~3~~2 =1.5	~~471~~234.5
Transported by Rail*	~~737~~362.5	0.83	0.83*25/2=~~21~~10	0.02	0.02*298~~=~~/~~6~~2 =2.5	~~784~~375
Transported by Ocean Tanker	~~1,856~~1,829 ~~2,449*~~	~~1.97~~1.94	~~1.97~~1.94*25=~~49~~48 ~~89~~	0.04	0.04*298= ~~12~~ ~~21~~12	~~1,917~~1,889 ~~3,152~~
Weighted Average*	2,413		67.5		16	2,496.5
Transported by Heavy Duty Truck	~~820~~807	0.9	~~23~~0.9*298=22.5	0.02	0.02*298= 6	~~859~~835.5
Distributed by Heavy Duty Truck*	~~328~~323.2	~~0.2~~0.4	~~5~~0.4*25=10	~~0.00~~0.01	~~1~~0.01*298= 3	~~334~~336.2
Total	~~3,597~~3,543.2		~~107~~100		~~28~~25	~~4,345~~3,668.2
Total GHG Emissions (gCO_2e/MJ)						~~4.1~~3.5

Note: *In Brazil, assumed 50% EtOH transportation travel by rail and 50% by pipeline, and 80% distributed by truck

Note: Anhydrous ethanol modeled here is not suitable for use in blending with the CARBOB component to produce California Reformulated Gasoline (CaRFG). Calculations pertaining to tailpipe emissions from the use of denatured ethanol blended with CARBOB (to produce CaRFG) are detailed in the CaRFG document and is available on the Low Carbon Fuel Standard website (www.arb.ca.gov/fuels/lcfs/lcfs.htm).

APPENDIX A2 (SCENARIOS 1 AND 2)

SCENARIO 1: MECHANIZED HARVESTING AND ELECTRICITY CO-PRODUCT CREDIT

SCENARIO 2: ELECTRICITY CO-PRODUCT CREDIT

Detailed calculations for the two additional scenarios analyzed for Brazilian sugarcane ethanol

This appendix details the calculations for the two additional scenarios presented in the summary section of this document. They include:

Scenario 1: Mechanized harvesting and export of co-product power from plant burning bagasse

Scenario 2: Export of co-product power from plants burning bagasse

Table A2 provides a comparison of the two scenarios with the baseline pathway completed in February 2009 and detailed in Appendix A1. All of the assumptions for the two scenarios are the same as those for the baseline pathway (except for the variations considered in the two scenarios).

Table A2 Comparison of Baseline Pathway with Two Additional Scenarios Analyzed In This Appendix

Pathway	Baseline Pathway	Scenario 1	Scenario 2
Mechanized Harvest	No	Yes	No
With Co-Product Electricity Credit	No	Yes	Yes
Total GHG Emissions (gCO2e/MJ)	**27.40**	~~**12.20**~~**12.40**	**20.40**

Scenario 1: Mechanized harvesting and export of co-product electricity from plant burning bagasse

The dominant practice of cane harvest in Brazil has been burning the straw prior to harvesting. This practice however is gradually being replaced by mechanized harvesting and new regulations prohibit burning prior to harvesting in Sao Paulo, Brazil by 2012 (the largest state in Brazil producing and importing sugarcane ethanol to the U.S)[5].

The baseline pathway calculated that burning generated 8.2 gCO2e/MJ of GHG emissions (details provided later in this Appendix). When a mechanized process is adopted, the baseline pathway is credited with this amount to provide a WTW emissions for the pathway with mechanized harvesting. For the co-product electricity, a GHG credit of 7.0 gCO2e/MJ is applied (details provided later in this Appendix). Therefore, this scenario has a total WTW of ~~**12.20**~~**12.40** **gCO2e/MJ** (baseline of 27.4 – ~~8.2~~**8.0** – 7.0 **= 12.4**).

5 Sao Paulo State Law: 11.241 on 19 September ~~2002~~**2002.**

Scenario 2: Export of co-product electricity from plants burning bagasse

As indicated in Scenario 1, the co-product credit is 7.0 gCO_2e/MJ which leads to WTW emissions for this scenario of **20.40 gCO_2e/MJ** (baseline of 27.4 – 7.0 **= 20.4**). A complete detail of the co-product credit is provided later in this Appendix.

Detailed CA-GREET model calculations of values used for scenarios 1 and 2

SECTION 1. GHG EMISSIONS FROM AVOIDING STRAW BURNING AND MECHANIZED HARVESTING OF SUGARCANE

As mechanization replaces field burning prior to harvesting by hand, the avoided emissions are calculated and presented as an emissions credit to the pathway. Section 1.3 in Appendix A1 presented details of the emissions from straw burning prior to harvest and the results are shown here in Table 1.01

Table 1.01 Avoided Emissions from Mechanized Harvestin

Emission Species	GHG Emissions (gCO_2e/MJ)
VOC	2.2
CO	~~14.4~~**14.2**
CH_4	6.6
N_2O	2.1
CO_2	163.2
Biogenic CO_2 Credit	(-~~180.2~~**180.3**)
Total GHG Emissions (gCO_2e/MJ)	**~~8.2~~8.0**

SECTION 2. GHG EMISSIONS ACCOUNTING FOR CO-PRODUCT CREDIT FROM ELECTRICITY GENERATION

Data was supplied to staff by the Brazilian Sugarcane Association (UNICA) for 39 plants that produce excess electric power using energy from burning of bagasse. The exported electricity is assumed to displace power from new generation, which in Brazil is natural gas derived. Table 2.02 summarizes the data from UNICA[6].

Table 2.02 Total Electricity Exported to Grid in 2008 in Brazil of 39 Mills Surveyed

Ethanol Mills **Survey**	Cane Crushed (tonnes)	Surplus Electricity Exported (MWh)	Average Surplus Electricity (kWh/tonne)
39	121,694,215	3,062,304	**25.16**

The CA-GREET model uses a default co-product electricity value of 0.96 kWh/gal for the export electricity scenario. This value is equal to **23.1** kWh/tonne cane which is close to the actual value. For the calculations provided below, this CA-GREET default value of **23.1** kwh/tonne cane has been used.

6 Data and Personal Communication with Joel Valesco and associates (UNICA) on 06/30/2009

Assumptions: (CA-GREET)[7]
Thermal energy of sugarcane: 1,188 MJ/tonne
LHV of bagasse: 12,947,318 Btu/ton
Bagasse moisture content: 50%
Biomass boiler efficiency: 80%
Power generation efficiency: 30%
Energy needed per gallon of cane ethanol:

$$\frac{1188\,MJ/tonnecane}{1055\,MJ/MMBtu} \times \frac{1}{80\%} \times \frac{1\,tonnecane}{24\,galEtOH} = 58{,}546 \text{ Btu/gal ethanol}$$

Bagasse Energy yield per gallon of Ethanol:

$$\frac{12{,}947{,}318\,Btu/ton}{10^6} \times \frac{1055\,MJ}{1\,MMBtu} \times \frac{1}{(2000\,lb/ton) \times (0.454\,kg/lb)} \times 50\% \times \frac{280\,kgbagass/1000\,kgcane}{0.024\,gal/kgcane}$$

= 83,124 Btu/gal ethanol

Extra bagasse Btu for Electricity Co-gen:

$$\frac{(83124\,Btu/gal - 58546\,Btu/gal) \times 30\%}{3412\,Btu/KWh} = 2.16\,kWh/gal$$

After internal deduction 1.2 kWh/gal from ethanol processing (0.5 kWh/gal electrical and 0.7 kWh/gal mechanical usage), the extra electricity export from bagasse is (2.16 - 0.5 - 0.7) kWh/gal = **0.96 kWh/gal**

The results are a CA-GREET calculation based on the electricity exported and the emission factor in the CA-GREET model for marginal natural gas based power generation. The first column in Table 1.03 is a CA-GREET calculation for Brazil marginal power in the **"***EtOH* ~~sheet~~**" tab**. The adjacent column calculates the co-product credit in g/gal with subsequent columns showing the unit conversions to g/MJ. Table 2.03 shows the results for co-product electricity credit (-7.0 gCO2e/MJ) as calculated in CA-GREET.

7 Using data from M. Wang et al: WTW Energy Use and GHG Emissions of Brazilian Sugarcane Ethanol - July 2007

Table 2.03 GHG Emissions for Co-product Electricity Credit

	Brazil Marginal Electricity	Co-Product Electricity Credit	Co-Product Electricity Credit	Co-Product Electricity Credit
Energy	**Btu/mmBtu**	**Btu/gal**	**Btu/mmBtu**	**J/MJ**
Total energy	~~2,984,567~~**2,9**	-8,981	-117,666	-117,666
Emissions	**g/mmBtu**	**g/gal**	**g/mmBtu**	**gCO_2e/mmBtu**
VOC	~~25.859~~**25.82**	-0.078	-1.018	~~-0.001~~
CO	~~97.830~~**97.54**	-0.294	-3.847	~~-0.004~~
CH_4	368.782	-1.110	-14.544	-~~0.014~~**363.6**
N_2O	~~3.624~~**3.62**	-0.011	-0.143	~~0.000~~**-42.6**
CO_2 **only**	~~176,859~~**176,7**	**-532**	~~-6,972~~	~~-6.6~~
CO_2 (~~incl.~~**including** VOC and CO)	~~177100~~**177,032**	-533	-6,982	-~~6.6~~**6,982**
~~Total~~ **GHG**	~~**187,399**~~	~~**-564**~~	~~**-7,388**~~	**-~~7.0~~7,388.2**
Total GHG Emissions (gCO_2e/MJ)				**-7.0**

The calculations for the electricity credit are based on the product of the co-product power and the emission intensity of the electricity in g/mmBtu.

Sample Calculation ~~for~~of CO_2 shown Table 2.03 above:

Electricity Fuel Shares = 0.96 kWh * 3,412 Btu/kWh = 3,276 Btu/gallon.
3,276 Btu/gallon * ~~176,859~~**(176,797** g/mmBtu/~~10^6~~**10^6** Btu**)*(1-8.1%)** =
532 g/gal (see entry in Table ~~1.03~~**2.03**).

APPENDIX B

INPUT VALUES FOR ETHANOL FROM BRAZILIAN SUGARCANE

Scenario: Ethanol made in Brazil from Brazil Sugarcane and transported to California.

Parameters	**Units**	**Values**	**Note**
		GHG Equivalent	
CO_2		1	CA-GREET Default
CH_4		25	CA-GREET Default
N_2O		298	CA-GREET Default
VOC		3.1	CA-GREET Default
CO		1.6	CA-GREET Default
Sugarcane Cultivation			
Fuel Use Shares			
Diesel		38.3%	CA-GREET Default
Gasoline		12.3%	CA-GREET Default
Natural Gas		21.5%	CA-GREET Default
LPG		18.8%	CA-GREET Default
Electricity		9%	CA-GREET Default
Cultivation Equipment Shares			
Diesel Farming Tractor		80%	CA-GREET Default
CO_2 Emission Factor	g/mmBtu	77,411	CA-GREET Default
Diesel Engine		20%	CA-GREET Default
CO_2 Emission Factor	g/mmBtu	77,349	CA-GREET Default
Gasoline Farming Tractor		80%	CA-GREET Default
CO_2 Emission Factor	g/mmBtu	75,645	CA-GREET Default
NG Engine		100%	CA-GREET Default
CO_2 Emission Factor	g/mmBtu	57,732	CA-GREET Default
LPG Commercial Boiler		100%	CA-GREET Default
CO_2 Emission Factor	g/mmBtu	68,036	CA-GREET Default
Sugarcane Farming			
Sugarcane energy use	Btu/tonne	41,592	CA-GREET Default
Sugarcane harvest yield	tonne/ha	75	CA-GREET Default
Sugarcane T&D			
Transported from Sugarcane Field to Stack			
by medium truck	miles	10	2,199 Btu/mile-tonne Energy Intensity
fuel consumption	mi/gal	7.3	capacity 8 tonnes/trip
CO_2 emission factor	g/mi	1,369	CA-GREET Default
Transported from Stack to EtOH Plant			
by heavy duty diesel truck	miles	40	1,713 Btu/mile-tonne Energy Intensity
fuel consumption	mi/gal	5	capacity 15 tonnes/trip
CO_2 emission factor	g/mi	1,999	CA-GREET Default
Chemicals Inputs			
Nitrogen	g/tonne	1,092	CA-GREET Default
NH3			
Production Efficiency		82.4%	CA-GREET Default
Shares in Nitrogen Production		70.7%	CA-GREET Default
CO_2 Emission Factor	g/g	2.475	CA-GREET Default
Urea			
Production Efficiency		46.7%	CA-GREET Default
Shares in Nitrogen Production		21.1%	CA-GREET Default
Ammonium Nitrate			
Production Efficiency		35%	CA-GREET Default
Shares in Nitrogen Production		8%	CA-GREET Default

Parameters	Units	Values	Note
P_2O_5	g/tonne	149	CA-GREET Default
H_2SO_4			
Feedstock input	tonnes	2.674	CA-GREET Default
Phosphor Rock			
Feedstock input	tonnes	3.525	CA-GREET Default
K_2O	g/tonne	193.6	CA-GREET Default
$CaCO_3$	g/tonne	5,337.7	CA-GREET Default
Herbicide	g/tonne	8.1	CA-GREET Default
Pesticide	g/tonne	2.21	CA-GREET Default
CO_2 from $CaCO_3$ use	g/tonne	2,349	CA-GREET Default
Sugarcane Straw Burning Credit	g/tonne	-349,067	CA-GREET Default
EtOH Production			
Yield			
EtOH Yiel	gal/wet tonne	24.0	CA-GREET Default
Sugarcane Straw Yield	Dry tonne/tonne sugarcane	~~0.14~~**0.19**	CA-GREET Calculations
Bagasse Burning/gal EtOH Yield	Dry tonne/gal	0.00642	CA-GREET Default
Production			
Energy use for Sugarcane Mill EtOH	Btu/gal	251	CA-GREET Default
From Residual Oil		0.3%	CA-GREET Default
Residual Oil Industrial Boiler	g/mmBtu	85,045	CA-GREET Default
From Bagasse burning		99.7%	CA-GREET Default
Bagasse –burned, small Industrial Boiler	g/mmBtu	118,834	CA-GREET Default
EtOH T&D			
Transported by rail – inside Brazil	miles	500	370 Btu/mile-tonne Energy Intensity, CA-GREET Default
Transported by pipeline – inside Brazil	miles	500	253 Btu/mile-tonne Energy Intensity, CA-GREET Default
Transported by Ocean Tanker to U.S.	miles	7,416	26 Btu/mile-tonne Energy Intensity from original, CA-GREET Default
From U.S. back to Brazil	miles	7,416	39 Btu/mile-tonne Energy Intensity from destination, CA-GREET Default
Transported by HHD truck to distribution center	miles	100	1,028 Btu/mile-tonne Energy Intensity both ways, CA-GREET Default
Transported by HHD truck to blending terminal	Miles	50	1,028 Btu/mile-tonne Energy Intensity both ways, CA-GREET Default
Fuels Properties	**LHV (Btu/gal)**	**Density (g/gal)**	
Crude	129,670	3,205	CA-GREET Default
Residual Oil	140,353	3,752	CA-GREET Default
Conventional Diesel	128,450	3,167	CA-GREET Default
Conventional Gasoline	116,090	2,819	CA-GREET Default
CaRFG	111,289	2,828	CA-GREET Default
CARBOB	113,300	2,767	CA-GREET Default
Natural Gas	83,868	2,651	As liquid
EtOH	76,330	2,988	Anhydrous ethanol (neat)
EtOH	77,254	2,983	Denatured ethanol (2.5% by volume)
Bagasse (Btu/dry tonne)	12,947,318	n/a	CA-GREET Default

Document comparison done by Workshare DeltaView on Thursday, October 01, 2009 9:17:53 AM

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Document 1	file://C:/My Documents/10-01-09/072009lcfs_sugarcane_etoh.doc
Document 2	file://C:/My Documents/10-01-09/092309lcfs_cane_etoh.doc
Rendering set	Enhanced K&E

Legend:	
Insertion	
~~Deletion~~	
~~*Moved from*~~	
Moved to	
Style change	
Format change	
~~Moved deletion~~	
Inserted cell	
Deleted cell	
Moved cell	
Split/Merged cell	
Padding cell	

Redline Summary:		
No.	**Change**	**Text**
1-2	Change	"Release Date: July 20, 2009" changed to "Release Date: September 23, 2009"
3-4	Change	"Version 2.2" changed to "Version 2.3"
5-6	Change	"Section 3. SUGARCANE TRANSPORT 28" changed to "Section 3. SUGARCANE TRANSPORT 29"
7-8	Change	"Energy for Sugarcane Transportation 28" changed to "Energy for Sugarcane Transportation 29"
9-10	Change	"Calculations from Sugarcane Transportation 29" changed to "Calculations from Sugarcane Transportation 30"
11-12	Change	"Section 4. ETHANOL PRODUCTION 31"

		changed to "Section 4. ETHANOL PRODUCTION 32"
13-14	Change	"4.1 Ethanol Production 31" changed to "4.1 Ethanol Production 32"
15-16	Change	"Emissions from Ethanol Production 32" changed to "Emissions from Ethanol Production 33"
17-18	Change	"ETHANOL TRANSPORT AND DISTRIBUTION 34" changed to "ETHANOL TRANSPORT AND DISTRIBUTION 36"
19-20	Change	"Transportation and Distribution 34" changed to "Transportation and Distribution 36"
21-22	Change	"Transportation and Distribution (T&D) 36" changed to "Transportation and Distribution (T&D) 38"
23-24	Change	"APPENDIX A2 (SCENARIOS 1 AND 2) 38" changed to "APPENDIX A2 (SCENARIOS 1 AND 2) 40"
25-26	Change	"and Electricity Co-product Credit 38" changed to "and Electricity Co-product Credit 40"
27-28	Change	"2: Electricity Co-product Credit 38" changed to "2: Electricity Co-product Credit 40"
29-30	Change	"of Sugarcane 40" changed to "of Sugarcane 42"
31-32	Change	"Generation 40" changed to "Generation 42"
33-34	Change	"APPENDIX B 43" changed to "APPENDIX B 45"
35-36	Change	"ETHANOL FROM BRAZILIAN SUGARCANE 43" changed to "ETHANOL FROM BRAZILIAN SUGARCANE 45"
37-38	Change	"Chemicals 24" changed to "Chemicals25"
39-40	Change	"Chemicals 25" changed to "Chemicals26"
41-42	Change	"Production of Agricultural Chemicals 26"

		changed to "Production of Agricultural Chemicals 27"
43-44	Change	"Farming 26" changed to "Farming 27"
45	Deletion	27
46	Insertion	28
47-48	Change	"3.01 Sugarcane Transport Inputs28" changed to "3.01 Sugarcane Transport Inputs 29"
49-50	Change	"3.02 Sugarcane Transport Energy 28" changed to "3.02 Sugarcane Transport Energy 29"
51	Deletion	9
52-53	Change	"Calculating GHG Emissions from Sugarcane 29" changed to "Calculating GHG Emissions from Sugarcane30"
54-55	Change	"Sugarcane Transport - CO2 Emissions 29" changed to "Sugarcane Transport - CO2 Emissions 30"
56-57	Change	"Transport –Total GHG Emissions 30" changed to "Transport –Total GHG Emissions 31"
58-59	Change	"Shares and Primary Energy Inputs 31" changed to "Shares and Primary Energy Inputs 32"
60-61	Change	"Parameters and Total Energy Use 32" changed to "Parameters and Total Energy Use 33"
62-63	Change	"Factors (EF) for Ethanol Production 32" changed to "Factors (EF) for Ethanol Production 33"
64-65	Change	"Table 4.03 33" changed to "Table 4.03 34"
66-67	Change	"Terminals 34" changed to "Terminals 36"
68-69	Change	"Transport Energy by Transport Mode 35" changed to "Transport Energy by Transport Mode 37"

70-71	Change	"Emissions from EtOH Transportation 36" changed to "Emissions from EtOH Transportation 38"
72	Deletion	EtOH Transport and Distribution 37
73	Change	"Table A2 Comparison of Baseline" changed to "39 Table A2 Comparison of Baseline"
74-75	Change	"This Appendix 39" changed to "This Appendix 41"
76-77	Change	"Emissions from Mechanized Harvesting 40" changed to "Emissions from Mechanized Harvesting 42"
78-79	Change	"in Brazil of 39 Mills Surveyed 41" changed to "in Brazil of 39 Mills Surveyed 43"
80-81	Change	"for Co-product Electricity Credit 42" changed to "for Co-product Electricity Credit 44"
82	Deletion	6
83	Deletion	7
84	Insertion	8
85	Change	"Figure 1 below outlines the discrete" changed to "Figure 1 below outlines the discrete"
86	Deletion	9
87	Deletion	9
88	Deletion	9
89-90	Change	"12.20" changed to "12.40"
91	Deletion	10
92-93	Change	"26,407" changed to "26,219"
94-95	Change	"59,616" changed to "59,562"
96-97	Change	"2.7%" changed to "2.6%"
98-99	Change	"25,722" changed to "25,344"
100-101	Change	"1,093,376" changed to "1,093,320"
102-103	Change	"44,442" changed to "43,795"
104-105	Change	"2%" changed to "1.9%"
106-107	Change	"55.6%" changed to "55.5%"
108-109	Change	"44.4%" changed to "44.6%"
110-111	Change	"44.4%" changed to "44.6%"

112-113	Change	"2,249,563" changed to "2,248,240"
114	Deletion	11
115-116	Change	"2.0%" changed to "1.9%"
117	Insertion	Energy Distribution from Sugarcane Ethanol
118-119	Change	"44.4%" changed to "44.5%"
120	Deletion	GHGs Energy from Sugarcane Ethanol
121-122	Change	"Energy Inputs for Ag Chemicals, 2.7%" changed to "Energy Inputs for Ag Chemicals, 2.6%"
123-124	Change	"9.9" changed to "9.8"
125-126	Change	"8.7" changed to "9.2"
127-128	Change	"1.9" changed to "2.1"
129-130	Change	"4.1" changed to "3.5"
131-132	Change	"Total Tank-to-wheel" changed to "Total Tank-to-Wheel"
133	Deletion	12
134-135	Change	"7.1%" changed to "7.9%"
136-137	Change	"Energy Emissions of Sugarcane Ethanol" changed to "GHG Emissions of Sugarcane Ethanol"
138	Deletion	Ethanol T&D, 15.4%
139-140	Change	"Impacts, 32.7%" changed to "Impacts, 34.6%"
141	Insertion	Ethanol T&D, 13.2%
142	Deletion	13
143-144	Change	"10,247" changed to "10,113"
145-146	Change	"3,401" changed to "3,357"
147-148	Change	"5,213" changed to "5,221"
149-150	Change	"4,790" changed to "4,768"
151-152	Change	"2,756" changed to "2,760"
153	Deletion	Total Energy for Sugarcane Farming (Btu/mmBtu)
154-155	Change	"26,407" changed to "26,219"
156	Change	"Farming" changed to "GHG Emissions of Farming"
157	Change	"Straw Burning" changed to "GHG Emissions of Straw Burning"

158-159	Change	"< 0.01" changed to "0.1"
160-161	Change	"14.4" changed to "14.2"
162-163	Change	"1.69" changed to "1.8"
164-165	Change	"1.74" changed to "1.8"
166-167	Change	"8.2" changed to "8.0"
168	Deletion	Total GHG Emissions (gCO2e/MJ)
169-170	Change	"9.9" changed to "9.8"
171	Deletion	14
172	Insertion	Chemical Type (Btu/mmBtu)
173	Change	"Energy Use" changed to "Total Energy Use"
174	Deletion	Nitrogen Fertilizer (Btu/mmBtu)
175-176	Change	"31,054" changed to "31,076"
177	Deletion	Phosphate Fertilizer(Btu/mmBtu)
178-179	Change	"880" changed to "878"
180	Deletion	Potash (Btu/mmBtu)
181-182	Change	"885" changed to "889"
183	Deletion	Lime (Btu/mmBtu)
184-185	Change	"22,354" changed to "22,467"
186	Deletion	Herbicide (Btu/mmBtu)
187-188	Change	"3,853" changed to "3,875"
189	Deletion	Insecticide (Btu/mmBtu)
190-191	Change	"375" changed to "377"
192-193	Change	"59,616" changed to "59,562"
194	Deletion	Ethanol Pathway
195	Deletion	Agricultural Chemicals
196	Deletion	Soil N2O and NO
197	Deletion	CO2 from Application of Lime
198	Deletion	Total
199	Deletion	Fertilizers
200	Deletion	Herbicide
201	Deletion	Pesticide
202	Deletion	GHGs (gCO2e/MJ)
203	Deletion	3.7
204	Deletion	0.3
205	Deletion	0.03
206	Deletion	3.5
207	Deletion	1.2

208	Deletion	8.7
209	Insertion	GHG Emissions
210	Insertion	GHG Emissions from Agricultural Chemicals
211	Insertion	GHG Emissions from Soil N_2O and NO
212	Insertion	GHG Emissions from CO_2 from Application of Lime
213	Insertion	Total GHG Emissions
214	Insertion	Fertilizers
215	Insertion	Herbicide
216	Insertion	Pesticide
217	Insertion	GHGs (gCO_2e/MJ)
218	Insertion	4.18
219	Insertion	0.3
220	Insertion	0.03
221	Insertion	3.5
222	Insertion	1.2
223	Insertion	9.2
224	Change	"Total Energy for Sugarcane Transport (Btu/mmBtu)" changed to "Total Energy Use for...Transport (Btu/mmBtu)"
225-226	Change	"25,722" changed to "25,344"
227	Insertion	GHG Species
228	Insertion	GHG Emissions
229	Insertion	VOC (gCO_2e/MJ)
230	Insertion	< 0.01
231	Insertion	CO (gCO_2e/MJ)
232	Insertion	< 0.01
233	Insertion	CH_4 (gCO_2e/MJ)
234	Insertion	0.05

235	Insertion	N2O (gCO2e/MJ)
236	Insertion	0.01
237	Insertion	CO2 (gCO2e/MJ)
238	Insertion	1.88
239	Insertion	Total GHG Emissions
240	Insertion	2.0
241	Deletion	GHG Species
242	Deletion	GHG Emissions
243	Deletion	VOC (gCO2e/MJ)
244	Deletion	<
245	Deletion	0.01
246	Deletion	CH4 (gCO2e/MJ)
247	Deletion	<
248	Deletion	0.01
249	Deletion	N2O (gCO2e/MJ)
250	Deletion	<
251	Deletion	0.01
252	Deletion	CO (gCO2e/MJ)
253	Deletion	<
254	Deletion	0.01
255	Deletion	CO2 (gCO2e/MJ)
256	Deletion	2.0
257	Deletion	Total GHG Emissions (gCO2e/MJ)
258	Deletion	2.0
259	Insertion	Total Energy Use
260-261	Change	"284" changed to "279"
262-263	Change	"83,415" changed to "83,411"
264-265	Change	"1,093,743" changed to "1,093,320"
266	Insertion	GHG Species (gCO2e/MJ)
267	Change	"CO2 from Residual Oil (gCO2e/MJ)" changed to "Residual Oil (gCO2e/MJ)"
268-269	Change	"CO2 from Bagasse" changed to "GHG from Bagasse"
270-271	Change	"from Bagasse Burning" changed to "from Bagasse burning"
272-273	Change	"124.9" changed to "124.93"
274-275	Change	"CO2 credit for Bagasse" changed to "Credit for Bagasse"

276	Change	"for Bagasse (gCO2e/MJ)" changed to "for Bagasse burning (gCO2e/MJ)"
277-278	Change	"-122.97" changed to "-122.9"
279	Deletion	CH4 (gCO2e/MJ)
280	Deletion	< 0.01
281	Deletion	N2O (gCO2e/MJ)
282	Deletion	< 0.01
283	Deletion	VOC from Residual Oil (gCO2e/MJ)
284	Deletion	< 0.01
285	Deletion	VOC from Bagasse Burning (gCO2e/MJ)
286	Deletion	0.02
287	Deletion	VOC from non-combustion source (gCO2e/MJ)
288	Deletion	0.09
289	Deletion	CO from Residual Oil (gCO2e/MJ)
290	Deletion	< 0.01
291	Deletion	CO from Bagasse Burning (gCO2e/MJ)
292	Deletion	0.12
293-294	Change	"1.9" changed to "2.1"
295	Change	"Energy" changed to "Total Energy"
296	Change	"Energy Use" changed to "Energy Use"
297-298	Change	"21,510" changed to "21,661"
299-300	Change	"4,614" changed to "4,638"
301-302	Change	"3,056" changed to "3,069"
303-304	Change	"10,251" changed to "10,305"
305-306	Change	"2,460" changed to "4,122"
307-308	Change	"44 ," changed to "43 ,"
309-310	Change	",442" changed to ",795"
311	Insertion	(gCO2e/mmBtu)
312	Insertion	GHG Emissions (gCO2e/MJ)
313-314	Change	"1.81" changed to "1,901"
315	Insertion	1.81
316	Deletion	By Rail (gCO2e/MJ)
317-318	Change	"0.72" changed to "755"
319	Insertion	0.72
320	Deletion	By Pipeline (gCO2e/MJ)
321-322	Change	"0.45" changed to "468"
323	Insertion	0.45

324	Deletion	By Heavy Duty Truck (gCO2e/MJ)
325-326	Change	"0.81" changed to "839"
327	Insertion	0.81
328	Deletion	By Heavy Duty Truck (gCO2e/MJ)
329-330	Change	"0.32" changed to "419"
331	Insertion	0.32
332-333	Change	"4.1" changed to "3,687"
334	Insertion	3.5
335-336	Change	"-8.2" changed to "-8.0"
337-338	Change	"12.20" changed to "12.40"
339	Deletion	GHG Emissions (gCO2e/MJ)
340	Insertion	Baseline Pathway Emissions (gCO2e/MJ)
341	Insertion	Electricity Co-product Credit (gCO2e/MJ)
342-343	Change	"18,803" changed to "18,527"
344-345	Change	"10,247" changed to "10,113"
346-347	Change	"6,240.4" changed to "6,150"
348-349	Change	"3,400.8" changed to "3,357"
350-351	Change	"9,565.2" changed to "9,565"
352-353	Change	"5,212.7" changed to "5,221"
354-355	Change	"8,789.3" changed to "8,735"
356-357	Change	"4,789.9" changed to "4,768"
358-359	Change	"R*S/10^{6}" changed to "R*S/1 ^{06}"
360-361	Change	"5,057.8" changed to "5,055"
362-363	Change	"2,756.3" changed to "2,760"
364-365	Change	"48,456" changed to "48,032"
366-367	Change	"26,407" changed to "26,219"
368-369	Change	"31,657 Btu/mmBtu" changed to "39,213 Btu/mmBtu"
370-371	Change	"125,303 Btu/mmBtu" changed to "123,805 Btu/mmBtu"
372-373	Change	"169,676 Btu/mmBtu" changed to "162,914 Btu/mmBtu"
374-375	Change	"72,626 Btu/mmBtu" changed to "69,596 Btu/mmBtu"
376-377	Change	"48,835 Btu/mmBtu" changed to "48,896 Btu/mmBtu"
378-379	Change	"31,657 Btu/mmBtu" changed to "39,213 Btu/mmBtu"
380-381	Change	"75,622 Btu/mmBtu" changed to "75,862 Btu/mmBtu"

382-383	Change	"1,347,391 Btu/mmBtu" changed to "1,350,521 Btu/mmBtu"
384-385	Change	"WTTCrude Recovery = 44,499" changed to "WTTCrude Recovery = 28,285"
386-387	Change	"28,249*1.00006 +" changed to "28,285*1.00006 +"
388-389	Change	"*1.00006 +3,406 =" changed to "*1.00006 +10,925 ="
390-391	Change	"= 31,657" changed to "= 39,213"
392-393	Change	"(CA-GREET default)...calculated) WTTCrude" changed to "(CA-GREET default)...calculated) WTTCrude"
394-395	Change	"WTT Res Oil = 55,561" changed to "WTT Res Oil = 74,239"
396	Deletion	= 1.106
397	Insertion	= 1.113
398-399	Change	"WTT diesel = 124,812" changed to "WTT diesel = 123,805"
400-401	Change	"1.157. LFdiesel = 1.00004 (CA-GREET default)." changed to "1.163. LFdiesel = 1.00004 (CA-GREET default)."
402-403	Change	"WTT $_{gasoline=}$ 164,227 (CA-GREET calculated)" changed to "WTT $_{gasoline=}$ 162,914 (CA-GREET calculated)"
404-405	Change	"gasoline + WTT gasoline)/ 10^6 = 1.201" changed to "gasoline + WTT gasoline)/ 10^6 = 1.202"
406-407	Change	"LFT&D + WTTT&D = 69,664" changed to "LFT&D + WTTT&D = 69,596"
408-409	Change	"WTT NG Recovery = 31,125, WTT NG Process =" changed to "WTT NG Recovery = 31,148, WTT NG Process ="
410-411	Change	"WTT NG Process = 31,843,...= 1.00148 and WTT" changed to "WTT NG Process = 31,854,...= 1.00148 and WTT"
412-413	Change	"LFProcessing = 1.00148 and WTT NG T&D = 9,381." changed to "LFProcessing = 1.00148 and WTT NG T&D = 6,498."
414-415	Change	"WTTelectricity = 1,347,391" changed to "WTTelectricity = 1,350,521"
416	Change	"S Electricity = (WTT" changed to "S Electricity = 1 + (WTT"

417-418	Change	"(WTT feedstock + WTT $_{fuel)/}$ 10^6 =" changed to "(WTT $_{electricityl)/}$ 10^6 ="
419-420	Change	"$_{)/}$ 10^6 = 2.347" changed to "$_{)/}$ 10^6 = 2.351"
421	Change	"component of the pathway and uses IPCC[4]" changed to "component of the pathway and uses IPCC[44]"
422-423	Change	"1,435" changed to "1,441"
424-425	Change	"782" changed to "787"
426-427	Change	"466" changed to "335"
428-429	Change	"254" changed to "183"
430-431	Change	"599" changed to "601"
432-433	Change	"326" changed to "328"
434-435	Change	"69" changed to "70"
436-437	Change	"3,120" changed to "2,999"
438-439	Change	"1,701" changed to "1,637"
440-441	Change	"3,120 (g/tonne)/(24 (gallons/tonne)*76,330" changed to "2,999 (g/tonne)/(24 (gallons/tonne)*76,330"
442-443	Change	"(gallons/tonne)*76,330...= 1,701 g/mmBtu where:" changed to "(gallons/tonne)*76,330...= 1,637 g/mmBtu where:"
444-445	Change	"7.82" changed to "7.85"
446-447	Change	"106.5" changed to "107"
448-449	Change	"11.9" changed to "13"
450-451	Change	"3,035" changed to "3,163"
452-453	Change	"1,654" changed to "1,726"
454-455	Change	"1.57" changed to "1.6"
456-457	Change	"1.7" changed to "1.8"
458	Change	"(1,660 g/kg straw)(0.190 dry tonne straw/tonne" changed to "(1,660 g CO2/kg...dry tonne straw/tonne"
459-460	Change	"GHG Emissions (gCO2e/m mBtu)" changed to "GHG Emissions (gCO2e/mmBtu)"
461	Change	"GHG Emissions" changed to "GHG Emissions"
462-463	Change	"2,287" changed to "2,264"
464-465	Change	"15,204" changed to "15,001"
466-467	Change	"14.4" changed to "14.2"
468-469	Change	"7,003.90" changed to "7,004"
470-471	Change	"2,164.50" changed to "2,164"
472-473	Change	"8.2" changed to "8.0"

474-475	Change	"and straw burning is therefore 1.74 +" changed to "and straw burning is therefore 1.8+"
476-477	Change	"+ 8.2 =" changed to "+ 8.0 ="
478-479	Change	"= 9.9 gCO2e/MJ." changed to "= 9.8 gCO2e/MJ."
480	Change	"Total Energy Use" changed to "Total Energy Use"
481-482	Change	"45.9" changed to "52.2"
483-484	Change	"50,133" changed to "56,930"
485-486	Change	"31,054" changed to "31,076"
487-488	Change	"1,604" changed to "1,608"
489-490	Change	"880" changed to "878"
491-492	Change	"1,624" changed to "1,629"
493-494	Change	"892" changed to "889"
495-496	Change	"41,019" changed to "41,158"
497-498	Change	"22,512" changed to "22,467"
499-500	Change	"262.8" changed to "263.9"
501-502	Change	"7,070" changed to "7,098"
503-504	Change	"3,898" changed to "3,875"
505-506	Change	"311.3" changed to "312.4"
507-508	Change	"688" changed to "690"
509-510	Change	"379" changed to "377"
511-512	Change	"59,616" changed to "59,562"
513-514	Change	"Fertilizer: WTT Energy...= 45.9 (Btu/g) *" changed to "Fertilizer: WTT Energy...= 52.2 (Btu/g) *"
515-516	Change	"(Btu/g) * 1,092 (g/tonne) =" changed to "(Btu/g) * 1,091.7 (g/tonne) ="
517-518	Change	"(g/tonne) = 50,133 Btu/tonne" changed to "(g/tonne) = 56,930 Btu/tonne"
519-520	Change	"(50,133 Btu/tonne)/((24 gallons/tonne)*76,330" changed to "(56,930 Btu/tonne)/((24 gallons/tonne)*76,330"
521-522	Change	"gallons/tonne)*76,330...59,616 Btu/mmBtu where :" changed to "gallons/tonne)*76,330...31,076 Btu/mmBtu where :"
523	Insertion	29
524	Insertion	VOC
525	Insertion	<0.01

526	Insertion	<0.01
527	Insertion	<0.01
528	Insertion	<0.01
529	Insertion	<0.01
530	Insertion	<0.01
531	Insertion	CO
532	Insertion	<0.01
533	Insertion	<0.01
534	Insertion	<0.01
535	Insertion	<0.01
536	Insertion	0.01
537	Insertion	0.02
538-539	Change	"2.39" changed to "1.81"
540-541	Change	"20.53" changed to "20.63"
542-543	Change	"23.87" changed to "23.99"
544-545	Change	"2.9" changed to "2.8"
546-547	Change	"21.3" changed to "21.4"
548-549	Change	"24.84" changed to "24.9"
550	Insertion	PRELIMINARY DRAFT DISTRIBUTED FOR PUBLIC COMMENT
551	Insertion	32
552	Insertion	30
553-554	Change	"(g/ton ne)" changed to "(g/tonne)"
555-556	Change	"(g/mm Btu)" changed to "(g/mmBtu)"
557	Change	"(gCO2/MJ)" changed to "(gCO2e/MJ)"
558-559	Change	"2,971" changed to "3,431"
560-561	Change	"1,619" changed to "1,870"
562-563	Change	"118" changed to "119"
564-565	Change	"64" changed to "65"
566-567	Change	"127" changed to "128"
568-569	Change	"69" changed to "70"
570-571	Change	"3,210" changed to "3,224"
572-573	Change	"1,749" changed to "1,757"
574-575	Change	"552" changed to "555"
576-577	Change	"301" changed to "302"
578	Change	"Total CO2 emissions (gCO2/MJ)" changed to "Total CO2 emissions (gCO2e/MJ)"
579-580	Change	"7,031" changed to "7,509"
581-582	Change	"3,832" changed to "4,092"
583-584	Change	"3.63" changed to "3.88"
585	Insertion	PRELIMINARY DRAFT DISTRIBUTED FOR

		PUBLIC COMMENT
586	Insertion	33
587	Insertion	31
588	Insertion	PRELIMINARY DRAFT DISTRIBUTED FOR PUBLIC COMMENT
589	Insertion	34
590	Insertion	GHG Type (g/tonne)
591	Insertion	3
592	Insertion	VOC
593	Insertion	6.86
594	Insertion	0.04
595	Insertion	0.02
596	Insertion	0.42
597	Insertion	0.07
598	Insertion	0.01
599	Insertion	7.43
600	Insertion	CO
601	Insertion	6.94
602	Insertion	0.14
603	Insertion	0.12
604	Insertion	2.80
605	Insertion	0.39
606	Insertion	0.05
607	Insertion	10.45
608	Deletion	CH4 (g/tonne)
609-610	Change	"3.1" changed to "2.99"
611-612	Change	"0.2" changed to "0.17"
613-614	Change	"0.2" changed to "0.17"
615-616	Change	"4.9" changed to "4.23"
617-618	Change	"0.8" changed to "0.70"
619-620	Change	"0.1" changed to "0.07"
621-622	Change	"9.3" changed to "8.32"
623	Deletion	N2O (g/tonne)
624-625	Change	"1.8" changed to "3.23"
626-627	Change	"0.05" changed to "0.03"
628-629	Change	"1.8" changed to "3.27"
630	Deletion	CO2 (g/tonne)
631-632	Change	"2,971" changed to "3,431"
633-634	Change	"118" changed to "119"
635-636	Change	"127" changed to "128"

637-638	Change	"3,210" changed to "3,224"
639-640	Change	"552" changed to "555"
641-642	Change	"6,743.4" changed to "7,509"
643	Deletion	GHGs (g/tonne)
644-645	Change	"3,579" changed to "4,500"
646-647	Change	"7524.2" changed to "8,730"
648-649	Change	"1,951" changed to "2,453"
650-651	Change	"68" changed to "67"
652-653	Change	"3,913" changed to "4,415"
654-655	Change	"4,256" changed to "4,758"
656-657	Change	"1.85" changed to "2.33"
658-659	Change	"3.70" changed to "4.18"
660-661	Change	"4.03" changed to "4.5"
662	Deletion	g
663	Change	"(g!tonne)" changed to "(g!tonne)"
664-665	Change	"emission: Soil CO2...g CO2/1 00" changed to "emission: Soil CO2...g CO2/1 00"
666-667	Change	"3/tonne)*(44 g CO2/1 00 g CaCO3) = 2,349" changed to "3/tonne)*(44 g CO2/1 00 gCaCO3) = 2,349"
668-669	Change	"3) = 2,349 g CO2/tonne = 1,282" changed to "3) = 2,349 gCO2/tonne = 1,282"
670-671	Change	"2/tonne = 1,282 g CO2/mmBtu =" changed to "2/tonne = 1,282 gCO2/mmBtu ="
672-673	Change	"2/mmBtu = 1.2 g CO2" changed to "2/mmBtu = 1.2 gCO2"
674	Change	"2/MJ." changed to "2e/MJ."
675-676	Change	"3.7" changed to "4.18"
677-678	Change	"8.7" changed to "9.2"
679	Change	"(Btu/tonne -" changed to "(Btu/tonne-"
680	Change	"-mile)" changed to "- mile)"
681	Change	"Distance" changed to "Distance"
682	Change	"from Origin" changed to "from Origin"
683	Change	"Origin" changed to "Origin"
684-685	Change	"Fuel Consumption" changed to "Fuel Cons."
686-687	Change	"Consumption of Truck" changed to "Cons. of

		Truck"
688-689	Change	"miles one-way...+ 1,511 Btu/ton-mile" changed to "miles one-way...+ 1,511 Btu/ton-mile"
690-691	Change	"Btu/ton-mile back-haul)*(Diesel share 1 00%)*(1" changed to "Btu/ton-mile back-haul)*(Diesel share 100%)*(1"
692-693	Change	"(tonnes/ton) = 47,200 Btu/tonne" changed to "(tonnes/ton) = 46,506 Btu/tonne"
694-695	Change	"47,200" changed to "46,506"
696-697	Change	"25,722" changed to "25,344"
698-699	Change	"3,701" changed to "3,644"
700-701	Change	"2,017" changed to "1,986"
702	Change	"Total CO2 Emissions (gCO2/MJ)" changed to "Total CO2 Emissions (gCO2e/MJ)"
703-704	Change	"2.0" changed to "1.88"
705	Insertion	GHG Emissions
706	Deletion	Emissions (gCO2e/MJ)
707-708	Change	"4.078" changed to "3.98"
709-710	Change	"0.088" changed to "0.09"
711-712	Change	"1.493" changed to "1.53"
713-714	Change	"6.553" changed to "6.83"
715-716	Change	"3,701" changed to "3,644"
717-718	Change	"2.222" changed to "54.27"
719-720	Change	"0.048" changed to "14.62"
721-722	Change	"0.814" changed to "2.60"
723-724	Change	"3.571" changed to "5.84"
725-726	Change	"2,017" changed to "1,986"
727-728	Change	"Total GHG Emisisons" changed to "Total GHG Emissions (gCO2e/MJ)"
729-730	Change	"<0.01" changed to "0.05"
731	Change	"<0.01" changed to "0.01"
732-733	Change	"2.0" changed to "1.88"
734	Change	"Total Energy" changed to "Total Energy"
735-736	Change	"284 (Btu/gal)" changed to "2 7 9 (Btu/gal)"
737-738	Change	"WTT crude oil energy = 31,657 Btu/mmBtu" changed to "WTT crude oil energy = 39,213 Btu/mmBtu"

739-740	Change	"WTT of residual oil = 74,001 Btu/mmBtu" changed to "WTT of residual oil = 74,239Btu/mmBtu"
741-742	Change	"83,415" changed to "83,411"
743-744	Change	"83,415 Btu/gal / (76,330 Btu/gal) *10^6*1.001" changed to "83,411 Btu/gal / (76,330 Btu/gal) *10^6*1.001"
745-746	Change	"1,093,376" changed to "1,093,320"
747-748	Change	"99.65%" changed to "99.7%"
749-750	Change	"0.35%" changed to "0.30%"
751-752	Change	"284" changed to "251"
753-754	Change	"Conversion to g- CO2e/" changed to "to gCO2e/"
755	Change	"2e/mmBtu" changed to "2e/ mmBtu"
756	Insertion	gCO2e/ MJ
757	Change	"g/mmBtu)*1 .001/10^6" changed to "g/mmBtu)/10^6"
758-759	Change	"9,881" changed to "9,879"
760-761	Change	"9,881 g/gal/(76,330 Btu/gal)*" changed to "9 , 8 7 9 g/gal/(76,330 Btu/gal)*"
762-763	Change	"g/gal/(76,330 Btu/gal)*1 ^{06}" changed to "g/gal/(76,330 Btu/gal)*10^6"
764-765	Change	"129,519" changed to "129,423"
766	Insertion	122.67
767-768	Change	"- 9 , 8 9 7 g/gal/(76,330 Btu/gal)*10^6" changed to "- 9 , 8 9 7 g/gal/(76,330 Btu/gal)*1 ^{06}"
769-770	Change	"-129,732" changed to "-129,667"
771	Insertion	-122.9
772-773	Change	"EtOH Production" changed to "CH4"
774	Insertion	Bagasse burning = 0.00642...12,947,318 Btu/ton/10^6)
775	Insertion	2.63
776	Insertion	2 . 6 3 4 g/gal/(76,330 Btu/gal)*1 ^{06}
777	Insertion	862
778	Insertion	0.82
779	Insertion	N2O
780	Insertion	Bagasse burning = 0.00642...*12,947,318 Btu/gal/10^6)
781	Insertion	0.35

782	Insertion	0 . 3 5 1 g/gal/(76,330 Btu/gal)*1 06
783	Insertion	1,370
784	Insertion	1.3
785-786	Change	"CH4" changed to "VOC"
787-788	Change	"Bagasse burning = 0.00642...(31 .6 g/mmBtu" changed to "Bagasse burning = 0.00642...tonne/gal* (5.34 g/mmBtu"
789-790	Change	"2.634" changed to "0.44"
791-792	Change	"2.634 g/gal/(76,330 Btu/gal)*" changed to "0 . 4 4 g/gal/(76,330 Btu/gal)*"
793-794	Change	"g/gal/(76,330 Btu/gal)*10^6 = 34.45" changed to "g/gal/(76,330 Btu/gal)*1 06"
795-796	Change	"963.5" changed to "18"
797	Insertion	0.02
798-799	Change	"N2O" changed to "CO"
800-801	Change	"Bagasse burning = 0.00642 tonne/gal* (4.2g/mmBtu" changed to "Bagasse burning = 0.00642...tonne/gal* (76.8 g/mmBtu"
802-803	Change	"g/mmBtu* 12,947 ,318 Btu/gal/10^6)" changed to "g/mmBtu *12,947,318 Btu/gal/10^6)"
804-805	Change	"0.351" changed to "6.3"
806-807	Change	"0.351" changed to "6.3"
808-809	Change	"g/gal/(76,330 Btu/gal)*10^6 = 4.60" changed to "g/gal/(76,330 Btu/gal)*1 06"
810-811	Change	"1,395" changed to "131"
812	Insertion	0.12
813-814	Change	"2.1" changed to "2.10"
815	Change	"(2.1 g/gal) /(76,330 Btu/gal)*" changed to "(2.1 g/gal) /(76,330 Btu/gal)*1"
816-817	Change	"10^6" changed to "06"
818-819	Change	"28.0" changed to "28"
820	Insertion	0.03
821-822	Change	"residual oil, Btu/gal) *10%* (3,260 g/mmBtu)*1" changed to "residual oil, Btu/gal) *10%* (3,868 g/mmBtu)*1"
823-824	Change	"0.1" changed to "0.10"
825-826	Change	"(0.1 g/gal) /(76,330 Btu/gal)*1 06" changed to "(0.1 g/gal) /(76,330 Btu/gal)*10^6"
827	Insertion	<0.01
828-829	Change	"residual oil, Btu/gal) *10%* (5,607 g/mmBtu)/10^6" changed to "residual oil,

		Btu/gal) *10%* (5,613 g/mmBtu)/10^6"
830-831	Change	"0.1" changed to "0.10"
832	Insertion	<0.01
833-834	Change	"VOC" changed to "CH4"
835-836	Change	"use of residual oil, Btu/gal) *(0.9 g/mmBtu)" changed to "use of residual oil,...*10%* [(3.24 g/mmBtu)"
837	Change	"g/mmBtu)/" changed to "g/mmBtu)~ (90.166 g/"
838-839	Change	"/1 ^{06}" changed to "/mmBtu)*1.000 ~ 4.94 g/mmBtu) /10^6 = 0.002"
840-841	Change	"(<0.01 g/gal)" changed to "(0.002 g/gal)"
842-843	Change	"g/gal) / (76,330 Btu/gal)*(3.1)*1 ^{06}" changed to "g/gal) / (76,330 Btu/gal)*10^6"
844-845	Change	"<0.01" changed to "0.8"
846	Insertion	<0.01
847-848	Change	"CO" changed to "N2O"
849-850	Change	"residual oil, Btu/gal) * (15.8 g/mmBtu)" changed to "residual oil, Btu/gal) *10%* [(0.36 g/mmBtu)"
851	Change	"g/mmBtu)/1 0^6" changed to "g/mmBtu)~ (0.65...~ 0.54 g/mmBtu) /1 0^6"
852	Insertion	/1 0^6 = < 0.01
853-854	Change	"(<0.01 g/gal)" changed to "(< 0.00 g/gal)"
855-856	Change	"g/gal) / (76,330 Btu/gal)*(1 .6)*1 ^{06}" changed to "g/gal) / (76,330 Btu/gal)*10^6"
857-858	Change	"0.08" changed to "< 0.01"
859	Insertion	<0.01
860	Deletion	Total GHGs for ethanol production (gCO2e/mmBtu)
861	Deletion	2,021
862	Deletion	Total GHGs for ethanol production (gCO2e/MJ)
863	Deletion	1.9
864	Insertion	PRELIMINARY DRAFT DISTRIBUTED FOR PUBLIC COMMENT
865	Insertion	42
866	Insertion	VOC
867	Insertion	(Direct energy use of...g/mmBtu)/1 ^{06}
868	Insertion	<0.01
869	Insertion	(<0.01 g/gal)/ (76,330 Btu/gal)*(3.1)*1

870	Insertion	06
871	Insertion	< 0.01
872	Insertion	<0.01
873	Insertion	CO
874	Insertion	(Direct energy use of...* (15.8 g/mmBtu)/10^6
875	Insertion	<0.01
876	Insertion	(<0.01 g/gal)/ (76,330 Btu/gal)*(1 .6)*1
877	Insertion	06
878	Insertion	0.02
879	Insertion	<0.01
880	Insertion	Total GHGs for ethanol production (gCO2e/mmBtu)
881	Insertion	2,169
882	Insertion	Total GHGs for ethanol production (gCO2e/MJ)
883	Insertion	2.1
884-885	Change	"06/A)*B)/...(C)*(D)*[6%*(H)*100%]" changed to "06/A)*B)/...(C)*(D)*[6%*(H)*1 00%]"
886	Deletion	%] = 440
887	Deletion	(106/A)*B...00%*(1 ~(F)] = 1,260
888	Deletion	(106/A)*B... = 3,010
889-890	Change	"06/A)*B)/((g/lb)*(lb/tonne)*(C)*(D)* [24%*100%*(1" changed to "06/A)*B)/...[24%*1 00%*(1"
891-892	Change	"%*(1 ~(K)] = 1,402" changed to "%*(1 ~(K)]*50%"
893-894	Change	"F = Diesel energy = 0.157 Btu/Btu" changed to "F = Diesel energy = 0.163 Btu/Btu"
895-896	Change	"G = Residual oil energy = 0.106 Btu/Btu" changed to "G = Residual oil energy = 0.113 Btu/Btu"
897-898	Change	"H = Electricity Energy in Brazil = 1.347 Btu/Btu" changed to "H = Electricity Energy (U.S. Average) = 2.647"
899-900	Change	"K = NG energy = 0.073 Btu/Btu" changed to "K = NG energy = 0.070 Btu/Btu"
901-902	Change	"6,202" changed to "3,069"
903	Deletion	100% diesel use: $1 0^6$
904	Change	"/A*B/((g/lb)*(lb/tonne)*I*K*[E*(1" changed to "$1 0^6$/A*B/((g/lb)*(lb/tonne)*I*K*[E*(1"

905	Insertion	/A*B/((g/lb)*(lb/tonne)*I*K*[E*(1 ~F)] *50%
906-907	Change	"9,414" changed to "4,638"
908-909	Change	"21,992" changed to "21,661"
910-911	Change	"Transportation used in Brazil = 50%*6,202 + 50%" changed to "Transportation used in...= 50% by pipeline, 50%"
912-913	Change	"50%*9,414 + 21,992 =" changed to "50% by rail"
914-915	Change	"29,800" changed to "29,368"
916-917	Change	"10,459" changed to "10,305"
918-919	Change	"40,259" changed to "39,673"
920-921	Change	"4,183" changed to "4,122"
922-923	Change	"44,442" changed to "43,795"
924-925	Change	"30" changed to "50"
926	Change	"CO2e" changed to "CO2e[1]"
927	Insertion	Transported by Pipeline*
928-929	Change	"449" changed to "223.5"
930-931	Change	"0.77" changed to "0.76"
932-933	Change	"0.77*25" changed to "0.76*25"
934	Change	"*25=" changed to "*25/2="
935-936	Change	"=19" changed to "= 9.5"
937-938	Change	"0.01*298=" changed to "0.01*298/"
939-940	Change	"3" changed to "2 =1.5"
941-942	Change	"471" changed to "234.5"
943	Insertion	Transported by Rail*
944-945	Change	"737" changed to "362.5"
946	Change	"0.83*25=" changed to "0.83*25/2="
947-948	Change	"=21" changed to "=10"
949-950	Change	"0.02*298=" changed to "0.02*298/"
951-952	Change	"6" changed to "2 =2.5"
953-954	Change	"784" changed to "375"
955	Deletion	Transported by Ocean Tanker
956-957	Change	"1,856" changed to "1,829"
958-959	Change	"1.97" changed to "1.94"
960-961	Change	"1.97*25=" changed to "1.94*25="
962-963	Change	"*25=49" changed to "*25=48"
964	Deletion	0.04*298= 12
965-966	Change	"1,917" changed to "1,889"
967	Insertion	Tanker

968	Deletion	2,449*
969	Deletion	89
970-971	Change	"21" changed to "12"
972	Deletion	3,152
973	Insertion	Weighted
974	Insertion	Average*
975	Insertion	2,413
976	Insertion	67.5
977	Insertion	16
978	Insertion	2,496.5
979	Deletion	Transported by Heavy Duty Truck
980-981	Change	"820" changed to "807"
982-983	Change	"23" changed to "0.9*298=22.5"
984	Change	"6" changed to "0.02*298= 6"
985-986	Change	"859" changed to "835.5"
987	Insertion	Duty Truck
988	Deletion	Distributed by Heavy Duty Truck
989-990	Change	"328" changed to "323.2"
991-992	Change	"0.2" changed to "0.4"
993-994	Change	"5" changed to "0.4*25=10"
995-996	Change	"0.00" changed to "0.01"
997-998	Change	"1" changed to "0.01*298= 3"
999-1000	Change	"334" changed to "336.2"
1001	Insertion	Duty Truck*
1002-1003	Change	"3,597" changed to "3,543.2"
1004-1005	Change	"107" changed to "100"
1006-1007	Change	"28" changed to "25"
1008-1009	Change	"4,345" changed to "3,668.2"
1010-1011	Change	"4.1" changed to "3.5"
1012	Insertion	travel by rail and 50% by...80% distributed by truck
1013-1014	Change	"12.20" changed to "12.40"
1015-1016	Change	"State Law: 11.241 on 19 September 2002" changed to "State Law: 11.241 on 19 September 2002."
1017-1018	Change	"this scenario has a total...(baseline of 27.4 –" changed to "this scenario has a total...(baseline of 27.4 –"
1019-1020	Change	"gCO2e/MJ (baseline of 27.4 – 8.2 – 7.0"

		changed to "gCO2e/MJ (baseline of 27.4 – 8.0 – 7.0"
1021	Change	"– 7.0)." changed to "– 7.0 = 12.4)."
1022	Change	"gCO2e/MJ (baseline of...detail of the co-product" changed to "gCO2e/MJ (baseline of...detail of the co-product"
1023-1024	Change	"14.4" changed to "14.2"
1025-1026	Change	"(-180.2)" changed to "(-180.3)"
1027-1028	Change	"8.2" changed to "8.0"
1029	Insertion	Ethanol Mills Survey
1030	Change	"for Brazil marginal power in the EtOH" changed to "for Brazil marginal power in the “EtOH"
1031-1032	Change	"EtOH sheet. The adjacent column calculates" changed to "EtOH” tab. The adjacent column calculates"
1033	Deletion	Electricity (Btu/mmBtu, g/mmBtu)
1034	Deletion	Credit (Btu/gal, g/gal)
1035	Deletion	Credit (Btu/mmBtu, g/mmBtu)
1036	Deletion	Credit (J/MJ, g/MJ)
1037	Insertion	Energy
1038	Insertion	Btu/mmBtu
1039	Insertion	Btu/gal
1040	Insertion	Btu/mmBtu
1041	Insertion	J/MJ
1042-1043	Change	"2,984,567" changed to "2,983,664"
1044	Insertion	Emissions
1045	Insertion	g/mmBtu
1046	Insertion	g/gal
1047	Insertion	g/mmBtu
1048	Insertion	gCO2e/mmBtu
1049-1050	Change	"25.859" changed to "25.82"
1051	Deletion	-0.001
1052-1053	Change	"97.830" changed to "97.54"
1054	Deletion	-0.004

1055-1056	Change	"-0.014" changed to "-363.6"
1057-1058	Change	"3.624" changed to "3.62"
1059-1060	Change	"0.000" changed to "-42.6"
1061	Insertion	CO2 only
1062-1063	Change	"176,859" changed to "176,797"
1064	Deletion	-6,972
1065	Deletion	-6.6
1066-1067	Change	"CO2 (incl. VOC and CO)" changed to "CO2 (including VOC and CO)"
1068-1069	Change	"177100" changed to "177,032"
1070-1071	Change	"-6.6" changed to "-6,982"
1072	Change	"Total GHG" changed to "GHG"
1073	Insertion	GHG Emissions
1074	Deletion	187,399
1075	Deletion	-564
1076	Deletion	-7,388
1077-1078	Change	"-7.0" changed to "-7,388.2"
1079	Insertion	Total GHG Emissions (gCO2e/MJ)
1080	Insertion	-7.0
1081-1082	Change	"Sample Calculation for CO2" changed to "Sample Calculation of CO2"
1083	Change	"CO2:" changed to "CO2 shown Table 2.03 above:"
1084-1085	Change	"3,276 Btu/gallon * 176,859 g/mmBtu/" changed to "3,276 Btu/gallon * (176,797 g/mmBtu/"
1086-1087	Change	"g/mmBtu/1 0^6 Btu" changed to "g/mmBtu/10^6 Btu"
1088	Change	"Btu = 532 g/gal (see entry in Table" changed to "Btu)*(1-8.1%) = 532 g/gal (see entry in Table"
1089-1090	Change	"= 532 g/gal (see entry in Table 1.03)." changed to "= 532 g/gal (see entry in Table 2.03)."
1091-1092	Change	"0.14" changed to "0.19"

Statistics:	
	Count
Insertions	595

Deletions	497
Moved from	0
Moved to	0
Style change	0
Format changed	0
Total changes	1092

APPENDIX B

September 15, 2009

TO: United States Environmental Protection Agency
Washington, D.C.

RE: **DOCKET NO EPA-HQ-OAR-2005-0161**

FROM: Caribbean Basin Ethanol Producers Group

My name is George Fitch and I am the executive director of the Caribbean Basin Ethanol Producers Group, a position which I have held since its formation in 1988.

The Group consists of Trinidad Bulk Traders Ltd, Gasohol de El Salvador, LAICA of Costa Rica, Petrojam Ltd, Jamaica Ethanol Company and Jamaica Broilers Group. They have made substantial investments in ethanol dehydration and related facilities in response to the Caribbean Basin Economic Recovery Act , aka "CBI", which encouraged investments in non traditional exports by offering duty free access to the US market.

The US International Trade Commission has concluded in their annual reports on the impact of CBERA that ethanol exports from the region have had the most positive impact on US industry and to the US consumer than any other export from the Caribbean Basin. The ethanol industry is considered the success story of the Caribbean Basin Initiative. Now, the proposed RFS rules could shut down our industry.

We account for approximately 5% of the US market. Last year ethanol exports from the region were 339 million gallons, well within the 7% quota. A provision in the Steel Trade Liberalization Act of 1989 carved out a 7% quota of the US market for the Caribbean Basin countries. We can export more than the quota amount but have to pay a graduated duty on exports above the 7%. The production capacity is 745 million gallons. We have always been a reliable and valuable supplier of ethanol to the coastal markets which US producers sometimes have difficulty supplying at competitive prices.

Since we produce little sugar based alcohol and what is produced goes mainly for the beverage (rum) market, we import our feedstocks, hydrous alcohol. For many years, it was wine alcohol from Europe which the EC determined had to be disposed of outside of Europe. Now, it is sugar cane alcohol from Brazil. We anticipate that for years to come Brazil will be our primary source of feedstock. However, we need the proposed RFS2 rules to be modified to allow us to continue to operate.

IMPACT OF RFS 2 PROPOSED RULES

We have several concerns with the proposed rules.

First of all, with regard to traceability it is impossible for us to verify that the hydrous alcohol we purchase from Brazil was made from sugar cane on land currently under cultivation.

Typically, we contract with a company in Brazil to supply us with regular shipments, usually on a quarterly basis, of hydrous alcohol. The company will pool together lots from a number of different mills in Brazil and combine them into a single shipment. When the shipment arrives at one of our plants, the seal has to be broken in order for us to process. The shipment is discharged into a tank that already contains hydrous alcohol from previous shipments. For most of us, we have one large tank for incoming hydrous alcohol and one large tank for outgoing anhydrous ethanol. So the hydrous alcohol from Brazil is co-mingled with other hydrous alcohol shipments from Brazil and the co mingling occurs again with the anhydrous ethanol stored for shipment to the U.S. Therefore, it is impossible to trace the anhydrous ethanol back to a particular sugar cane mill in Brazil.

Another concern is RINS. Since the origins of each gallon of the hydrous alcohol processed into anhydrous ethanol at one of our plants cannot be accurately determined, the generator of the RINS would be reluctant to purchase our ethanol. At a minimum, they would require that we assume the cost of the bond. Also, they would probably offer us a lower price to offset their risk.

With regard to the life cycle analysis, we use fossil fuels in the production process. These fuels are Bunker C, diesel or natural gas. Since these are stand alone dehydration facilities close to the ports, they are no sugar mills nearby to supply bagasse to power the plants. However, we are exploring ways to use bagasse from sugar mills in the country.

The emissions of fuel oil and natural gas could add significantly to the total grams of CO_2 emissions of our sugar cane pathway which could disqualify us as an advanced biofuel or at a minimum impose a prohibitive penalty. This would be devastating to our industry.

RECOMMENDATIONS

We propose several recommendations.

First, we recommend that we be grandfathered as an eligible producer of advanced biofuels.

Second, we recommend that the generator of the RINS be the importer of record.

Third, we recommend that the traceability requirements be modified to reflect the nature of how hydrous alcohol is collected, shipped, discharged, processed and stored.

Fourth, we request that we be allowed to voluntarily transition from the use of fossil fuels to power our plant to an alternative energy such as bagasse to reduce our emissions of CO_2.

If you require additional information or would like to discuss this further, I can be reached at, gfitch1@verizon.net or telephone, (540)347-5283.

Sincerely,

George Fitch
Caribbean Basin Ethanol Producers Group

APPENDIX C

ISSCT PROCESS WORKSHOP
Saint Denis, REUNION ISLAND
20 - 23 October 2008
"*Green cane impact on sugar processing*"

REPORT

By

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KEYWORDS: green cane, trash, extraneous matter, losses, workshop

Abstract

The ISSCT Process Section workshop held on Reunion Island was attended by 51 delegates from 10 countries. The theme was *Green cane impact on sugar processing*. The workshop provided a valuable and timely opportunity to review and discuss the impact on factory operations and performance from a green cane supply that could include significant levels of trash. It was particularly relevant to those mills that were considering options to boost their biomass intake for increased co-generation capacity. Several of the speakers related their experiences with processing 'whole of crop' cane supplies through the factory. Speakers detailed the problems and increased losses that were incurred when processing cane with high trash levels. The consensus of the delegates was that the best scenario would involve a cane cleaning plant at the factory so that only clean cane would be processes through the factory. The forum recommended that more research was required to address the issues of increased impurities in the process streams associated with high trash levels. Site visits to the two factories and a cane delivery station were arranged as part of the workshop.

Introduction

The Process Section Workshop was held at the Hotel Mercure Créolia, Saint Denis, Reunion Island from 19 to 23 October 2008 and hosted by CERF (Centre d'Essai de Recherche et de Formation).

The theme for the workshop was *Green cane impact on sugar processing*. The workshop provided a valuable and timely opportunity to review and discuss the impact on factory operations and performance from a green cane supply that could include significant levels of trash. It was particularly relevant to those mills that were considering options to boost their biomass intake for increased co-generation capacity.

It was attended by 51 delegates representing 10 countries including some delegates who had travelled from as far away as Brazil, Nicaragua and Japan for the workshop. All of the organisational matters for the workshop were handled extremely well by CERF and, in particular, by Laurent Corcodel and Carmille Roussel.

The program included the following activities:

Sunday, 19/10/2008	Visit to CERF facilities Welcoming cocktail function
Monday, 20/10/2009	Site visits to the Casernes cane delivery and transfer station, Le Gol Mill and the Centrale Thermique du Gol cogeneration plant

Tuesday, 21/10/2008	Session 1 – Sugar losses in storage: green cane versus burnt cane Session 2 – Mill detrashing equipment: design, operation and optimization Site visit to Bois Rouge Mill and Savanna Distillery
Wednesday, 22/10/2008	Session 3 – Effects of trash on factory operations Session 4 – Whole crop processing
Thursday, 23/10/2009	Session 5 – Forum review and discussion Close

The detailed workshop program is presented in Appendix A. The delegate list is attached as Appendix B.

Opening session

The opening session of the workshop included presentations by Jean-François Moser, President of CERF, and Laurent Corcodel.

Moser's presentation provided an insight into the sugar industry on Reunion Island and its significant importance to the local economy. He described how infrastructure had been developed to allow water collected on the eastern side of the island to be transferred to the western side to irrigate the crops. A modernisation program had resulted in the closure of all but two mills. Cogeneration plants using both bagasse and coal were established at each factory. The remaining two mills had been upgraded to handle the full crop. Cane delivery stations were developed in several areas (mostly on old mill sites) to allow farmers to deliver the cane to local collection points. Each load is sampled on arrival before being transferred to semi-trailers for transport to one of the mills.

Laurent Corcodel reviewed the performance of the cane sugar industry in Reunion since 1984. Some of the important changes to the industry have included:

- The sugar industry on Reunion Island was consolidated to two factories (Le Gol and Bois Rouge), each processing about 1,000,000 Mt per year between July and December and producing 100,000 t of raw sugar each.

- The cane crop comprises two main varieties; R570 (high trash) and R579 (self trashing);

- Each paddock can be rationed up to nine times;

- All cane is harvested green and much of the trash is included with the cane supplied to the factories;

- Cane is delivered to one of 12 transfer stations or direct to one of the two factories;

- Only 10-30 % is mechanically harvested;

- The true purity of the mixed juice ranges between 86 and 90;

- Ash % brix in mixed juice trends down from about 5 % at the start of the milling season in July to less than 4 % in December;

- Reducing sugars % brix range from about 3 % in July to 3.5 to 4.0 in December; and

- Plant reliability has improved significantly over the twenty year period from about 12 % downtime to an average of 4 % breakdown rate in 2007.

Technical sessions

Session 1 – Sugar losses in storage: green cane versus burnt cane

Determination of sucrose loss in storage of green billet cane (Michael Saska, Stuart Goudeau, Irina Dinu and Mike Marquette. Presented by Rod Steindl)

A series of tests was done to measure the sucrose loss during twenty-four hour storage of green billet cane. Several tests were also organized in a sugar factory where in addition to the storage on the ground, some damage or loss of cane may be expected from handling the cane with front end loaders. The mass loss of sucrose in storage of green billets of twenty four hours or less was found to be adequately represented by a linear model based on the length of time (hours) within three temperature ranges: <17 °C (63 °F), 17-27 °C (63-81 °F) and >27 °C (81 °F), representing cold, moderate and warm conditions. The predicted relative sucrose change (tons of sucrose lost or gained for each 100 tons of initial sucrose per hour) in the three temperature ranges are 0.022 (gain), -0.017 (loss) and -0.323 (loss), respectively.

An analogous model was found to apply to the cane weight loss during storage of green billet cane. The predicted relative cane weight loss (tons of cane per 100 tons initial per hour) in the three temperature ranges <17 °C, 17-27 °C and >27 °C was 0.02, 0.02 and 0.26 respectively. The six factory cane yard tests broadly agreed with the conclusions from the pilot storage tests done at ASI, indicating that the cane and sucrose mass losses from handling the cane in the cane yard were relatively small compared with the losses from the enzymatic and microbial action within the stored cane.

Whether the small sucrose gain predicted by their model for cold storage of green billets was related to enhanced activity of sucrose synthesizing enzymes or suppressed invertase activity in post-harvest cane as a reaction to low temperatures, or was rather an artefact of the experimental technique was uncertain.

The financial impact of the sucrose loss predicted for storage of cane at high temperatures (3.2% in ten hours at over 27 °C) is serious, and considerations should be given to improving through their design the natural or forced ventilation of cane wagons and piles, and to the scheduling of harvest and storage of cane.

Cane deterioration: Comparison green cane vs burnt cane – Research of green cane deterioration indicator (Camille Roussel, Arnaud Petit and Laurent Corcodel)

In the period 1990-1995, the Process Department of CERF carried out some studies on cane deterioration. The aims of those studies were to compare cane deterioration between whole cane and burnt cane and to find a criterion to gauge cane deterioration. Those studies showed that ethanol was a good criterion in burnt cane, but not in green cane. As cane is no longer burnt in Reunion Island, deterioration trials undertaken since 1995 have dealt only with green cane. Decreases in weight, sucrose content and purity meant that growers lost about €1/ton of cane per day from post-harvest delays.

As chemical inversion is not the only evolution during deterioration, biochemical measurements were undertaken in 2005 and 2007. In 2005, aconitic acid ratio appeared as a good deterioration criterion. In 2007, a preliminary trial was carried out to find other deterioration criteria using chromatography (HPIC and HPLC). Organic acids, polyols, and amino acids were measured. Of particular interest was 1-kestose, which increased linearly with post-harvest delays. Results showed also that citrate, alanine, proline, cysteine, isoleucine, and leucine (amino acid) correlated well with the post-harvest delay.

NIR evaluation of the post harvest deterioration of sugarcane quality (M. Ueno, E. Taira, Y. Kawamitsu, K. Kikuchi and Y. Komiya)

All of the sugarcane is harvested green, because burnt cane is not accepted by the mills in Japan. The trash is transported with the cane and separated at the factory. About 60% of the sugarcane is harvested manually. Mechanical harvesters included small machines that load billets into bags on the back of the harvester through to large machines that load directly into trucks. Manual harvesting requires a lot of labour, and is hard work. One to three weeks is required from harvesting to loading the transport truck. Therefore, deterioration occurred in the duration resulting in sugar losses. These deteriorated canes affect the milling process and lower the efficiency of the mill.

In order to measure the quality of sugarcane for payment, a 5 kg sample of cane is collected by the core sampler from every vehicle at the entrance of each factory. These samples are fibrated and near infrared spectrometer (NIR) is used to measure the pol in cane (PIC) as a quality index. If the mill staff can quickly and easily know the degree of deterioration, the information becomes very useful for process control. An NIR calibration equation to measure the ethanol content was investigated as an index of deterioration of cane. VIS/NIR absorbance spectra (570 to 1848 nm) were measured using an NIR instrument (Foss InfraXact), and the calibration equation for ethanol was developed by PLS regression analysis. As a result of PLS regression, the values of R square (r^2), standard error of calibration (SEC), and standard error of cross validation (SECV) were 0.908, 0.09 %, and 0.11 %, respectively. The developed calibration equation successfully measured the ethanol concentration of deteriorated cane with simultaneous measurement of PIC. Ethanol concentration was examined by the developed calibration equation after 0, 21, 28 and 36 days after harvesting. Although ethanol was not detected from fresh cane, the ethanol content increased dramatically as the delay increased. Ethanol content of all sugarcane samples of 11 sugar mills in Okinawa Prefecture were calculated by the developed calibration equation. The 5 % of all samples showed more than 1 % ethanol content. It was concluded that the NIR method gave information of the sugarcane deterioration to support the operation of all sugar mills in Okinawa without any chemicals or apparatus.

Session 2 – Mill de-trashing equipment: Design, operation, optimisation

The development of a prototype factory based trash separation plant (Phil Hobson. Presented by Rod Steindl)

Several sugarcane industries are actively seeking an efficient way of bringing the biomass to the factory to increase the co-generation potential. As well, some countries have or are about to ban the burning of cane. This has increased the interest in trash separation plants located either at the factory or in centralised locations closer to the cane supply areas. This presentation discussed investigations by SRI to separate the trash at the factory.

Trash left in the field after harvest constitutes a large, currently untapped source of available biomass. Harvesting the whole cane plant and subsequently separating the trash from the cane stalk in the cane supply entering the factory could potentially double the amount of fuel available for power generation. The Queensland Treasury (Office of Energy), Stanwell Corporation Ltd, and the NSW Sugar Milling Co-operative funded the development by SRI of a commercial scale prototype cane cleaning plant. Funding by the Australian Greenhouse Office assisted with the installation of a fully commercial cane cleaning plant at Condong Mill. Preliminary trials carried out at SRI in 2000 provided much of the basic information for the design of the prototype cleaning plant. Construction at Condong Mill of the prototype trash separation plant was completed by, and initial commissioning began, in early December 2000. Extensive testing and further development of the plant was continued through 2001. The performance testing program showed that the plant was able to achieve high levels of trash separation at low levels of cane loss (less than 1 %), at commercial pour rates. Trials with an industry standard shredder indicated that the shredder could reduce the trash to approximate bagasse like consistency, but with a power requirement of the order of 12 kW/t of trash per hour. Conventional cyclone technology was shown to remove at least 99 % of the air-borne trash which flowed from the cleaning chamber.

Cane field residues as supplementary boiler fuel (Kassiap Deepchand and A.F. Lau)

Cane field residues (CFR) consist of the dry cane trash and the green leaves left in the field after harvest and last for around six months of the year (June to Nov/Dec). The CFR confers a certain number of agronomic advantages such as soil moisture conservation in dry areas, control of soil erosion and maintenance of soil organic matter. But it also imparts a number of disadvantages in that it harbours pests and affects cane re-growth especially in areas with high rainfall. In an original approach, investment was made in a dry cane cleaning plant with a capacity of 150 tonnes of whole cane per hour and operated next to a sugar factory. The concept was to reduce sugar loss in bagasse and minimize sugar manufacture difficulties due to the CFR adhering/brought together with cane while at the same time targeting the long term additional CFR recovery to increase fuel availability for power plants and thus displace coal. Difficulties were encountered in continuous operation of the plant due to a lack of a constant flow of cane and of an inefficient separation of the trash from the long cane. Subsequently some modifications were made to the plant but it could not run beyond 90 t/h, although an improvement in the separation process was noted.

An alternative approach of using CFR as an additional fuel to bagasse is being looked into and the objective is to increase and extend electricity generation period from these resources by displacing coal. The total amount of CFR (which normally contains around 25 % moisture depending on climatic conditions prevailing at harvest and in the subsequent days) is around 15 t/ha. The project aims at collecting up to 50 % of the CFR from the fields under ratoon crop and almost all the CFR from fields which are to be replanted after 7-8 year crop cycle. Whereas equipment for collection (windrowing and baling – square or cylindrical) and transport are available for industrial applications, those for debaling/shredding have still to be identified or developed for such applications. The emphasis on current R&D has thus been focused on this particular aspect. Analysis of naturally dried CFR has revealed that it has a moisture content varying between 9 and 11 %. Its calorific value at 10 % moisture is around 15 000 kJ/kg. Industrial scale trials using existing conventional mills have shown that such naturally dried CFR can conveniently be burnt in existing boilers. However in view of the fact that the naturally dried CFR has a relatively higher ash content (8 %) compared to bagasse (2.5 %) it is proposed that it will, after preparation, be mixed with bagasse in a proportion of up to 25 %.

Preliminary estimates indicate that if 30 % of the CFR is collected, prepared and mixed with bagasse from an annual cane production of 5.0 million tonnes, it can potentially generate 250 GWh of electricity. In so doing this will replace 150 000 t of coal and avoid the generation of 400 000 t of CO_2 and 30 000 t of coal ash. In monetary terms, the foreign exchange saved will be US$30 million assuming a coal price of US$200/t as projected for the near future.

Session 3 – Effects of trash on factory operations

Ledesma's green cane project (Mario Rostagno, Carlos Bada, Federico Knauff, Miguel Ullivarri, Juan Carlos Mirande and Rodolfo Dofonzo. Presented by Rod Steindl)

Ledesma, a cane sugar factory in Argentina, has seen a significant increase in mechanised harvesting of cane in recent years. In 2007, 85 % of the cane was harvested mechanically. The progression to mechanised harvesting has seen the proportion of green cane delivered to the factory increase from 11 % of the crop in 2002 to more than 50 % in 2005. The proportion of green cane has remained static in the following years. As part of their effort to maintain factory efficiency and product quality, factory staff has undertaken a number of investigations to quantify the effects of the increased proportion of green cane in the raw sugar factory, refinery, distillery and on their energy production. During season 2005, some trials were undertaken to determine the green cane effect on milling capacity, sugar losses and bagasse moisture. The results can be summarised as follows:

- The final bagasse moisture increased by 7.3 %;
- There was an increased frequency in chute blockages along the milling tandem due to the extra trash;
- The pol loss in bagasse increased from 0.64 % to 0.70 %;
- The throughput capacity of the milling tandems decreased by 7 %;
- Although the molasses % cane remained relatively steady at about 3.66, the pol loss in molasses increased

by 8%;

· The raw sugar colour increased by 10 %; and

· Because of the higher starch content of the trash, the consumption of α-amylase increased from 40 kg/day to 120 kg/day.

In the refinery, the consumption of chemicals such as decolorant, phosphoric acid and filter aid increased significantly. In the distillery, the total production of ethanol increased by 5.8 % as a result of the higher sugar content in the molasses. However, the efficiency decreased to 79 % because of the problems associated with the higher ash levels in the fermentation broth. The additional bagasse for combustion allowed the factory to reduce its consumption of supplementary fuel (natural gas).

New laws in São Paulo State and a new agreement between the State and the mills have started a green revolution in the Brazil sugarcane business. By 2014, the cane fields where the harvesters will be able to operate must be harvested as green cane. By 2017, all the cane fields will be harvested as green cane and cane fires will be eliminated.

This green revolution which begins in the fields goes also to the mills. The crop of green cane has a strong impact in the agriculture and industry areas. The challenges for the agricultural sector will include:

· Varieties that withstand the impact of cutter blades on harvesters;
· Effects of trash blanketing on ratooning ability and pest activity;
· Increasing the row spacing to 1.5 m;

· Changes to farm implements to better cultivate the soil and apply fertiliser through the trash blanket; and
· Adoption of 100 % mechanical harvesting.

The impact on the factory processes will include:

· Increased impurity loading from the higher extraneous matter in the cane supply;
· Reduced milling throughput;
· Increased dirt loading in the bagasse going to the boilers;
· Potential for lower sugar quality;
· Higher costs for maintenance and chemicals; and
· Greater sugar losses in the mud and bagasse.

The option being favoured is to transport the cane and trash to the factory and separate the trash through dry cleaning plants. The cleaning plant is based on pneumatic separation of the trash followed by cleaning of the trash to remove soil and then shredding of the trash. However it was recognised that the cane cleaning technology was only at the beginning.

The two advantages of the trash supply are the increased biomass for cogeneration and as a feedstock for second generation fuels.

Clarification properties of stalk and trash tissues from U.S. sugarcane varieties (Gillian Eggleston and Michael Grisham. Presented by Barbara Muir)

The effect of the U.S. change from burnt to unburnt or "green" sugarcane harvesting on processing has not been fully characterized. Furthermore, the current trend to investigate sugarcane trash (leaves and tops) as biomass for the production of bio-products has made the processing quality of trash more important.

Sugarcane whole-stalks were harvested from the first ratoon crop of five commercial sugarcane varieties (LCP 85-384, HoCP 96-540, L 97-128, L 99-226, and L 99-233) with varying yield and harvest characteristics. Four replicated tissue samples of brown, dry leaves (BL), green leaves (GL), growing point region (GPR) or apical internodes, and stalk (S), were separated. Juice from each tissue type was clarified following a hot lime clarification process (operated by most U.S. factories). Only GPR and GL juices foamed on heating and followed the normal settling behaviour of global sugarcane juice, although GL was markedly slower than GPR. GPR juice was critical to clarification. S juice tended to “thin out” rather than follow normal settling, and much more upward motion of flocs was observed. Most varietal variation in settling and clarified juice characteristics occurred for GL.

The quality and not the quantity of impurities in the different tissues affected the volume of mud produced. Tissue juice brix (% dissolved solids) had no relationship with the amount of mud produced. After 30 min settling, mud volume per unit tissue juice brix varied markedly among the tissues (S=1.09, BL=11.3, GPR=3.0, and GL=3.1 mL/brix). Heat transfer properties of tissue juice and CJ were described. Clarification was unable to remove all BL cellulosic particles. GL and BL increased color, turbidity and suspended particles in the clarified juice with BL worse than GL. This would cause difficulty downstream in the factory boiling house and make the future attainment of Very Low Color (VLC) raw sugar more difficult. Strategies to reduce the delivery of green and, especially, brown leaves to the factory need to be urgently identified and implemented.

The effects of extraneous matter on factory operations (Rod Steindl)

The author provided a summary of several separate investigations that considered the effects of extraneous matter (tops, trash, roots and soil) on the composition of mixed juice and the downstream processes. The objectives in each case were to quantify the effects of green cane harvesting with increased levels of trash on factory throughput and sugar quality so that economic models could be developed. Although different methodologies were used, the outcomes were similar.

In the first investigation, estimates were determined for the composition of a cane stalk by separating the stalk into clean cane, trash, tops and top leaf components. The averaged values for a number of varieties were:

- Clean cane 81.2 %;
- Trash 7.1 %;
- Tops 6.1 %; and
- Top leaf 5.6 %.

It must be accepted that these quantities depend on many factors and can only be used as a guide. In a series of laboratory trials, composite samples of clean cane and added tops and trash were milled and samples of mixed juice and clarified juice were analysed. As expected, the samples of ‘dirty’ cane had higher levels of non-sugars, ash and colour. In another series of trials conducted at a factory, paired tests of dirty and clean cane were milled and the factory process streams were analysed to provide data to determine the economic impact of the trash content. Trash levels were up to 15 % of the cane supply. Some of the statistically significant effects included reductions in the sugar content for cane payment, crushing rates and syrup quality and an increase in the production of final molasses.

In a further series of factory trials, the harvesting operations were organised into clean and dirty cane periods of up to six days each and the effects measured in the factory operations. The main effects measured were statistically significant increases in the starch, phosphorus and mud solids content of juice from dirty cane. The filter cake % cane increased by up to 37 % and the pol loss in cake % pol in cane increased by 16 %. The A massecuite quantity dropped marginally while the B massecuite % cane increased by 7 % and the final molasses % cane increased by about 20 %.

Interestingly, there was no statistically significant difference in the quality of the sugar produced. It should be noted that the factories involved in these trials only produced raw sugar with a typical pol of 98.8 to 99.0.

Improving the exhaustion of C-sugar magma through on-line measurements of the crystal content (Teddy Libelle, Michael Benne, Bridgitte Grondin-Perez and Jean-Pierre Chabriat)

On-line measurements and supervision tools become essential tools when trying to optimize the boiling crystallization process and to limit the impact of the variability of incoming feed streams. This study presents the on-line measurement of the crystal contents of the sugar magma (massecuite). The measurement technique was simply based on the comparison between the brix of the massecuite (Bx_{MC}) and the brix of the mother liquor (Bx_{ML}). Thus, its implementation was simplified due to the fact that both these types of sensors are often present at industrial sites. The complete mass of crystals in the C-sugar magma, C_m, depends on the crystal contents. From industrial measurements collected at Bois Rouge sugar mill (La Reunion), we showed that C_m can either increase, decrease or be stable during a boiling crystallization. When analyzing the evolution of C_m , we can propose some methods to optimize the exhaustion of C-sugar magma.

Impact of trash and high fibre cane on sugar recovery: CERF preliminary results (Laurent Corcodel, Camille Roussel, Eslyne Lemoine, Audrey Thong Chane and Laurent Barau)

The effect of cane composition on sugar processing has been discussed worldwide. With the development of high fibre cane, an investigation into the high fibre effects on sugar processing was considered to be necessary. High fibre elite variety was at the end of the CERF breeding program and the effect of this variety on the sugar milling processes had to be investigated. Firstly, the theoretical impact in sugar plants (sugar losses and milling capacity) was described and secondly, laboratory extractability trials were done. Those experiments were conducted jointly between the CERF breeding department and the sugar processing department.

Different CERF cane varieties were pressed at different pressures (between 50 to 250 bar) by a hydraulic press to calculate their extraction rate. Results showed significant differences between those varieties which could be explained by their pith / fibre ratio. Those indicators will be studied further with the aim to integrate them into the CERF breeding program to select high fibre clones with a good milling ability.

Factory trials to determine the effect of green trash on downstream processing (Barbara Muir, Gillian Eggleston and Bryan Barker)

There is a worldwide shift to green cane from burnt cane harvesting. In South Africa 89% of the cane is still burnt and most of it is hand-cut. Certain areas are changing to green cane harvesting due to environmental pressures, increasing labour costs and the current trend to investigate sugarcane trash as biomass for the production of bio-products. This paper reports on the effects of harvesting green billeted and/or whole-stalk sugarcane compared to burnt billeted and/or whole-stalk sugarcane at three South African mills that operate either a tandem mill or diffusers. Sufficient cane of each treatment was harvested and processed at each mill to purge the extraction plant of other cane. Trash tissues, shredded cane, juice and bagasse samples in the front end were collected and analysed. A bulk sample of mixed juice was then transported to the SMRI in Durban and further processed in the SMRI pilot plant to clarified juice, syrup, “A” massecuites, molasses and raw sugar.

Some of the differences reported include:

- There was a six to ten fold increase in trash for mechanically harvested burnt and green cane over manually cut burnt cane;
- The cane and juice purities decreased with increasing trash content;
- RS/ash ratios in juice, syrup, massecuite and A molasses increased from burnt billets to green billets in some cases or were similar in other cases; and
- At one factory there was a slight increase (~10 %) in affined sugar colour while the samples from another

factory showed a decrease of ~22 % in affined sugar colour from burnt to green cane.

Session 4 – Whole crops

Whole crop harvesting and processing (Michael Saska and Nicolas Gil Zapata. Presented by Rod Steindl)

This report presents results from tests done in 2006 in a Louisiana factory with harvesting and processing of the whole crop or "complete cane" (stalk plus trash). The objective was to determine if there was any benefit if the whole crop was harvested green and transported to the factory and then to process the cane with or without the extraneous matter.

For complete cane (CC), the mill harvested green cane with the extractor turned off on the harvester, and the normal green cane (NC) was harvested with the fans on as usual. On December 15, 2006, 367 tons of CC were processed in about 4.5 hours at an average of 82 t/h. Sampling of normal cane as a reference could not be done on the same day, because cane delivery problems delayed the start of processing the cane. Sampling of the normal cane (NC) was therefore done on December 20 for a total of seven hours. The mill operation was interrupted because of boiler problems for about 2 hours, about two hours into the test. Based on the information regarding the code and weight of the wagons that arrived at the mill, an estimated 974 tons of cane were processed within the period of the test, for an average rate of 139 t/h. The code, weight, and core lab analysis of the cane wagons delivered during each test were averaged and compared with the analysis of prepared cane taken at regular intervals during the test. Because of the time difference between the two tests, the variations reported here between NC and CC may be due in part to other factors than the trash content, e.g. cane and processing conditions, etc. Freezing temperatures at the start of December affected the cane quality, and the four day delay between the tests probably resulted in further deterioration of the freeze damaged cane and skewed the comparison between complete and normal cane.

No problems were noted when processing whole green cane although the mill operated well below capacity at the time of both tests for other reasons.

An Excel model was set up to estimate the economic viability of harvesting, transporting and processing cane with a variable amount of extraneous matter, including the case of whole crop processing, with co-generation with the extra bagasse. Other factors included in the model were the cane composition, sugar content and price, extra cane yield above the "normal cane" case, the power generation efficiency and sale price, and harvester fuel requirements, with the extractor fans either on or off. The field-to-factory distance and the fuel cost were the decisive factors whether whole-crop harvesting could be profitable. The model also shows the critical effect of pol in bagasse, when milling cane with increased amounts of extraneous matter.

The experiences gained from whole crop milling (David Moller)

Whole cane milling (WCM) has been undertaken at two of the factories in the NSW Sugar Milling Co-operative to supply enough biomass to power a co-generation boiler of 30 MW during the six months of the non-crushing season. Whole crop milling is the supply of the whole crop (cane billets, leaves and trash) to the factory for processing through the milling tandem.

The initial plan was to transport the whole crop to the factory and then separate the leaf and trash material from the billets prior to milling. However the prohibitive capital costs were such that this proposal was later rejected. After a short trial it was decided that all the material would be processed through the milling train. This method of processing was trailed for three weeks during the 2007 crushing season before the factory returned to burnt cane processing.

In the 2008 crushing season the factory has been processing whole cane for the first eight weeks. Due to an extreme frost in the 2007 growing period, the cane supply during this eight week period has included approximately 30 % of frost affected cane. Assessing the effects of processing the whole crop has been complicated by the inclusion of this frosted cane. Processing whole cane has impacted on every part of the factory. Changes have been made in the feeding, milling and boiler stations, but no changes have been made to the clarification, evaporation, pan or fugal stages until the effects of whole crop processing can be better determined. The observed effects in the factory include:

- Cane feeding - lower bulk density, trash binds together more than billets alone;
- Milling – the fibre rate increased from 40 t/h to 77 t/h and greater variability;
- New cane payment formula needed;
- NIR system needed to measure fibre in each sample for cane payment;
- Clarification – lower settling rates, additional phosphate not effective in assisting clarification, and higher turbidity of clarified juice;
- Evaporation – poor HTC, faster scaling rate and scale harder to remove;
- Pan boiling – pans operating at only 60-70 %, poor circulation (it is possible that frost affected cane contributed to this);
- Sugar quality – higher colour in molasses layer, no real impact on refinery operations; and
- Recovery – pol recovery dropped by 9 %, bagasse loss increased by 4 %, and molasses loss increased by 5 %.

Composition of non-stalk components of sugarcane and field residues and their effects on composition of mixed juice (Michael Saska and Nicolas Gil Zapata. Presented by Rod Steindl)

This presentation summarised four independent investigations, carried out at different times and following somewhat differing methodologies. However, the objective was the same: add to the understanding of the composition of the various components of the sugarcane plant, with a focus on the effects of non-stalk components on the composition of the mixed juice, and to some degree on the potential new industrial uses for field residues after cane harvest, or after separation from stalk billets.

Specifically, the various facets of the work included the 2002 tests in Louisiana of the cane composition during the growth and harvest period, a one-time sampling and determination of composition in 2003 of non-sugars in a major sugar cane variety grown in Colombia, determination of the effects of a commonly used chemical ripener on non-sugar composition of the cane in 2005, and a four year (2002 to 2006) test to determine the chemical composition of both the biomass remaining in the field after harvest and the juice extracted from these field residues using laboratory milling equipment.

It is well known that the non-sucrose content of the juice (e.g. ash, reducing sugars, starch, and colorants) extracted from cane trash is higher when expressed on the dry solids basis, than in juice from clean stalk, and therefore the purity of the industrial mixed juice is lower than it would be if only clean stalks were milled. However, even though the present data are far from complete and may have been affected by various experimental factors, it is quite apparent that the ratio of reducing sugars over the sum of concentrations of potassium and aconitate (the two major contributors to ash in cane juices) tends to be larger in juices from tops and leaves, than in the juice in the clean billets. This would seem to indicate that cane trash (tops and leaves) in commercial cane supplies may increase the overall RS/Ash ratio and therefore lower the target molasses purity.

Session 5 – Forum review and discussion

Processing of green cane through sulphitation process (J.J. Bhagat)

The author provided an overview of the Indian sugar industry that included such topics as:

- The importance of the sugar industry to the national economy;
- Value-added products that are generated from the 260 Mt crop of sugarcane;
- The major constraints being faced by the industry; and
- Strategies being adopted to improve productivity including new varieties, sustainable farming systems, extensive upgrades and modernisation of factories and energy conservation, optimisation and power export.

Indian factories produce a bold grain sugar with a very low colour of 50-150 IU typically. The process includes double sulphitation and usually syrup clarification. Trash and other extraneous matter that would cause an increase in the sugar colour is avoided. Mixed juice colour can vary from about 14,000 IU for clean cane up to more than 30,000 IU for cane plus tops and trash.

Some of the disadvantages of the high extraneous matter present in the cane supply when all the biomass is delivered to the factory include:

- Reductions in grinding capacity and sucrose extraction;
- Mill efficiency reduces by 5 % and milling capacity by 10-15 %;
- Lower quality clear juice (increases in turbidity, residual CaO and PO_4, lower purity, and additional consumption of chemicals);
- The leaf matter introduces an extra high loading of colorants, ash and RS;
- Increases the purity of final molasses; and
- The net benefit to a factory processing 0.5 Mt of clean cane rather than cane with extra trash was estimated at US$1.3 M (without a co-generation facility).

Literature review of burnt / green cane effects on factory processing (Laurent Corcodel)

A brief summary of some papers to past ISSCT and SASTA conferences was presented. The summary highlighted the difficulties confronting current technologists when trying to reconcile the range of previous investigations because the focus of individual investigations is usually different and this makes comparisons difficult.

Poster papers

Technological measurement of sugarcane quality: Sugarcane variety extractability trials (Laurent Corcodel, E. Lemoine, G. Chabot, C. Soundron and Camille Roussel)

Cane constitution effect on sugar processing has been discussed worldwide. With the development of high fibre cane, investigations of fibre effect on sugar processing are necessary. High fibre elite is at the end of the CERF breeding program and before industrial plantation the effect of this variety on sugar processing has to be forecast. Firstly, the theoretical impact in sugar plants (sugar losses and milling capacity) is described and secondly, laboratory extractability trials are done. Those experiments are conducted between CERF breeding department and sugar processing department.

Different CERF cane varieties are pressed at different pressure (between 50 to 250 bar) by a hydraulic press, in order to calculate their extraction rate. Results show significant differences between those varieties which could be explained by their pith / fibre ratio. Those two indicators will be studied further with the aim to integrate them into the CERF breeding program to select high fibre clones with a good milling ability.

A pilot plant developed in house for yield and quality increasing of sugar crystallisation (Cédric Damour, Patrick Jeanty, Yannis Hoarau, Michel Benne, Brigitte Grondin-Perez and Jean-Pierre Chabriat)

Crystallization process is the key stage of sugar production. Increasing demands for yield and quality created a need for optimization and control of the process. To reduce the influence of variations in cane quality and changes in agro-climatic conditions on the process efficiency, it is essential to perform manufacturing protocols and to develop predictive control strategies. These steps require a series of experiments to reach the best trade-off. In an industrial context, each experiment could damage or stop the production. Development of a pilot offers the opportunity to run many tests and experiments in the same experimental conditions but at a reduced scale. This poster describes a 1:1 000 scale pilot plant for sugar crystallisation developed in house at the Laboratory of energetic electronic and processes (LE2P) at University of La Reunion. This pilot plant should allow us to test and implant some new advanced control methods that have not been tested *in situ*. Results obtained on C-sugar crystallisation and experimental design of the seeding point study justify the scientific interest in the pilot plant development.

Site visits

Casernes cane delivery and transfer station

Cane is delivered to one of the 11 transfer stations by the farmer, usually as single trailer loads towed by a tractor. A core sample is taken from each delivery to the station on arrival. The cane is then transferred to a stockpile if whole stick or transferred directly to a waiting 20 t trailer if billet cane. The core sample is then sub sampled into a 5 kg lot and analysed at the site. The subsample is shredded and a 1 kg aliquote is placed into a press at 200 bar for 90 s to provide a juice sample for pol and brix. The fibre is calculated from a regression equation and the weight of the press plug.

Le Gol Mill

Some of the factory data are:

- Factory stops every Sunday for maintenance including hammer change and evaporator boil using 28 % caustic for 10 h where caustic is recirculated around individual vessels;
- 4 MW electric drive on shredder, Hagglunds hydraulic drive on #1 mill and electric drives on #2, #3, #4 and #5 mills;
- 6 effect evaporation: #1 – semi-Kestner, #2 – falling film with 12 m tubes, #3, #4, #5 and #6 – Roberts but with floating calandrias;
- Extensive vapour bleeding: V6, V5 and V4 to primary heaters; V3 and V2 to secondary heaters; V2, V1 and LP to CJ heating to 112 °C in Barriquand heaters; V2 to pans; V3 to CVP;
- LP steam is about 100 kPa;
- Condensate from #2 effect used for MJ heating in Barriquand platular heater;
- CVP for A and C massecuites;
- A massecuite split between continuous and batch fugals;
- Raw sugar pol is 98-98.5 and special DC sugar pol is about 99.0;
- A high level of automation and centralised process control;
- Co-generation plant separated from factory;

- 3 x 125 t/h plus 1 x 114 t/h boilers on both bagasse and coal;
- 2 x 30 MW and 1 x 50 MW sets for cogeneration; and
- 150 kPa vapour in closed loop for ‘pre-evaporator’ to generate 100 kPa LP steam supply for factory.

Bois Rouge Mill

This factory was similar to Le Gol Mill but with the following exceptions:

- The initial mill is a 2 roll mill with electric drives and used as a ‘pre-extractor’ before a diffuser with the following objectives: (i) 75 % extraction, (ii) higher crushing rate, (iii) reduce imbibition rate, and (iv) reduce pol loss in bagasse.
- The diffuser has typical imbibition rates of 280-340 % on fibre;
- A belt press filter has been installed to assist with mud filtration;
- Molasses % cane is about 3.5; and
- A refinery is attached to the back-end of the factory.

Concluding forum

The forum discussed the use of the word ‘trash’ and what it represented. This arose because there were variations between research groups on what constituted trash and what was extraneous matter. The consensus within the workshop delegates was as follows:

- Trash – the fibrous non stalk material from the cane plant. This includes all leaf matter and the growing point of the cane stalk.
- Extraneous matter – everything left in the field or delivered to the factory that is not processable stalk.

There was general agreement that the best practice for factories to produce good quality sugar was to process clean cane. However it was also recognised that future economic conditions will dictate that factories will need to maximise the amount of biomass brought into the factory for energy and bio-commodities. Individual condition will define the most economical and sustainable balance for each organisation.

There was some discussion about future research needs. The papers delivered to the workshop identified a range of problems that factories have faced when processing cane with high levels of trash. The forum concluded that more research should be directed towards the following issues:

- An economical trash separation system to handle a cane supply with high levels of trash;
- Identify suitable chemicals that would assist to alleviate the problems associated with the additional impurities in trash when processing a ‘whole of crop’ cane supply through the factory; and
- Consider the idea of a joint workshop for both agricultural scientists and factory engineers to consider the operating constraints of each sector of the industry and to consider options that benefit the operations of both the field and the factory.

Acknowledgements

The contributions of CERF for hosting the workshop and the organisational efforts of the staff of CERF

was greatly appreciated. Other organisations that provided financial support for the workshop included:

Sucrière de La Réunion,

Sucrerie de Bois Rouge,

SFSR (Sugar Producers Associations of Reunion Island)

ARTAS (Association of Sugarcane Technologists of Reunion Island)

REI (Réalisations Electroniques & Informatiques)

Departément de la Réunion

IRT (Ile de la Réunion Tourisme)

Appendix A Workshop Program

	Sunday, October 19, 2008
	Registration – Hotel Mecure Créolia
17:00	Depart for CERF
17:30	Visit to CERF - Visit of facilities (greenhouses and laboratories) - CERF presentation
18:30	Opening introduction – Jean-Françcois Moser and Bernard Siegmund
19:00	Welcoming cocktail – Sponsored by ARTAS
21:30	Depart for hotel
	Monday, October 20, 2008
07:00	Depart for site visits
08:30	Sugarcane delivery and sampling – Casernes Delivering Station
10:30	Coffee break – Le Gol Mill
11:00	Visit to Le Gol Mill
12:30	Lunch – sponsored by Le Gol Mill
14:30	Visit to co-generation plant – Centrale Thermique de Gol
15:30	Depart for hotel - tourist tour via volcano slides
	Tuesday, October 21, 2008
08:30	Introduction – Rod Steindl (Chairman)
08:50	The sugarcane industry in Reunion - Jean-Françcois Moser
09:20	A review of milling season in Reunion since 1984 – Laurent Corcodel
10:00	Coffee break
	Session 1 – Sugar losses in storage: green cane versus burnt cane
10:30	Determination of sucrose loss in storage of green billet cane – Michael Saska
11:10	Cane deterioration: Comparison green cane vs burnt cane / Research of green cane deterioration indicator – Camille Roussel
11:50	NIR evaluation of the post harvest deterioration of sugarcane – Masami Ueno and Koh Kikuchi
12:30	Lunch
	Session 2 – Mill de-trashing equipment: Design, operation, optimisation
14:00	The development of a prototype factory-based trash separation plant – Rod Steindl

14:40	Cane field residues as supplementary boiler fuel – Kassiap Deepchand
15:20	Coffee break
16:00	Depart for Bois Rouge Mill
16:30	Visit to Bois Rouge Mill and Savanna Distillery
19:00	Dinner – sponsored by Bois Rouge Mill
Wednesday, October 22, 2008	
	Session 3 – Effects of trash on factory operations
08:30	Ledesma's green cane project – Mario Rostagnos
09:10	Green revolution in the Brazil sugarcane business – Jean-Claude Religieux
09:50	Coffee break
10:20	Clarification properties of stalk and trash tissues from U.S. sugarcane varieties – Gillian Eggleston by Barbara Muir
11:00	The effects of extraneous matter on factory operations – Rod Steindl
11:40	Improving the exhaustion of C-sugar magma through online measurements of the crystal content – Teddy Libelle
12:30	Lunch
	Session 4 – Whole crops
14:00	Impact of trash and high fibre cane on sugar recovery: CERF preliminary results and future project – Laurent Corcodel
14:40	Factory trials to determine the effect of green trash on downstream processing – Barbara Muir
15:20	Coffee break
16:00	Whole cane processing – Michael Saska
16:40	The experiences gained from whole crop milling – David Moller
17:20	Composition of non-stalk components of sugarcane and field residues and their effects on composition of mixed juice – Michael Saska
18:30	Depart for Gala Dinner
19:00	Gala dinner – Villa du Département – Saint Denis
	Thursday, 23 October 2008
	Session 5 – Final forum discussion
08 :30	The Indian experience – J.J. Bhagat
09:20	Literature review of burnt/green cane effects on factory processing - Laurent Corcodel
10:00	Coffee break
10:30	Forum discussion – Rod Steindl and Laurent Corcodel
11:30	Close

Appendix B List of delegates

Delegate name	**Company**	**Country**	**E-mail**
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APPENDIX D

Biomass power generation

Sugar cane bagasse and trash

Série Caminhos
para a Sustentabilidade

01

PNUD
Brasil

Biomass power generation
Sugar cane bagasse and trash

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Published by:

PNUD - Programa das Nações Unidas para o Desenvolvimento
CTC - Centro de Tecnologia Canavieira

1st edition

Piracicaba, Brazil
2005

PNUD - Programa das Nações Unidas para o Desenvolvimento

www.pnud.org.br

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H355b

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Biomass power generation: sugar cane bagasse and trash / Suleiman José Hassuani, Manoel Regis Lima Verde Leal, Isaías de Carvalho Macedo - Piracicaba: PNUD-CTC , 2005. p. il. 27cm. (Série Caminhos para Sustentabilidade)

ISBN 85-99371-01-0

1. Biomass 2. Sugar cane - Bagasse 3. Sugar cane - Trash 4. Gaseification I. Leal, Manoel Regis Lima Verde II. Macedo, Isaías de Carvalho III. Title.

DDC 664.122
UDC 664.11

Technical revisor: Antonio Carlos Fernandes

Front cover design: Zoltar Design

Typesetting and Layout: Mesly De Nadai Fernandes

Foreword

This document summarizes the findings of Project BRA/96/G31 – Biomass Power Generation – Sugarcane Bagasse and Trash, conducted during the period of 1997 to 2005, with the purpose of evaluating and developing the technology for using sugar cane residues, bagasse and trash as fuel for the advanced cogeneration system of biomass integrated gasification gas turbine (BIG-GT), integrated with sugar/ethanol mills.

The Project funded by the Global Environment Facility – GEF (www.gefweb.org) and Copersucar further received the partnership of the Swedish National Energy Administration and the European Commission. The project, developed under the focal area of Climate Change, was implemented by the United Nations Development Programme – UNDP having the Ministry of Science and Technology of Brazil – MCT (www.mct.gov.br) as coordinator.

Project development was undertaken by CTC, the Copersucar Technology Center, which belonged to a cooperative of 32 sugarcane mills and, in 2004, evolved into CTC – Centro de Tecnologia Canavieira (www.ctc.com.br), a research center with more than a hundred associates (including sugar cane mills and sugar cane growers associations). Gasification development, on its turn, was carried out by TPS – Termiska Processer AB (www.tps.se).

The project's relevance was recognized by several institutions, sugar cane mills and equipment manufacturers, a number of which assisted in various phases of the development (see acknowledgements in the following page).

During project execution 98 reports were issued by CTC and 11 issued by TPS, describing all the activities performed and results attained. The process of information dissemination was one of the most successful activities of the project, with several results already being applied by the sugar cane sector.

Project development indicated four main issues, namely: (i) trash recovery, processing and use, (ii) gasification of bagasse and trash, (iii) integration of the gasification and gas turbine to sugar cane mill and (iv) environmental impacts assessment and mitigation measures. Challenges, either technical or economic, are described and dealt with and trends and alternatives for implementation of the technology are indicated.

Professor Francelino Grando

Secretary of Technological Development and Innovation

Ministry of Science and Technology

Acknowledgements

Copersucar and TPS would like to thank the following institutions that made possible the successful completion of Project BRA/96/G31.

Global Environment Facility
United Nations Development Programme
Brazilian Ministry of Science and Technology
European Commission
Swedish National Energy Administration
Açucareira Quatá
Açucareira Zillo Lorenzetti S.A.
Usina Barra Grande
Usina São Martinho
Usina São Luiz AA
Usina Da Pedra
Usina São Francisco
Usina Santa Luiza
Usina Da Barra
Usina Nova América
Case IH

Special thanks are given to Dr. Eric Larson of Princeton University for suggestions and review of some technical reports.

Nomenclature

ACFBG	Atmospheric circulating fluidized bed gasifier
ANC	Average number of canes
ARENA	Software – Systems Modeling
ASTM	American Society for Testing and Materials
bag./tra.	Bagasse/ trash
BFW	Boiler Feed Water
BIG-CC	Biomass Integrated Gasification/Combined Cycle
BIG-GT	Biomass Integrated Gasification/Gas Turbine Technology
BNDES	National Bank for Economic and Social Development
BOD	Biological Oxygen Demand
BTU/scf	British Thermal Unit per standard cubic feet
BTX	Benzene, toluene, xylene
C%	Constancy
cal	Calorie (energy)
CENBIO	National Biomass Reference Center
CEST	Condensing - Extraction Steam Turbine
CETESB	Companhia de Tecnologia de Saneamento Ambiental - Estado de São Paulo
CFB	Circulating Fluidized Bed
CFBG	Circulating Fluidized Bed Gasifier
COD	Chemical Oxygen Demand
cm	Centimeter
CONAMA	Conselho Nacional do Meio Ambiente
CPFL	Companhia Paulista de Força e Luz
CRC	Capital Recovery Cost
CRF	Capital Recovery Factor
CTA	Centro Tecnológico da Aeronáutica
CTC	Centro de Tecnologia Canavieira, formely Copersucar Technology Center
db	Dry basis
DLMC	Dry leaves moisture content (%)
dm	Decimeter
DM	Dry mater
EC	European Commission
EE	Eletric energy
equiv.	Equivalent
ESALQ	Agricultural College "Luiz de Queiroz"
ETP	Estimated trash potential (t/ha)
F%	Frequency
F.W. Pump	Boilers Feed Water Pump
g/kg	Grams/ kilogram
GC	Gas Chromatograph
GEF	Global Environment Facility
GHG	Green House Gases
GLMC	Green leaves moisture content (%)
GWh	Gigawatt hour
ha	Hectare (10.000 square meters)
HB	Hand cut burned cane
HGG	Hot Gas Generator
HHV	Higher heating value
hp	Horsepower
HP	High pressure cogeneration
HRSG	Heat Recovery Steam Generator
ICMS	Imposto sobre Circulação de Mercadorias e Serviços (Service and Merchandise Circulation Tax)
IDF	Induced Draft Fan
IPCC	Intergovernmental Panel on Climate Change
IPT	São Paulo Institute of Technology
ISSCT	International Society of Sugar Cane Technologists
ITA	Instituto Tecnológico Aerospacial
kg	Kilogram
km/h	Kilometer/ hour
kV	Kilovolts

kW	Kilowatt
kWh	Kilowatt per hour
L/h	Litres/ hour
L/t	Litres/ ton
LHV	Lower heating value
LP	Low pressure cogeneration
m	Meter
M.A.	Brazilian Department of Agriculture
maf	Moisture and ash free
MB	Mechanically Harvested Burned Cane
MCT	Ministry of Science and Technology - Brazil
mg/kg	Milligrams/ kilogram
MINAZ	Ministry of Sugar - Cuba
MJ	Mega Joule
MP	Medium pressure cogeneration
MSRI	Mauritius Sugar Industry Research Institute
MU	Mechanically harvested unburned cane
MVA	Mega Volt Ampere
MW	Megawatt
MWe	Megawatt electric
MWh	Megawatt hour
MWt	Megawatt total
NGO's	Non Governmental Organizations
Nm^3	Normal cubic meter
NPV	Net Present Value
Op. capac.	Operational capacity
PC	Personal Computer
PLC	Programmable Logic Control
PPT	Priority Thermoelectricity Program
PROINFA	Incentive to Alternate Sources Program
P.W. Pump	Process Water Pump
Ref.	Reference
RPM	Rotation Per Minute
RS	Row Spacing
Scen.	Scenario
SMRI	Sugar Milling Research Institute
SRI	Sugar Research Institute - Australia
ST	Steam Turbine
STAB	Brasilian Society of Sugar Technologists
STEM	Swedish National Energy Agency
t	Metric tons
t/ha	Tons per hectare
TC	Tons of cane
TCH	Tons of cane per hectare
TG	Turbo generator
TMC	Tops Moisture Content (%)
TO	Total
TOC	Total Organic Carbon
TPH	Tons of pol per hectare
TPS	Termiska Processer AB
TWCE	Trash Weed Control Efficiency
UNDP	United Nations Development Programme
UNICA	Union of the Cane Agroindustry of São Paulo
UNICAMP	University of Campinas
UNIFEI	Universidade Federal de Itajubá
USEPA	United States Environmental Protection Agency
wb	Wet basis
WBP	Woodchips Brazilian Project
WDL	Weight of dry leaves
WGL	Weight of green leaves
WT	Weight of tops

Executive Summary

Introduction

Brazil has a long time tradition in the use of renewable energy. A look at the primary energy supply shows that in 2002, 41% was renewable energy with hydropower contributing with 14% and biomass with 27%. The hydropower plants amount to 65 GW of the 82 GW of total installed capacity.

This is an unique situation, which has a positive aspect of renewable energy use, but leaves the country exposed to the seasonality of the rain regime. The shortage that occurred in 2001 made the Government decide to diversify the energy supply sources, favoring the inclusion of a reasonable share of thermal power plants and creating a market share for other renewable sources of energy such as wind power and biomass.

The sugar cane sector in Brazil produces and processes more than 300 million metric tons of sugar cane, with more than 50% of the sucrose being used in the production of ethanol. The sugar cane bagasse provides all energy required to process the sugar cane and several mills are already generating surplus power and selling it to the utilities; this surplus power generation of the sugar/ethanol mills could be highly increased by the use of more efficient energy conversion systems, such as the biomass gasification integrated with gas turbines (BIG-GT), and the recovery of part of sugar cane trash, that is burned or wasted otherwise today, to supplement the bagasse as fuel; both the BIG-GT and trash recovery are emerging technologies that need development and demonstration to be able to reach the market.

Project conception

The conception of BRA/96/G31 was based on the context described above and on the fact that a BIG-GT based power generation project was being developed to be implemented in North East Brazil, using wood chips from planted forest as fuel. The project proposal was prepared by Copersucar Technology Center (CTC) to GEF and in July 1997 Copersucar and the United Nations Development Programme (UNDP) signed the contract that started the activities of Project BRA/96/G31 – Biomass Power Generation: Sugar Cane Bagasse and Trash. The administrative organization of the project had UNDP as the Implementing Agency, Ministry of Science and Technology (MCT) as the Executing Agency (representing the Brazilian Government). CTC was in charge of the project technical coordination and execution of the great majority of the activities, and TPS Termiska Processer AB (TPS) was responsible for the gasification technology development and BIG-GT package detailing.

The project main objective was to evaluate and to develop the required technology to use sugar cane residues, bagasse and trash, as fuel for advanced cogeneration systems, such as biomass integrated gasification gas turbine (BIG-GT), integrated with sugar/ethanol mills.

The project Immediate Objectives (**OI**) were:

OI1: Evaluation of sugar cane trash availability and quality.
OI2: Evaluation of agronomic routes of unburned cane harvesting with trash recovery.
OI3: Bagasse and trash atmospheric fluidized bed gasification tests.
OI4: Integration of BIG-GT system with a typical mill.
OI5: Identification and evaluation of environmental impacts.
OI6: Project information dissemination.

The total budget allocated to the project was US$ 7.39 million with US$ 3.75 million funded by GEF (through UNDP) and the remaining US$ 3.64 million provided by Copersucar.

Project results

The main project results are summarized for each Immediate Objective:

Evaluation of sugar cane trash availability and quality

Large variations in trash availability data are found in the literature. The amount of residues from sugar cane harvesting depends on many factors such as: harvesting system, topping height, cane variety, age of crop, climate, soil and others. Therefore, with the purpose of excluding the effects of harvesting conditions, experiments were carried out to determine de amount of trash (dry leaves, green leaves and tops) available in sugar cane field before harvesting, using a methodology established by CTC. These experiments were carried on for three sugar cane varieties, in two different regions, and in three stages of cut 1st cut within 18 months of the planting and the 3rd and 5th within 24 and 48 months from the first cut, respectively. Under these average conditions the potential of sugar cane trash (dry matter-DM) determined is around 14% of the stalk mass. Considering the sugar cane harvesting in the 97/98 season of 301.6 million tons, the potential of trash (dry matter) would be 42.2 million tons.

The characterization of sugar cane trash and bagasse to be used as fuel consists of a series of established analyses according to ASTM standards known as Proximate Analysis, Ultimate Analysis, Ultimate Mineral Analysis and Heating Value.

Proximate Analysis determined the average values for the trash components (dry and green leaves and tops) that presented practically the same composition in volatile material (~80%), ashes (~ 4%) and fixed carbon (~15%) expressed on dry basis. These figures are similar to those obtained for bagasse, except for ash that is lower in bagasse (~2%). The water content was approximately 13% for dry leaves 65% for green leaves, 80% for tops and 50% for bagasse.

The ultimate Analysis determined the fractions by weight for carbon, hydrogen, oxygen, sulfur and chlorine. It is observed that all materials present practically the same composition in carbon (~45%), hydrogen (6%), nitrogen (0,5 – 1%), oxygen (~43%) and sulfur (~0,1%). The chlorine figures vary considerably with the lowest for bagasse (0,02%) and the highest for the tops (0,7%).

The higher heating value determined does not vary much among the three components of trash and bagasse, when expressed as dry matter, with figures around 17,5MJ/kg.

Evaluation of agronomic routes of unburned cane harvesting with trash recovery

With the main objective of recovering trash to be used as fuel for energy generation, five routes for unburned cane harvesting with trash recovering were considered and evaluated.

Route A: Whole stalk cane harvesting; loading and transport cane with trash; cane cleaning and trash recovery at the mill.

Route B: Whole stalk cane harvesting; cane picked up, chopped and cleaned in the field; transporting clean cane; baling and transporting trash to the mill.

Route C: Chopped cane harvesting; cane cleaned and loaded during harvesting; transporting clean cane; baling and transporting trash to the mill.

Route D: Chopped cane harvesting with no trash removal (extractors fans off); transporting cane and trash; cane cleaning and trash recovery at the mill.

Route E: Chopped cane harvesting with part of the trash separated from the cane and left in the field for agronomic purposes and the rest of the trash is transported with the cane to the mill where trash separation is executed by a dry cleaning station.

Routes A and B were abandoned after the initial series of testes due to the poor performance of the whole stalk harvester in cane field with more than 70 ton of cane per hectare.

The best results were obtained for Route C and especially for Route E.

Trash recovery efficiency was around 64% in Route C and 50% in Route E; the estimated trash recovery costs were US$ 18.49 and US$ 13.70 for Route C and E, respectively.

In these values are included the costs of the impacts in the cane fields caused by the removal of the trash (such as loss of agricultural productivity due to soil compaction, loss of herbicide effect of the trash blanket, and others).

Bagasse and trash atmospheric fluidized bed gasification tests

A series of laboratory, bench scale and pilot plant tests were performed by TPS with samples of bagasse and trash, prepared by CTC in Brazil and shipped to TPS in Sweden. Samples of dolomite produced in Brazil were also included.

Laboratory tests were used to characterize the sugar cane residues and the dolomite, as a tar cracker catalyst.

Ash content, moisture content, volatile matter, fixed carbon, carbon content, nitrogen content, lower heating value and ash initial deformation temperature were measured to establish the main characteristics of these potential gasifier fuels. Tar yields with and without cracking were also measured.

Bench scale tests were intended to investigate the actual gasification behavior of bagasse and trash to obtain the operational information to be used in the planning of the atmospheric circulating fluidized bed (ACFB) pilot plant tests at a scale of 2 MW thermal.

The test campaign carried out in TPS's ACFB gasification pilot plant consisted of three tests with bagasse, three with trash and one with a blend of bagasse and trash; each test lasted five days. The conclusions of the tests indicated that both sugar cane residues are acceptable fuels for use in gasification process and data were collected to allow modeling of the process for operation with these fuels at larger scale.

Integration of BIG-GT system with a typical mill

In the Brazilian woodchips Project (WBP), which was used as reference to this project, the BIG-GT plant concept was an independent thermal power plant, operating in a combined Brayton/Rankine cycle, using woodchips from a dedicated planted eucalyptus forest.

To use the same BIG-GT module, based on the General Electric - GE LM 2500 gas turbine in sugar/ethanol mill, it was necessary to evaluate several points such as: supply/demand of biomass fuels – bagasse and trash, interference between BIG-GT module and mill operations, adjustment of mill steam demand to the BIG-GT steam supply, pre-conditioning of bagasse and trash, estimation of investment and power supply costs. The São Francisco mill (Sertãozinho, SP) was selected as the typical Mill to be used as reference for the development of the engineering and design of the BIG-GT/mill integration. TPS made the scale up simulations of the BIG-GT modules for several alternatives of integration suggested by CTC. Based on the preliminary simulation an alternative was selected for final detailing, performance assessment and cost estimation. The net power surplus of 26 MW, corresponding to 152kWh/ton of cane, was obtained in the calculations and the resulting energy cost was estimated to be around US$ 75/MWh for the first plant; this value is considered high for conventional power generation, but is a reasonable value for a first of a kind plant.

Identification and evaluation of environmental impacts

The production of sugar and ethanol from sugar cane, a highly energy intensive process, has a peculiarity that makes the activities CO_2 neutral – the fuel required to supply the energy demand of the cane processing activity in the factory comes in the cane, as fiber, that becomes bagasse after juice extraction. With some improvements in energy efficiency in the factory and recovery of part of trash, the energy balance becomes even positive, with the possibility of generating surplus electricity that could be injected in the grid, avoiding, possibly, the use of fossil fuels in thermal power plants. The estimated impacts for the Brazilian situation, can be determined considering 315 million tons cane/year, from which 250 million tons are harvested unburned with part of the trash recovered and used for power generation using BIG-GT technology, and the remaining 65 million ton being harvested burned and power generated by conventional systems (bagasse fired boilers and steam turbine generators). If this power generated using sugar cane residues is displacing the generation with natural gas fired plants with 502 g CO_2/kWh, the avoided CO_2 emissions will be 38 million tons of CO_2 equivalent per year in Brazil.

Project information dissemination

The dissemination of the project information was done in several ways. Eight newsletters were prepared and distributed according to a pre-established mailing list (Portuguese and English Versions) and upon request from interested persons or organizations. Publication of technical articles in important journals and presentations in national and international Congresses, Seminars and Workshops were also used to disseminated the project information aiming to increase the awareness of the world sugar cane and power generation sectors about the potential of sugar cane residues and advanced power generation technologies, such as BIG-GT, to provide significant amounts of renewable energy in technical and economically feasible conditions.

Final comments

Considering the initial project objectives and the results achieved, it can be said that the work fulfilled the expectation of those who planned and executed the project. The results analyzed under the aspects of Relevance, Performance, Success, Impacts, Sustainability and Capacity Development are also quite satisfactory. The potential of, and problems to be solved in, the use of advanced cogeneration system and the recovery and use of sugar cane trash, as a supplementary fuel to bagasse, are now well established and widely discussed.

The private sector involvement in the project is also remarkable with the participation of Copersucar, TPS, sugar/ethanol mills and equipment manufacturers in the project. The final budget of the project exceeded US$ 10 million, with US$ 3.75 million coming from GEF, EURO 575000 from the European Commission DG XVII and SEK 3.5 million from the Swedish National Energy Administration (STEM) and the balance, around US$ 5.3 million coming from Copersucar and its affiliated mills.

Brazilian energy sector

Brazil has a long time tradition in the use of renewable energy. A look at the primary energy supply shows that in 2002 40.8% was renewable energy with hydropower contributing with 13.6% and biomass with 27.2% (MME 2003). Although the hydropower potential is still far from being exhausted, the remaining sites to be exploited are mostly located in the Amazon region where the construction of large power plants will certainly face serious economic and environmental problems. The largest renewable fuel program in the world is the Brazilian Pro-Alcohol that produces roughly one third of the light duty vehicles (Otto Cycle) fuel. All this ethanol is derived from biomass – sugar cane. Also, 40% of the coal used in the steel mills is charcoal, mostly produced of wood from planted forests. Wood is also the raw material for one of the largest pulp and paper industry in the world. In summary, sugar cane and wood are planted in approximately 10 million hectares, which represents around 20% of the planted area in Brazil but less than 3% of the country total arable land.

Oil, coal and natural gas represent 43.2%, 6.6% and 7.5% of the energy supply, respectively. Coal is concentrated in the far south and oil and natural gas require imports to meet the demand, threatening the country's balance of payment.

Brazilian power system

The hydro power plants contribute with 65 GW of the 82 GW of installed capacity. This is an unique situation, which has a positive aspect of renewable energy use, but it leaves the country exposed to the seasonality of the water availability which has caused several problems in the past and a countrywide power shortage in 2001. The solution is to build enough spare capacity of hydro plants or to increase the participation of the thermal power plants in the electric power supply – or a combination of both.

Until mid 90's the Brazilian power sector was almost entirely State or Federal Government owned. With the privatization of government utilities and the changes in regulations, the participation of the private sector in electric power business increased significantly. The low tariffs culture, inherited from the times when the Government owned the power sector, survived even with privatization and discouraged large investments in new power plants. This fact associated with a lower than average rainfall in 2001 resulted in this power shortage. This created favorable conditions for the implementation of thermal power plants and as a consequence, several gas fired plants are being built or planned; the biomass could take a share of these new plants if adequate conditions are created to permit it to compete with fossil fuels, especially natural gas.

To stimulate the addition of new generating capacity the government created the "Programa Prioritário de Termoelétricas – PPT (Priority Thermoelectricity Program) in February 2000, providing resources at favorable interest rates, guaranteeing a controlled price for natural gas and other advantages. As response from the private sector and large government companies, like Petrobras, 49 thermal power plants totalling close to 20,000 MW have been programmed to be built until December 2003.

The publicity campaign in the media, led by the Government, asking for 20% energy economy to avoid blackouts was successful and, even after the threat passed, the population, industry and other sectors continued to save energy bringing the electric power consumption to 1999 levels, while new plants continued to be built (at a slower pace than planned). As a consequence, the country has a surplus of energy that is expected to last up to 2005, slowing down investments in new power plants, including the sugar cane sector. The PPT is being downsized to less than 7000 MW from 15 plants, by the end of 2003; this situation may jeopardize plans to have the thermal power plants generating at least 18% of the total electric energy consumed by the country in 2009 and reach a 12% share of the primary energy consumption for natural gas by 2010.

As bad as the situation looks today for power generators, it is expected that in the medium and long terms the supply and demand will be balanced, providing an adequate environment for investors to return to the power sector.

An outstanding support has been given to renewable energy by the Congress approving the Federal Law No. 10438, on April 26, 2002, which creates a market reserve for wind power, small hydro plants (up to 30 MW) and biomass. This law created the PROINFA – Programa de Incentivo a Fontes Alternativas (Incentive to Alternate Sources Program). The implementation of PROINFA is planned in two phases:

Phase 1 - Insertion of 3300MW of renewable energy until 2006, divided as follow:

Wind power:	1100 MW (2890 GWh/year)
Small hydro:	1100 MW (5780 GWh/year)
Biomass:	1100 MW (6750 GWh/year)

Phase 2 - After 2006, 15% of new power generation has to come from renewable sources until they reach a share of 10% of the total electric energy consumption. It is expected that this will represent more than 16000 MW of renewable energy added between 2006 and 2019.

This is an ambitions program but it is realistically based on the estimated renewable energy potentials, the impacts on the energy costs and the commitment of Brazil with renewable energy and reduction of GHG emissions.

It is expected that sugar/ethanol mills will have the largest share in biomass power generation with addition of surplus power generating capacity in the range of 10 to 100 MW per participating mill, with the advantage that mills are normally located near large consuming centers, easing off the grid load.

Sugar cane industry

Under normal conditions Brazil annually produces and processes more than 300 million metric tons of sugar cane which corresponds a quarter of the 1300 million tons grown worldwide in more than 100 countries. The Brazilian sugar cane sector gross annual income of US$ 10 billion represents around 2% of the Gross National Product.

Besides its economic importance, sugar cane heavily contributes for the country's energy matrix. Around 55% of sucrose in the cane is directed to the production of 12 million cubic meters of ethanol per year, displacing 11 million cubic meters of gasoline.

Cane production and processing are highly energy intensive activities requiring for each ton of cane, under Brazilian conditions, 190 MJ in agricultural area (in the form of fossil fuels, fertilizers and others chemicals) and 1970 MJ in industry (in the form of chemicals and bagasse, the latter providing nearly 100% of the energy requirement in the industry). A life cycle analysis for ethanol production has indicated, however, that for each unit of fossil energy input to the agroindustrial system, approximately nine units of renewable energy output (ethanol and surplus bagasse) result, to be used outside the system.

This situation has a huge potential for improvement if we bear in mind that ethanol represents only one third of the energy available in cane; the other two thirds represented by fiber in the cane stalks (bagasse) and in cane leaves (trash) is almost totally used in the process in the following way:

- 93% of the bagasse is used as fuel in cane processing, in a very inefficient way.
- 85% of the trash is burned prior to cane harvesting to reduce the cost of this operation; the other 15% is harvested unburned but the trash is left on the ground to decay. In both cases the net result is that carbon in the fiber returns to the atmosphere in the form of CO_2.

This fact indicates that with some effort and investment this potentially available fuel (cane fiber) can be saved and used to generate electric power for the grid. Three things are required to accomplish this.

- Improve process energy efficiency to generate more bagasse surplus.
- Harvest unburned cane and recover a reasonable fraction of the total trash.
- Use an efficient technology to generate power.

Previous studies already indicated that the two first points could become a reality if economic reasons would justify. The third condition has demanded attention of several institutions, and studies performed by the University of Princeton USA, indicated that Biomass Integrated Gasification/Gas Turbine Technology (BIG-GT) could be an interesting option to generate power in sugar mills.

These facts and the Brazilian Woodchips Project (WBP) motivated the proposal and implementation of Project BRA/96/G31. **Table A** shows a comparison of the BIG-GT technology with the conventional bagasse fired boiler/ steam turbine options.

BIG-GT technology situation

There are several medium to large size biomass gasifiers in operation around the world but most of them produce gas with only a mild cleaning process so the gas is burned in conventional boilers or lime kilns. Among them, the two 15 MWt units of Greve-in-Chianti, Italy (municipal solid waste pellets), the 35 MW thermal Varo plant (bark wastes) in Sweden and the 70 MW thermal Laliti plant (forest residues) in Finland deserve mention.

Table A

Alternatives for surplus power generation in sugar/ethanol mills:

Alternative	Power generation	Process steam consumption kg/TC	Surplus power kWh/TC	Potential for Brazil GWh/year	MW
22 bar/300°C steam backpressure ST	Season	500	0-10	3000	700
82 bar/480ºC steam backpressure ST	Season	500	20-40	12000	3000
82 bar/480ºC steam cond./ extraction ST	Year Round [(a)]	340	80-100	30000	4000
BIG-GT	Year Round [(a,b)]	< 340	150-300	90000	12000

(a) Supplementary fuel is required (trash); (b) Technology not commercial yet; TC= tons of cane; ST= steam turbine.

The use of product gas in gas turbine requires a sophisticated gas cleaning system consisting normally of tar cracking, dust filtering and alkali removal. Details of these cleaning systems varies from one plant to the other but are, in general, more complicated for pressurized gasification technology, where all the cleaning process is done at high temperatures.

All BIG-GT technologies under development present a similar sequence of processes and equipment – biomass dryer, gasifier, gas cleaning system, gas turbine, heat recovery steam generator and steam turbine – but differ in the operating conditions (pressure, temperature), heating process and gas cleaning process. The technologies that are closer to commercial stage are based in the fluidized bed, air blown type gasifier, and they are:

- Atmospheric fluidized bed air blown gasifier: the leading developer of this technology is the Swedish company TPS-Termiska Processer AB and the most representative demonstration plant is the ARBRE plant in the United Kingdom, designed for 8 MW electric using short rotation coppice as fuel; it was being commissioned when financial problems forced the plant temporarily to close.
- Pressurized fluidized bed air blown gasifier: the Värnamo plant with 6 MW electric plus 9 MW district heating load was designed, built and successfully operated by Bioflow from 1995 to 1999, with various fuels, using Ahlstrom (Foster Wheeler) technology. The plant was shut down after fulfilling the technology demonstration purpose.
- Atmospheric fluidized bed, indirectly heated gasifier: this technology, developed by the Battelle Columbus Laboratory, is being demonstrated in the McNeil Plant in Vermont, USA, fueled by woodchips (200 dry tons/day). The major advantage of this technology is that it produces medium calorific value product gas that can be used in gas turbines without modifications. It is being commercialized by FERCO – Future Energy Resources Corporation.

The Brazilian Woodchip Project (WBP) has evaluated in detail the Bioflow and TPS technologies and has selected the latter. Project BRA/96/G31 has been set up to use the information developed in the WBP project, to evaluate the use of BIG-GT technology in the sugar/ethanol mill environment, therefore the TPS technology has been used in the development of the project.

One critical point in the implementation of year round power generation in sugar/ethanol mills is recovery of part of the available trash, which requires that unburned cane harvesting is used. Economic and social reasons are keeping the adoption of mechanical harvesting of unburned cane at a low level. On the opposite direction, environmental pressures to stop cane burning have resulted in laws and regulations that are intended to limit cane burning and to program its phase out. More specifically, Federal Decree No. 2661 of July 9, 1998 and São Paulo State Law No. 11241 of September 19, 2002 have established a time schedule to cane burning phase out as shown in **Table B**.

The time schedules are the results of negotiations involving representatives from the population of the sugar cane regions, cane growers, cane sector workers, mill owners, government, environmental agencies and NGO's. It took into consideration issues such as unemployment, investment required and the cane field 5 year lifecycle.

The unburned cane harvesting and mechanization levels are presently around 15% and 35%, respectively. The trend is clearly toward increasing both of these figures and there are several mills, especially in the State of São Paulo that concentrates more than 60% of the cane in Brazil, already harvesting more than half of their cane unburned.

Table B

Sugar cane burning phase out.

Year	Federal Decree No. 2661 Mechanizable harvesting	Federal Decree No. 2661 Non mechanizable harvesting	SP State Law No. 11241 Mechanizable harvesting	SP State Law No. 11241 Non mechanizable harvesting
1998	Start count down	-	-	-
2002	-	-	20%	-
2003	25%	-	-	-
2006	-	-	30%	
2008	50%	-	-	-
2011	-	-	50%	10%
2013	75%	-	-	-
2016	-	-	80%	20%
2018	100%	-	-	-
2021	-	-	100%	30%
2026	-	-	-	50%
2031	-	-	-	100%

Note: Mechanizable harvesting areas are cane fields with slope less than 12% and areas at least 150ha.

A few mills, that operate during the off season (with annex refineries), have already started to recover some of the trash to use as supplementary fuel to bagasse – CTC has provide information and some support in these cases based on the experience gained with Project BRA/96/G31.

In the State of São Paulo it is estimated that there are several mills selling surplus power to the utilities, during the harvesting season, totaling 400 MW. Countrywide there are already several projects totaling 1150 MW either approved or being analyzed by the BNDES (National Bank for Economic and Social Development) for financing. The total installed power capacity in the Brazilian mills is estimated in 1600 MW with 1100 for own consumption and 500 MW for sale.

Independent foreign studies have indicated that Brazil has the sugar lowest cost in the world and there is a growing interest in other sugar producing countries (India, Australia, Thailand, Guatemala, Colombia, Mexico, Cuba and others) to start producing ethanol fuel, that will convert ethanol in an international commodity. These two facts will assure a bright future for the sugar cane industry in Brazil.

Project objectives

Considering the existing context the Project BRA/96/G31 has been conceived with the objective to investigate the possibility of promoting a significant reduction in atmospheric CO_2 accumulation, performing tests, studies and developing technologies to fill gaps to create enough information to evaluate the use of advanced power generating technology – the BIG-GT, integrated with sugar/ethanol mills.

The motivation behind this concept is to evaluate the use of a technology that will allow the generation of an amount of electric power, per ton of cane milled, much higher than with the conventional technology – high pressure boiler/condensing – extraction steam turbine (CEST); also, it can become and incentive to stop burning the cane in the pre-harvest and to recover cane trash to be used as supplementary fuel to bagasse. These two conditions will increase significantly the potential to displace fossil fuels in power generation, thus avoiding the associated CO_2 emissions.

The project work plan to achieve this main objective has been based in the following Immediate Objectives and related activities.

Evaluation of sugar cane trash availability and quality:

- Potential biomass of the sugar cane plant;
- Potential trash biomass of the sugar cane plantation, including recovery factors;
- Characterization of sugar cane trash and bagasse;
- Benefits/problems of trash left in the field;
- Selection and field test of high biomass producing cane.

Evaluation of agronomic routes to unburned cane harvesting with trash recovery:

- Development and test of Copersucar 2-row whole cane harvester;
- Development and test of a sugar cane dry cleaning station;
- Trash recovery;
- Selection of process/equipment for trash recovery;
- Selection or development of trash processing equipment;
- Trash recovery costs.

Bagasse and trash atmospheric fluidized bed gasification tests:

- Trash sample preparation;
- Gasification test runs (laboratory, bench scale and pilot plant);
- Test evaluation reports.

Integration of BIG-GT system with a typical mill:

- Typical mill selection;
- BIG-GT data for the integration (process and preliminary basic engineering);
- Bagasse/trash dryer design;
- Detailed engineering of the integration;
- Investment, operating and energy costs.

Identification and evaluation of environmental impacts:

- Impacts on the atmosphere;
- Impacts on the soil;
- Impacts on terrestrial – biological environment;
- Impacts on jobs;
- Impact analysis and mitigation measures.

Project information dissemination:

- Project newsletters;
- Workshop.

This project work plan has been closely followed except for some additional work that has been done, with the prior approval of MCT/UNDP and within the original budget, aiming to optimization of trash recovery routes, improvements in the cane dry cleaning station, execution of four more gasification pilot plant tests, additional investigation on trash blanket herbicide effect and high biomass cane varieties. This additional work had also financial support of the European Commission and the Swedish National Energy Agency.

1. Potential trash biomass of the sugar cane plant

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1.1. Introduction

Until the end of the 80's, the only concern of sugar cane growers was the amount of cane stalks produced in the field. Most of the harvesting was done by hand, and some mills were starting to test and use chopped cane harvesters as a mean to reduce cost and labor dependency. At that time, all the harvesting was done after burning of the sugar cane field. Burning, a common practice on those days, had the purpose of eliminating the trash and animal and insects hazards, achieving good manual and mechanized harvesting rates.

In the beginning of the 90's, with the concern of soil conservation, Centro de Tecnologia Copersucar (Copersucar Technology Center – CTC) started to test harvesting sugar cane without burning, and leaving the trash in the field. Today, with environmental laws and new harvesters designed for this job, unburned cane harvesting is becoming a reality. First, sugar cane producers noticed only the bad effects of trash, such as the increase of vegetal impurities in the harvested cane and the reduction in harvester capacity. Only recently, that the new harvesters overcame these problems, they have began to notice that the trash can play an important role in soil agronomic and as an energy resource. Thus, there is an increasing interest in finding out reliable data about trash quantities left in the field.

To increase the role of biomass for electric power production to significant levels it will be necessary to have either (or both) high efficiency low capacity (15 – 50 MWe) cycles or very low cost, and abundant sources of biomass. This points to BIG-GT systems, and the use of energy plantations or agricultural residues besides the bagasse as fuel. The first activities of the project had been directed, thus, to the assessment of cane biomass (trash) quantity and quality in the sugar cane field prior and after the harvesting activities.

Fernandes & Oliveira (1977), published data from 15 reports on the ratio between the amount of trash left in the field and sugar cane yield (**Table 1**), showing a large variation among them.

Table 1:

Ratio between sugar cane residues and stalk yield (bibliography data).

Author	% Residues	Local
Niestrath	20	Louisiana, USA
Daubert	10	Louisiana, USA
Stewart	10.6	Louisiana, USA
Le Blanc	5.2-7.4	Louisiana, USA
Keller	15.43	Louisiana, USA
Lopez Hernandez	10	Tucuman, Argentina
Payne & Rhodes	35	Hawaii
Mayoral & Vargas	7.0-9.4	Puerto Rico
Betancourt	4.2	Cuba
Deacon	5	Trinidad
Clayton & Whittemore	13	Florida, USA
Fanjul	7.5	Louisiana, USA
Azzi	2.0-4.5	São Paulo, Brazil
Humbert	9-12	Mexico
Castro & Balderi	10.9	Florida, USA

Source: Fernandes & Oliveira (1977)

De Beer et al. (1996) report that the amount of green leaves, dry leaves and tops, with respect to the total amount of sugar cane stalks varies from 10 to 60% in Colombia and from 20 to 35% in South Africa. According to these authors, green leaves, dry leaves and tops left unburned in the field have average moisture content around 50%. This moisture content falls to 30% in 2 to 3 days and to 15% in two weeks, showing large moisture content variations according to the period the trash stayed in the field.

Zulauf et al. (1985a) report figures found in Cuba, with a total mass of 144 t, 28 t for the tops and 16 t of green and dry leaves, equivalent to 19.4% and 11.1%, respectively.

According to Kadam & Jadhav (1996), in India it is estimated an amount of about 10 t/ha of harvesting residues.

Rozeff (1994) reports 39 t residues/ha for a yield of stalks of 81.49 t/ha as a typical unburned cane harvesting production for the Rio Grande Valley region, Texas.

Table 2 presents some bibliography results found regarding residues per variety. Large variations in trash availability can be observed, even when comparing data from the same cane variety.

Table 2

Dry residues estimate per sugar cane variety.

Source	Variety	Residues (t/ha)*	Cane yield (t/ha)	Residue/ stalk ratio (%)
Rípoli et al. (1991)	NA56-79	13.3	72.5	18.4
Trivelin et al. (1996)	SP70-1143	11.7	70.0	16.7
Rípoli et al. (1991)	SP70-1143	11.0	88.3	12.4
Rípoli et al. (1991)	SP70-1284	7.4	77.2	9.7
Rípoli et al. (1996)	RB72454	19.0	83.1	22.9
Rípoli et al. (1991)	SP71-1406	14.4	75.6	19.1
Furlani Neto et al. (1997)	SP71-1406	13.5	68.6	19.7
Molina Jr. et al. (1991)	SP71-6163	14.2	79.5	17.8
Rípoli et al. (1991)	SP71-6163	11.7	74.9	15.6
Furlani Neto et al. (1997)	SP71-6163	24.3	82.5	29.5
Average (standard deviation)		14.1 (4.4)	77.2 (5.9)	18.2 (5.2)

* Dry basis

» Objective

The amount of residues from sugar cane harvesting depends on many factors such as: harvesting system (burnt or unburned cane), topping height, cane variety, age of crop (stage of cut), climate, soil and others. Therefore, with the purpose of excluding the effect of harvesting conditions on the biomass residue estimate, an experiment was carried out to determine the amount of trash (dry leaves, green leaves and tops) available in sugar cane field before harvesting. This information is usually not available in the bibliography. The amount of trash left in the field would be a function of the amount of trash available in the field prior to sugar cane harvesting and of the harvesting process itself.

1.2. Methodology

For the evaluation of the amount of trash (dry leaves, green leaves and tops) available in sugar cane field before harvesting, a methodology was established. In a sugar cane field 10 plots were sampled. Each plot was formed by three rows of cane wide and 10 meters long (**Figure1**).

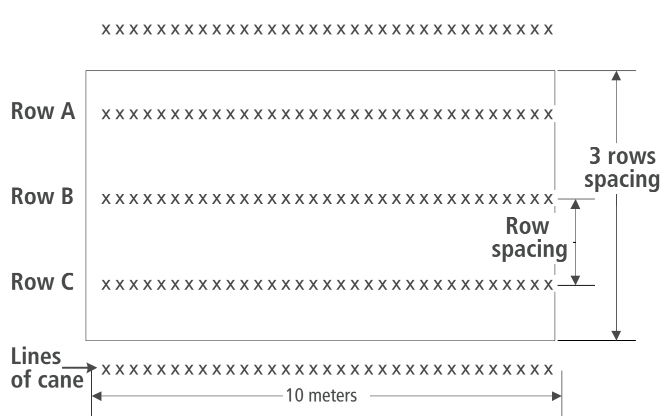
For each row of cane (A, B, C) the total number of stalks per 10 meters was counted and the weight of dry leaves, green leaves, tops and stalks for 20 canes determined. The 20 canes were taken in sequence from any place of each row, without any selection. At this point, some definitions as indicated in **Figure 2** should be made:

a) Dry leaves - Leaves that have already dried; they are usually brown;

b) Green leaves - All the leaves that are green or yellow;

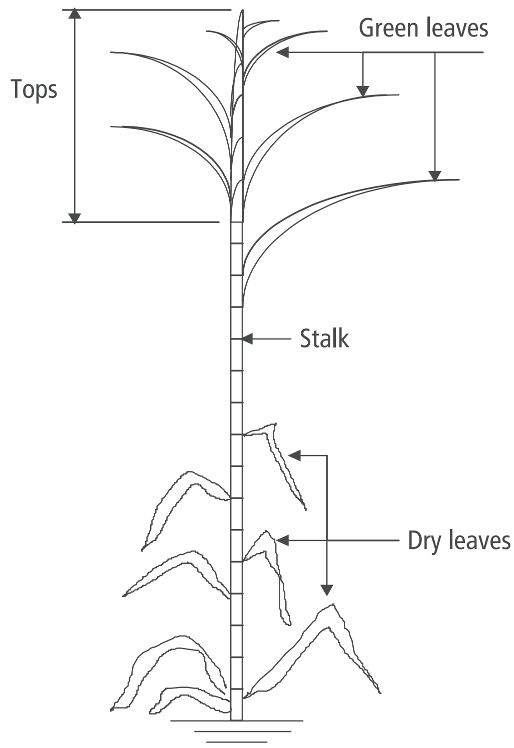
c) Top - Piece of cane plant between the top end and the last stalk node.

Figure 1



Plot description.

Figure 2



Cane plant parts.

Moisture content of dry leaves, green leaves and tops should be measured according to ASAE S358.2 DEC93. For this purpose, samples of dry leaves, green leaves and tops, for each plot, should be collected in plastic bags and very well sealed to avoid loss of water. **Appendix 1** shows an example of a field data collection form.

The determination of the estimated trash potential (ETP) was performed by the formula:

ETP = { [WDL * (1- DLMC / 100) + WGL * (1 - GLMC / 100) + WT * (1 - TMC / 100)] * (ANC / 20) * 10000 } / (10 * RS * 1000)

Where:

ETP = Estimated Trash Potential (t/ha)
WDL = Average weight of dry leaves for 20 stalks in the 10 plots (kg)
DLMC = Average dry leaves moisture content (%) in the 10 plots
WGL = Average weight of green leaves for 20 stalks in the 10 plots (kg)
GLMC = Average green leaves moisture content in the 10 plots (%)
WT = Average weight of tops for 20 stalks in the 10 plots (kg)
TMC = Average tops moisture content in the 10 plots (%)
ANC = Average number of canes in 10 meters in the 10 plots
RS = Row spacing (m)

The methodology described here is not unique. Other methods have been tried by Copersucar (CTC) and other sugar cane research groups. Nevertheless, this methodology has been used for some years and it combines reliable data with easily executed experiments. In terms of effort, it is not too demanding. A technician and a group of four men can handle the ten plots of a field experiment in one day.

Trying to cover majority of factors affecting the amount of trash found in the field, the experiment for determination of trash potential in the field prior to harvesting was performed using three sugar cane varieties (SP79-1011, SP80-1842 and RB72454), in two different regions (Ribeirão Preto and Piracicaba in São Paulo State) and in three stages of cut: 18 months plant cane, 2^{nd} ratoon and 4^{th} ratoon (**Table 3**).

The chosen varieties were the most representative Brazilian varieties at the time of the experiment, each one planted in adequate environment (soil, climate) with experiments always placed in areas of mechanized unburned cane harvesting. The samples were collected in the best harvesting period for each variety (higher sugar content).

Each line of Table 3 refers to two experiments for the determination of the trash available in the field (before harvesting) for a given variety and stage of cut considering two different regions, in the indicated mills. Each 10 plot experiment (for a given mill) was surveyed by four workers and a technician in a 12 hour job, and an extra trip to the mill and preparation time for the technician. A total of 18 experiments were carried out during 97/98 and 98/99 seasons, with 180 plots surveyed.

Table 3:

Varieties, stage of cut and location (region and mill) of the experiments.

Variety	Cut	Region 1	Sugar mill	Region 2	Sugar mill
SP79-1011	Plant cane	Ribeirão Preto	Santa Luiza	Piracicaba	São João
	2^{nd} ratoon		Santa Luiza		São João
	4^{th} ratoon		Santa Luiza		Iracema
RB72454	Plant cane	Ribeirão Preto	Santa Cruz OP	Piracicaba	Rafard
	2^{nd} ratoon		Santa Cruz OP		São João
	4^{th} ratoon		Santa Cruz OP		São João
SP80-1842	Plant cane	Ribeirão Preto	São Martinho	Piracicaba	Cresciumal
	2^{nd} ratoon		Santa Luiza		Cresciumal
	4^{th} ratoon		Santa Luiza		Cresciumal

* Dry matter

1.3. Results and discussion

A summary of the results for the tests conducted during the 97/98 and 98/99 seasons is shown in **Table 4**. Each line of this table is an average of the results obtained for the two regions, and the figure obtained for each region is an average of 10 plots.

Table 4

Estimate of sugar cane biomass availability - trash (dry basis), in the form of dry leaves, green leaves and tops, average of Ribeirão Preto and Piracicaba Regions, for 18 months plant cane, 2nd ratoon and 4th ratoon.

Variety	Stage of cut	Yield (t/ha)	Trash* (t/ha)	Trash/stalk ratio
SP79-1011	Plant cane	120	17.8	15%
	2nd ratoon	92	15.0	16%
	4th ratoon	84	13.7	16%
SP80-1842	Plant cane	136	14.6	11%
	2nd ratoon	101	12.6	13%
	4th ratoon	92	10.5	11%
RB72454	Plant cane	134	17.2	13%
	2nd ratoon	100	14.9	15%
	4th ratoon	78	13.6	17%
Average		104	14.4	14%

* Dry matter

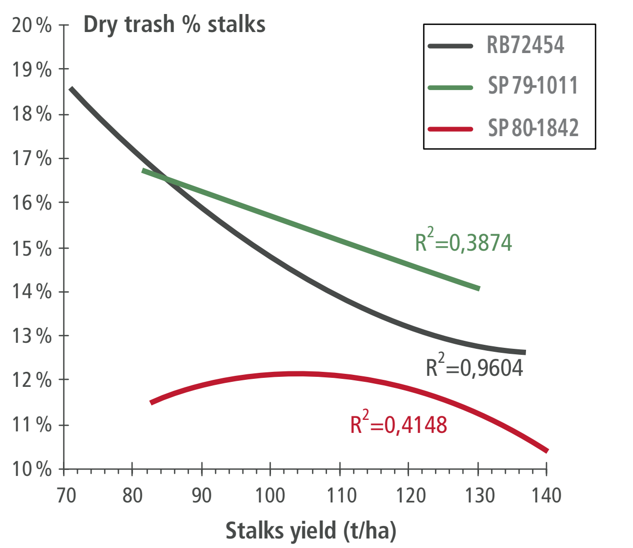
The potential of cane residues (dry mater - DM) is around 14% of the stalk mass. This means that for each ton of stalks, there are 140 kg of dry residues. A significant difference can be observed between the 14% value for the Trash/Stalk Ratio determined in the experiment and the average value of 18.2% found in the summarized bibliography (**Table 2**). This can be explained mainly by methodology differences and experiments not taking into account the effect of moisture content and stage of cut. Besides that, the varieties considered are different. All these factors affect the trash/stalk ratio.

Despite the large number of varieties cultivated today in Brazil, the varieties tested are quite representative of those cultivated in the 98/99 season. At that time, these varieties composed 35% of the harvested sugar cane area in Brazil, 40% in the CenterSouth region, 21% in the NorthNortheast and 40% in the State of São Paulo. The stages of cut considered (plant cane, 2nd and 4th ratoon) sample the field in different periods of its life cycle, with an average cane cycle of five cuts before replanting. Therefore, it is reasonable to accept 140 kg dry matter/t cane as the number to be used as an average for the amount of residues from different producing areas.

Figure 3 presents the curves (quadratic regression) of the sugar cane stalks yield versus the ratio weight of trash (dry matter)/ weight of stalks, for the three varieties tested (no distinction made between region and stage of cut). It can be observed that for the RB72454 variety, the ratio trash/stalks diminished with the increase in cane stalks yield, with a good correlation coefficient. The other two curves, for varieties SP79-1011 and SP80-1842, showed a very low correlation coefficient.

The low coefficient of correlation inhibit the use of equations to estimate the potential of trash production as a function of sugar cane yield.

Figure 3



Regression curves for the ratio [trash (dry matter)/stalks] versus stalks yield, for the varieties RB72454, SP79-1011 and SP80-1842.

1.4. Conclusions

The frequent introduction of new sugar cane varieties, with an unknown trash yield, and the difficulties in correlating sugar cane stalks yield with trash yield, lead us to adopt the average value of 140 kg dry matter per tone of cane to estimate the potential dry biomass residues for the main sugar cane producing regions of the country (**Table 5**).

Table 5:

Estimate of the potential dry biomass of sugar cane residues in Brazil.

Region	Crushed cane (million t)	Dry residues potential (million t)
State of São Paulo	181.5	25.4
Center South	249.7	35.0
North - Northeast	51.9	7.2
Brazil	301.6	42.2

* The Center South includes the State of São Paulo.

1.5. Comments

The potential of sugar cane residues determined here is an estimate of the amount of trash in the field, prior to the harvesting operation. The real availability of residues, that is, the effective amount of trash that will reach the mill and become a biomass fuel, depends on the percentage of area of unburned sugar cane harvesting and the efficiency of the trash recovery system. This recovery efficiency will be determined during the studies of the different harvesting alternatives with trash collection (harvesting routes). After that, the real availability of residues can be determined.

It is important to remember that whatever is the form of trash separation from the cane, a certain amount of vegetal impurity (trash) will still remain with the cane and it will be crushed with the cane at the mill. This vegetal impurity will be considered in the industrial process as it influences the amount of bagasse produced.

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2.1. Introduction

The characterization of the sugar cane trash used as fuel for gasifiers or conventional bagasse fired boilers consists of a series of established analyses according to ASTM known as: Proximate Analysis, Ultimate Analysis, Ultimate Mineral Analysis and Heating Value.

Lack of technical data to characterize sugar cane trash components was the main motivation for these tests, trying to gather information and knowledge of its potential as fuel.

The sugar cane trash was divided in three components: green leaves, dry leaves and tops, since these material have very different characteristics for moisture, alkali concentration and other relevant components. All these material have a similar basic composition – cellulose, hemicellulose and lignin.

The influence of sugar cane variety, age (stage of cut), and the use of vinasse (slop from distillery) as fertirrigation were considered as variables in the evaluation of the characteristics.

» Objective

Characterization of sugar cane trash by application of standard analysis, using samples that reflect a common situation of sugar cane plantations at São Paulo State, Brazil. Figures for bagasse analysis, previously determined by the Copersucar Technology Center (CTC), are presented with trash figures for comparisons.

2.2. Methodology

Three varieties of sugar cane with and without vinasse application and at three different ages were chosen (**Table 3**). A total of 54 samples (3 varieties x 3 ages x 2 vinasse or not x 3 components) were collected in associated mills during the potential trash determination in the sugar cane field prior to harvesting (see Chapter "Potential trash biomass of the sugar cane plant"). They were weighed and dried at 65ºC for 72 hours to constant weight, in forced air circulation oven. Dried samples were ground in a Willy type mill and screened through a 20 mesh sieve (0.84 mm) to obtain a uniform material.

Proximate Analysis was applied to determine the moisture content, volatile material, ash and fixed carbon content, and it has the purpose to quantify the proportion of combustible or non combustible components in the sample.

The analyses were based on the following ASTM Standards:

- D 3172 - Fixed carbon;
- D 3173 - Moisture;
- D 3174 - Ash;
- D 3175 - Volatile material.

Some modifications were done in the above methods to adapt them to the sugar cane material, since they were developed for mineral coal. These modifications did not interfere with the quality of the results.

The Ultimate Analysis determined the fractions by weight of the composition in carbon, hydrogen, nitrogen, oxygen, sulfur and chlorine and was based on ASTM D 3176-3179 and 4280 procedures.

The Ultimate Mineral Analysis, based on ASTM D 3682/D 2795, determined the fractions by weight of the material composition in phosphorus, potassium, calcium, magnesium, iron, aluminum, copper, zinc, manganese and sodium oxides.

The determination of the Higher Heating Value (total amount of heat generated when the material is burned) was based on ASTM D-2015.

All the methods were modifications of ASTM methods for mineral coal.

2.3. Results and discussion

The Ultimate Analysis Group determinations were made by Instituto Nacional de Tecnologia - Ministério de Ciência e Tecnologia, and all the other determinations were made by Copersucar Technology Center (Centro de Tecnologia Copersucar - CTC).

The great difference observed in the composition of the materials was the moisture content (**Table 6**). The samples of trash components presented practically the same composition in ashes (~4%), fixed carbon (~15%), and volatile material (~80%) expressed as dry basis. These figures are quite close to what was obtained with the bagasse, except for ash that was lower in the bagasse.

Table 6

Average results obtained for dry leaves, green leaves, tops and bagasse from the Proximate Analysis.

Determination % weight*	Dry leaves	Green leaves	Tops	Bagasse
Moisture content	13.5	67.7	82.3	50.2
Ash	3.9	3.7	4.3	2.2
Fixed carbon	11.6	15.7	16.4	18.0
Volatile matter	84.5	80.6	79.3	79.9

* Dry basis

All material presented practically the same composition in carbon (~45%), hydrogen (~6%), nitrogen (0.5 - 1%), oxygen (~43%), sulfur (~0.1%). The chlorine figures vary considerably with the lowest figure for bagasse (**Table 7**).

Table 7

Average results from Ultimate Analysis (ASTM D3176-3179/4280) for dry leaves, green leaves, tops and bagasse.

Determination*	Dry leaves	Green leaves	Tops	Bagasse
Carbon	46.2	45.7	43.9	44.6
Hydrogen	6.2	6.2	6.1	5.8
Nitrogen	0.5	1.0	0.8	0.6
Oxygen	43.0	42.8	44.0	44.5
Sulfur	0.1	0.1	0.1	0.1
Chlorine	0.1	0.4	0.7	0.02

* Dry basis

The average results for the content of phosphorus, potassium, calcium, magnesium, iron, aluminum, copper, zinc, manganese and sodium oxides (Ultimate Mineral Analysis) are presented in **Table 8**.

Table 8

Average phosphorus, potassium, calcium, magnesium, iron, aluminum, copper, zinc, manganese and sodium oxide (ASTM D 3682/D 2795) in dry leaves, green leaves, tops and bagasse.

Determination	Dry leaves	Green leaves	Tops	Bagasse
		Content (g/kg)*		
P_2O_5	0.5	2.0	2.5	0.5
K_2O	2.7	13.3	29.5	1.7
CaO	4.7	3.9	2.6	0.7
MgO	2.1	2.2	2.5	0.5
Fe_2O_3	0.9	0.5	0.2	2.3
Al_2O_3	3.5	1.4	0.5	2.3
		Content (mg/kg)*		
CuO	< 0.06	< 0.06	< 0.06	-
ZnO	9	15	35	-
MnO_2	169	120	155	62
Na_2O	123	128	119	45

* Dry basis

The average results obtained for the Higher Heating Value for the dry materials are presented in **Table 9**.

2.4. Conclusions and comments

The results obtained allow some important observations:

- There is a large variation in the moisture content of the sugar cane material from 13.5% in dry leaves up to 82.3% in the tops.
- The values of ash, fixed carbon and volatile matter have little variation among the three components of the trash, with a lower amount of ash for the bagasse.
- The Higher Heating Value does not vary much among the three components of the trash and the bagasse, when expressed as dry weight.
- The Proximate Analysis and Higher Heating Value results are not influenced significantly by the sugar cane variety and age (ratoon).
- Mineral composition for alkalis and phosphorus show some variation among the three components of the sugar cane trash, indicating that its content grows from the dry leaves to the tops, and are quite higher than for the bagasse.
- Slight tendency is observed on mineral content with variety and age.

Table 9

Average Higher Heating Value (ASTM D 2015) for dry leaves, green leaves, tops and bagasse.

Sample	Higher Heating Value MJ/kg*
Dry leaves	17.4
Green leaves	17.4
Tops	16.4
Bagasse	18.1

* Dry basis

3. Benefits and problems of trash left in the field

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3.1. Introduction

The unburned sugar cane harvesting system is being increasingly adopted in most regions of southeast Brazil. Its most noticeable characteristic is the large amount of residues (dry leaves, green leaves and tops) left in the field after unburned harvesting. The agronomic effects of the trash left in unburned sugar cane fields harvested mechanically should be taken into account since its removal is being considered.

Figure 4

Accidental fire in a sugar cane field, 90 days after harvesting.

Figure 5

Occurrence of gaps (discontinuity of sprouts in the line of cane) in an experiment with SP84-1201 variety, 39 days after unburned sugar cane harvest, with trash blanket conservation on the ground.

Several benefits of leaving the trash in the field (trash blanketing) have been observed and are under study, such as:

- Protection of the soil surface against erosion caused by rain and wind;
- Reduced soil temperature variations because the soil is protected from direct action of solar radiation;
- Increased biological activity in the soil;
- Increased water infiltration into the soil;
- More water available due to the reduction in water evaporation from the soil surface;
- Weed control, with the result that the use of herbicides can be reduced or even eliminated, thus reducing costs, the risk of human poisoning, and contamination of the environment.

Leaving the trash in the field has also some drawbacks. Problems associated with the maintenance of a trash blanket are being considered, such as:

- Fire hazards during and after harvesting (**Figure 4**);
- Difficulties in carrying out mechanical cultivation, ratoon fertilization and selective control of weeds through the trash blanket;
- Delayed ratooning and the occurrence of gaps (discontinuity of sprouts in the line of cane), causing a reduction in cane yield when temperatures are low and/or the soil is very wet after harvesting (**Figure 5**);
- An increase in population of pests that shelter and multiply under the trash blanket.

» Objective

To study the effect of the trash left in the field, defining conditions to remove or not the trash from the field.

Define the minimum amount of vegetal residues that should be left in the field surface to control weeds without using herbicides, in areas of unburned cane mechanically harvested.

3.2. Methodology

The study of the effect of the trash left on the field, defining conditions to remove or not the trash from the field was based on field observations in sugar cane commercial producing areas and also from several experiments, with different purposes, carried out by Copersucar Technology Center.

In order to define the minimum amount of vegetal residues that should be left on the field surface to control weeds without using herbicides, field experiments were carried out in areas of unburned cane mechanically harvested. For these experiments, sugar cane yield, pol % cane and tons of pol per hectare were determined.

Experiments were carried out at three sugar mills: Usina Da Pedra (Serrana-SP), Usina São Francisco (Sertãozinho-SP) and Usina São Martinho (Pradópolis-SP), with different initial levels of weed infestation, classified as high, medium and low respectively (**Table 10**).

Table 10

Description of the initial condition of the areas for the experiments to determine the effect of trash blanket on weed suppression and sugar cane yield.

Mill	**Usina da Pedra**	**Usina São Francisco**	**Usina São Martinho**
Farm	Santa Patrízia	Água Branca	Aparecida
Variety	RB785148	SP79-1011	SP80-185
Infestation level	Medium to High	Low	High

The effect of different amounts of trash on the population of weeds was assessed during a period of three consecutive years, using three different amounts of trash: 100% (T1), 66% (T2) and 33% (T3) of the original total amount of trash left after unburned cane harvesting. A control area (T4), from which all the trash was removed, was also included. Purple-nut-sedge (*Cyperus rotundus*) was not considered in the trash weed suppression analyses since it is not totally controlled by the trash.

The methodology used to set up the experiments with 100%, 66%, 33% and 0% of trash left on the field was developed to avoid the problem of trash moisture content determination and its variation during the tests.

If the different treatments of the experiment were set up, with the amount of trash to be left in the different plots determined by weight (t/ha of trash-dry matter), the weight of trash to be kept in the parcels of every treatment should be calculated after trash moisture content determination. But, in the meantime between collecting a sample and analyzing its moisture content, the moisture content of the trash exposed to sunlight would have changed and a wrong weight of trash would be put in the parcels. Even during the process of weighing the trash for the different parcels, the moisture content would be changing, since the process of setting the experiment takes all day. That is why this procedure is not recommended for this experiment.

To avoid this problem, a different procedure was developed. First, the total amount of trash left in the field is determined according to specific methodology, where for different plots the trash is weighed and a sample of the material collected for moisture content determination. With this value for several plots it is possible to estimate the amount of dry material per hectare (t/ha). Then, to leave only a certain percentage of the initial trash in the parcel, it is necessary to keep trash only on that percentage of area, and remove all the trash from the rest of the parcel and then spread uniformly the remaining trash on the total area of the parcel. To know how much trash per hectare that represents, one should multiply the total trash amount determined initially by the given percentage.

During the set up of the experiments, the parcels were divided in three equal areas, removing the trash from one area (treatment T2) or from two areas (treatment T3) and distributing the rest of the trash uniformly on the total area of the parcel (**Appendix 2**). Doing this way, each parcel of the treatment T2 will have 2/3 (66%) of the total trash and the parcels of treatment T3 will have 1/3 (33%) of the total amount of trash left in the field by the harvester. All the trash from the parcels of treatment T1 (100%) will be left in the field while for the parcels of treatment T4 (no trash), all the trash will be removed. The different treatments of the experiments were set up between 15 and 30 days after harvesting.

The determination of weed population in the parcels was carried out usually from 6 to 7 months after the experiment set up, identifying the different species and counting for each one the number of plants, as the example in **Appendix 3**. The weeds present in each experiment were not chemically suppressed after the weed population determination to keep determining the infestation level in the next years.

In the areas where the experiment was set up, the cane from each parcel was weighed and sampled during harvesting, with the purpose of determining the effect of different amounts of trash on cane yield and quality. The experiments were then set up again, over the same parcels after the first and second harvesting.

The described experiment lasted for three years (97/98, 98/99 and 99/00 crops) as planned. After this period, an extension of the project continued during the 00/01, 01/02 and 02/03 crops, to verify what would be the effect on weed population leaving only 50% of the initial trash on the soil.

The adopted procedure was similar to the experiment already being carried out, with the difference that for the diagram of **Appendix 2** only three treatments were applied (100%, 50% and 0% trash). For the parcels with 50% trash, half of the area of the parcel had the trash removed and the remaining trash distributed in the area of that parcel.

During this period, the experiment with 100%, 66%, 33% and 0% trash continued, with one of the experiments in the same area (the experiment at Usina São Martinho), while the other two (at Usina Da Pedra and Usina São Francisco) where set in a different area from the original experiment.

The control efficiency (%) by the trash effect in annual species, excluding nut-sedge (Cyperus), is defined as:

TWCE = 100 * [1 - (Number plants in the related treatment / Number plants in the control T4)]

TWCE = Trash Weed Control Efficiency (%)

The density of weed plants is represented by the total number of annual plants divided by the total area of the parcels of each treatment.

3.3. Results and discussions

In weed and herbicides studies, it is considered to be efficient a treatment that shows levels of weed control higher than 90%. It is important to mention that a considerable number of the chemical treatments for weed control, applied in sugar cane mills, have a control efficiency lower than 90%, due to factors associated with this practice such as errors in product specification and preparation, errors in application and equipment adjustment, wind occurrence during application, rain after application and inadequate ambient air temperature and humidity.

As for the "trash weed control efficiency", only treatment with 100% trash (T1) reached values above 90% in the first year (**Table 11**). In the second year, not only this treatment but also 66% trash (T2) exceeded this limit, due to an increase in the quantity of plants in the control treatment (T4).

Table 11:

Amount of trash, weed population density (excluding nut-sedge, *Cyperus rotundus*) and trash weed control efficiency, considering 100% (T1), 66% (T2), 33% (T3) and 0% (T4) trash in each treatment.

Crop	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3
		Trash (t/ha)*				Density (plants/m²)				TWEC (%)**	
Usina Da Pedra											
98/99	16.8	11.2	5.6	0.0	0.01	0.11	0.18	0.25	97	56	27
99/00	11.4	7.6	3.8	0.0	0.20	0.35	1.15	9.68	98	96	88
01/02(1)	14.9	9.9	5.0	0.0	0.01	0.01	0.03	0.04	86	64	21
Usina São Francisco											
97/98	13.6	9.0	4.5	0.0	0.04	0.13	0.34	0.39	88	64	4
98/99	11.8	7.8	3.9	0.0	0.02	0.19	0.55	0.95	98	80	42
99/00	13.4	8.9	4.5	0.0	0.04	0.19	0.71	2.06	98	91	66
00/01(1)	11.6	7.8	3.9	0.0	0.05	0.44	1.80	1.89	97	77	5
Usina São Martinho											
97/98	15.7	10.4	5.2	0.0	0.07	0.16	0.52	0.21	69	25	0
98/99	12.8	8.6	4.3	0.0	0.06	0.38	0.84	2.80	98	87	70
99/00	11.3	7.5	3.8	0.0	0.52	0.67	1.87	8.72	94	92	79
00/01	14.5	9.6	4.8	0.0	0.78	0.57	3.77	11.50	93	95	67
01/02	14.8	9.9	4.9	0.0	0.55	0.69	3.01	11.70	95	94	74
02/03	11.4	7.6	3.8	0.0	1.40	3.50	9.60	15.70	91	78	39

(1) At different location

* Dry matter basis

** Trash weed control efficiency (%) in relation to T4 (no trash)

Studies based on these results indicated that it is highly probable to have the herbicide effect with trash quantities above 66% of the total (around 7.5 t/ha, dry basis), controlling annual weeds with efficiencies greater than 90%, when uniformly distributed on the soil.

Figure 6

Different levels of infestation by crabgrass (*Digitaria horizontalis*) in parcels of the experiment at Usina Da Pedra, during the 98/99 crop.

A: Treatment T1, with trash left in the field after harvesting, showing low infestation of weeds

B: Treatment T3 (33% of the harvesting trash left in the field) and a medium to high infestation level by crabgrass (*Digitaria horizontalis*)

C: Control (Treatment T4), from which all the trash was removed, showing high infestation of crabgrass (*Digitaria horizontalis*).

Some species of perennial weeds are not normally suppressed by the trash left in the field after unburned cane harvesting, such as purple-nut-sedge (*Cyperus rotundus*). However, most of these plants were always affected in higher or lower degree by the presence of trash on the soil (**Figure 6**).

The continuity of the experiment at Usina São Martinho, during six crops of unburned harvesting for the experiment with 100% (T1), 66% (T2), 33% (T3) and 0% (T4) trash in each treatment, made it possible to follow the evolution of weed population under the effect of trash control (**Figure 7**). The observation of such evolution for other areas with different types of soil, weed species, cane varieties and climate, would be important. Unfortunately, the other experiments were not continued for the whole period of six crops. The evolution of weed population in terms of plants per m^2 was slower in the treatments with more trash (T1 and T2).

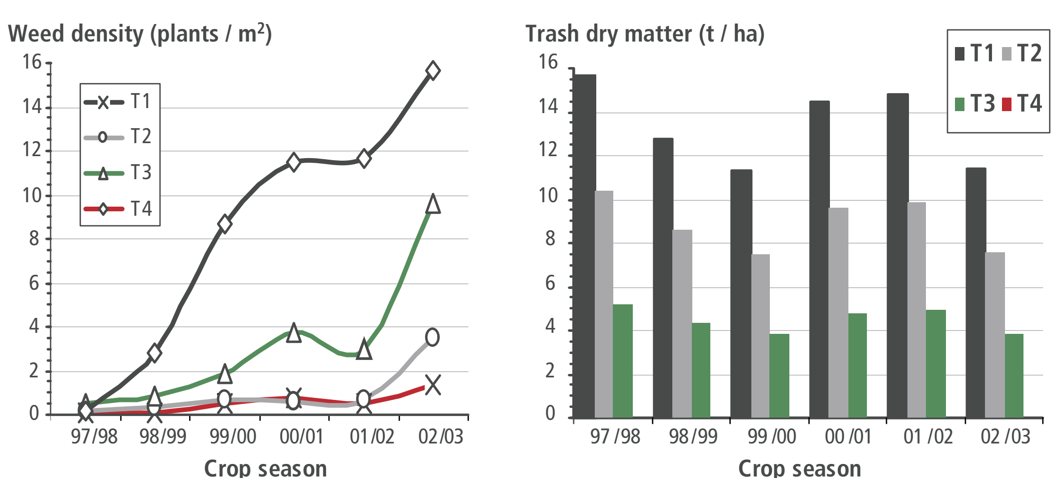
Assuming as a reference the density of plants/m^2 at the beginning of the experiment as treatment T4 (0.21 plants/m^2 in the first survey), the infestation level increased 75 times (from 0.21 to 15.7 plants per m^2) for treatment T4 (without trash on the soil), 45 times for treatment T3, 17 times for treatment T2 and seven times for treatment T1 (with all the trash on the soil), during the period of six crops.

The population of annual cycle weeds in treatments T1 and T2 (1.4 and 3.5 plants/m^2, respectively) was similar or even lower to what is found after six crops in areas without trash using herbicide for weed control.

Table 12 summarizes the sugar cane yield and quality (pol of cane and tons of pol per hectare) data from the experiment with different amounts of trash on the soil, considering 100%, 66%, 33% and 0%, for the 97/98, 98/99, 99/00, 00/01, 01/02 and 02/03 crops.

From these results, a reduction in sugar cane yield can be observed as the amount of trash increases in the field. Reduction in pol per hectare can also be verified (**Figure 8**, **Figure 9** and **Figure 10**), except for Usina São Francisco.

Figure 7



Evolution of the annual cycle weed population species (points and lines) during a six crop period in the presence of different quantities of trash (100% [T1], 66% [T2], 33% [T3] and 0% [T4]) on the soil (bars), in the experiment at Usina São Martinho.

Figure 8

Correlation of the average values for three crops (97/98, 98/99 and 99/00) between cane yield (TCH – tons of cane per hectare), pol of cane and TPH (tons of pol per hectare) with trash (%) for the experiment with 100% (T1), 66% (T2), 33% (T3) and 0% (T4) trash in each treatment at Usina São Francisco.

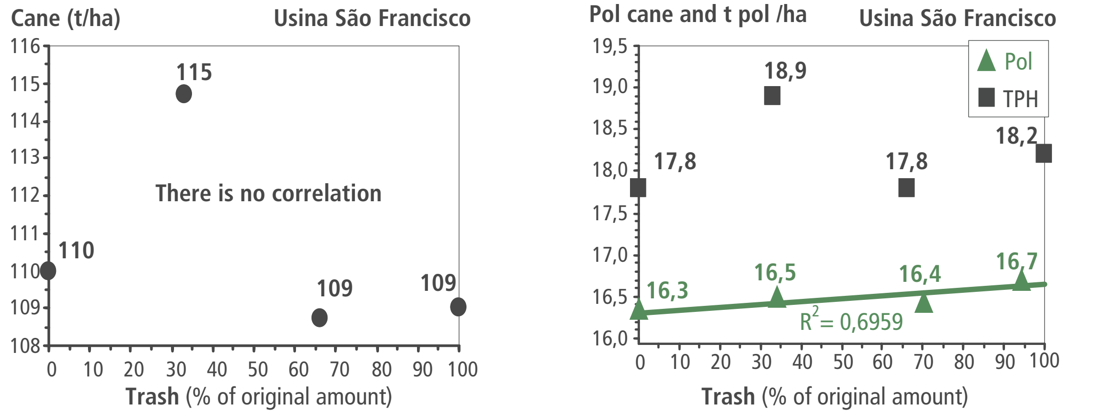


Figure 9

Correlation of the average values for three crops (97/98, 98/99 and 99/00) between cane yield (TCH – tons of cane per hectare), pol of cane and TPH (tons of pol per hectare) with trash (%) for the experiment with 100% (T1), 66% (T2), 33% (T3) and 0% (T4) trash in each treatment at Usina São Martinho.

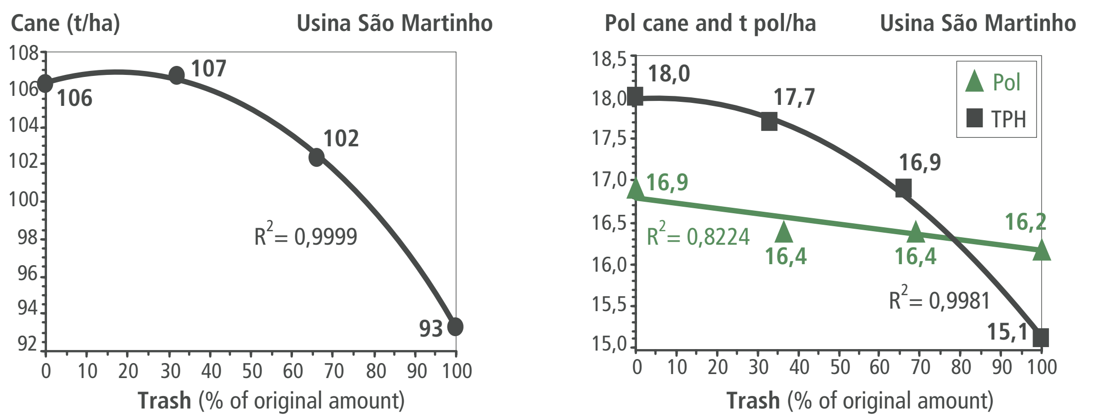


Figure 10

Correlation of the average values for two crops (98/99 and 99/00) between cane yield (TCH – tons of cane per hectare), pol of cane and TPH (tons of pol per hectare) with trash (%) for the experiment with 100% (T1), 66% (T2), 33% (T3) and 0% (T4) trash in each treatment at Usina Da Pedra.

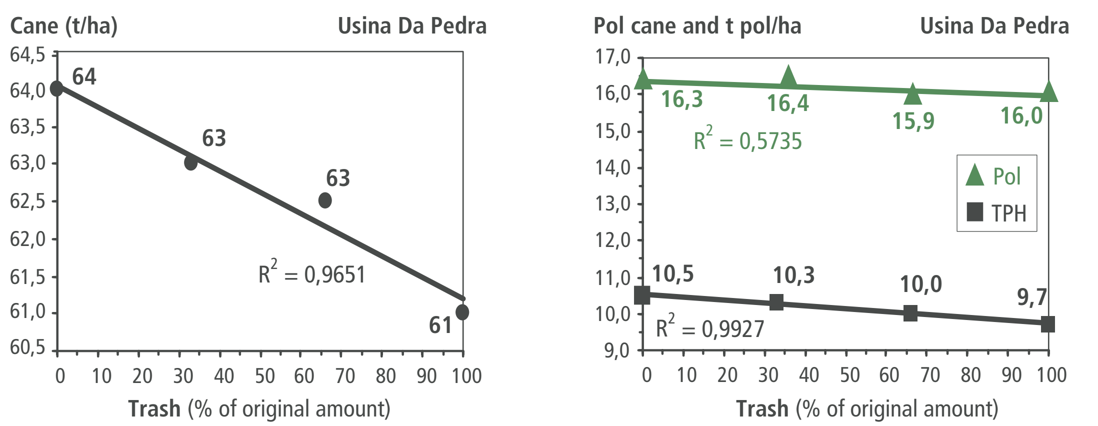


Table 12

Effect of different amounts of trash on cane yield and quality (pol cane and tons of pol per hectare).

Crop season	Cane (t/ha) T1	T2	T3	T4	Pol cane (%) T1	T2	T3	T4	Pol (t/ha) T1	T2	T3	T4
Usina Da Pedra												
98/99	53	59	57	61	16.1	15.3	16.4	16.1	8.5	9.0	9.4	9.8
99/00	69	66	69	67	15.9	16.5	16.3	16.5	10.9	10.9	11.2	11.1
01/02 (1)	61	72	71	81								
Usina São Francisco												
97/98	100	101	109	97	15.9	15.8	16.0	16.1	15.9	16.0	17.4	15.6
98/99	127	125	129	130	16.9	16.7	16.5	15.3	21.5	20.9	21.3	19.9
99/00	100	100	106	103	17.3	16.5	16.9	17.4	17.3	16.5	17.9	18.0
00/01 (1)	66	64	69	67								
Usina São Martinho												
97/98	95	104	104	108	16.0	15.9	15.8	16.9	15.2	16.5	16.5	18.1
98/99	95	112	120	116	17.2	18.0	18.5	18.2	16.4	20.1	22.2	21.1
99/00	90	91	96	95	15.4	15.4	15.0	15.6	13.8	14.0	14.4	14.8
00/01	89	94	92	96	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
01/02	99	90	90	81	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
02/03	53	53	50	47	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a

(1) At different location; n.a= non available information.

For the tests carried out during the 00/01, 01/02 and 02/03 crops (Project extension), with the objective of verifying what would be the effect on weed population leaving only 50% of the initial trash on the soil, the only experiment that lasted for the three crops was one at Usina São Martinho, Aparecida farm (**Table 13**). Due to this, it was not possible to follow the evolution of the experiment during three crops for most of the tests, and it became difficult to make a more accurate analysis. The experiments conducted during the 00/01, 01/02 and 02/03 crops, show that sugar cane yield values were affected in different ways by the different amounts of trash of the treatments. Experiments with an increase, others with a decrease and some with no effect in sugar cane yield can be observed (**Figure 11**). This can be justified by local conditions of climate, variety, soil, weed infestation and pests of each experiment area.

Table 13

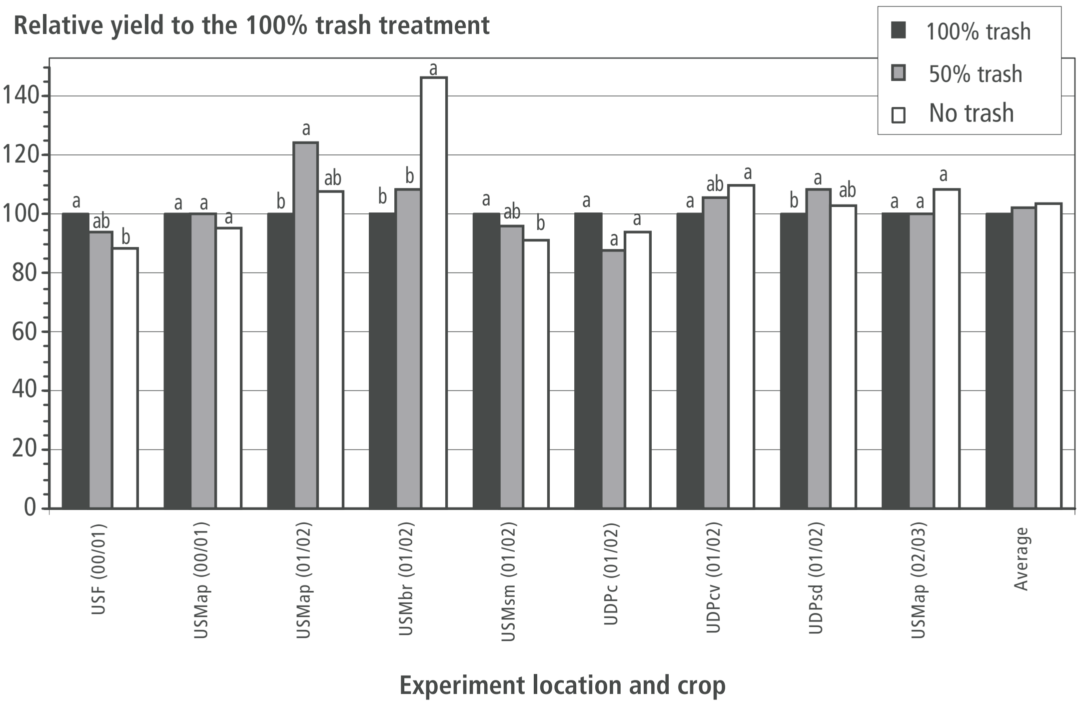
Amount of trash, weed population density (excluding Cyperus rotundus) and trash weed control efficiency (TWCE), considering 100% (T100), 50% (T50) and (T0) 0% trash, during three crops (Project extension).

Crop	Farm	T100	T50	T0	T100	T50	T0	T100	T50
		Trash dry matter (t/ha)			Density (plants/m²)			TWCE* (%)	
					Usina Da Pedra				
01/02	Capão I (UDPc)	6.6	3.3	0	0.59	2.23	6.63	91	66
01/02	Café Velho (UDPcv)	9.3	4.7	0	0.12	0.37	1.36	91	73
01/02	São Dimas (UDPsd)	14.9	7.5	0	0.01	0.07	0.08	78	28
					Usina São Francisco				
00/01	Água Branca (USF)	11.6	5.8	0	0.16	2.10	3.30	95	35
					Usina São Martinho				
00/01	Aparecida (USMap)	14.5	7.2	0	0.53	1.10	3.40	84	66
01/02	Aparecida (USMap)	14.8	7.4	0	0.36	1.56	5.12	93	69
01/02	Bronzini (USMbr)	14.7	7.4	0	0.20	0.51	0.52	63	3
01/02	Santa Marta (USMsm)	14.8	7.4	0	0.39	1.71	3.31	88	48
02/03	Aparecida (USMap)	11.4	5.7	0	0.91	4.5	6.2	85	28

* TWCE = Trash weed conrol efficiency (%) in relation to no trash treatment.

Figure 11

Effect of different amounts of trash (100%, 50% and 0%) on relative cane yield (tons of cane per hectare), during three crops (Project extension). Columns followed by the same letter do not differ at 5% level at Tukey test at the same location.



3.4. Definition of areas where trash can or should be removed

Depending on specific conditions of the sugar cane field, such as location, cane variety, stage of cut, harvesting period, climate and other combined aspects, the balance between advantages and disadvantages of maintaining trash on the soil can be altered, becoming even advisable in some cases its complete removal. The possibility that trash can be used as a fuel to generate electricity makes important the definition of areas or situations where trash removal, even partially, can benefit the sugar cane production system.

Based on information and knowledge acquired through experiments and field observations, indication of what to do with the trash after harvesting can be made.

3.4.1. Should be removed

• After cane harvesting in fields nearby inhabited areas or roads due to accidental or intentional fire hazards;

• After cane harvesting in fields located in areas under the occurrence of lightning electrical storms, usually high plateaus (flat area, isolated and in a higher position related to nearby areas), and areas on rocks of volcanic origin (magmatic rocks such as the basalt) with a history of frequent fires caused by lightning;

• Before cane replanting in fields infested by soil pests (*Sphenophorus levis*. for example), whose control demands the complete removal of the ratoons and trash through the frequent overturning of the arable soil;

• After cane harvesting in fields in regions of very humid winter with the frequent occurrence of rain during the harvesting period, especially if planted in soils with deficient internal drainage.

3.4.2. Can be removed, after technical and economic consideration

• After cane harvesting in fields with varieties that present significant reduction in yield and/or number of cuts due to delayed ratooning and gaps (discontinuity of sprouts in the line of cane) caused by trash blanket;

• After harvesting areas or regions with high occurrence of cane pests that shelter and multiply under the trash blanket, and that are favored by higher levels of humidity (or by the superficial rooting stimulated by the trash blanket), like the sugar cane froghopper nymphs *Mahanarva fimbriolata* (Homoptera: Cercopidae), in the absence of effective biological control (**Figure 12**);

• Before replanting sugar cane fields where there is any operational difficulty for the use of the planting system of minimum tillage (lack of technology/equipment) or the development of soil pests.

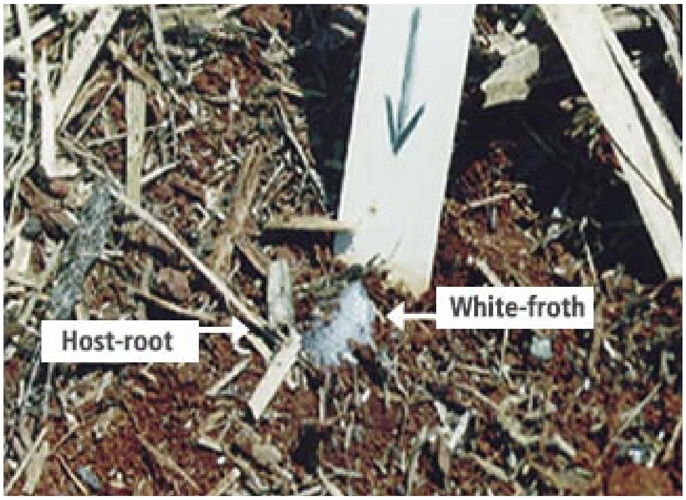
3.4.3. Can be partially removed

• During or after the harvesting, removing part of the trash from the total harvested sugar cane fields, leaving the rest of the residues uniformly spread on the soil, for agronomic purposes. If the amount of trash left in the field is greater than 7.5 t/ha (dry matter), and uniformly distributed, it is highly probable to have the herbicide effect.

• After harvesting, removal of all the trash in a region of approximately 60-cm wide over the lines of cane, in sugar cane fields planted with varieties which yield is reduced by the trash blanket.

The technical and economical feasibility of any of these operations have to be considered.

Figure 12



Sugar cane superficial roots (host) and white froth produced by sugar cane froghopper nymphs (parasite) *Mahanarva fimbriolata* (Homoptera: Cercopidae).

3.5. Conclusions and comments

This topic of the project describes the different benefits and problems of leaving the trash in the field after unburned sugar cane harvesting, studying in more detail the effect of trash on weed suppression and cane yield. The study of the impact of trash on soil and on terrestrial and biological environment is detailed in the "Impacts on terrestrial – biological environment" topic.

The amount of trash left in the field after unburned harvesting ranged from 6.7 to 14.9 t/ha dry matter, for the different experiments of the various crops. These values are a function of several factors, especially of the harvested variety, sugar cane field yield and harvester cleaning efficiency.

The majority of weeds of annual cycle were efficiently controlled by trash quantities between 7.5 and 9.0 t/ha (dry matter) evenly distributed on the soil, in experiments with no other external influence to the agronomic system.

Some species of weeds of annual cycle, which seeds do not need light or change of soil temperature to germinate, were not efficiently controlled, independently of the trash amount on the soil;

Some experiments showed that even with more than 7.5 t/ha of trash (dry matter) it is not sure that there will be an effective weed control, if other conditions such as weather, pests and weed infestation species are not favorable.

Regarding the effect of trash on sugar cane yield, the conclusion from the experiments was that the effect of local conditions such as variety, climate, pests and others, combined with the trash amount were more important than the trash amount alone. Experiments with an increase, others with a decrease and some with no effect in sugar cane yield could be observed.

Figure 13

Pictures of areas with weed species that are not controlled or partially controlled by trash.

3.5.1. Experiments with 100%, 66%, 33% and 0% of the initial trash

The results of the experiments showed that trash quantity above 66% of the total (above 7.5 t/ha, dry basis) controlled annual weeds with efficiencies greater than 90%, when uniformly distributed on the soil. This is considered equal to or higher than the efficiency obtainable with successful use of herbicides.

Exception to this happened in a few cases due to reasons such as: drought, pests, very low infestation in the control parcel (and then any weed appearance would reduce dramatically the control efficiency); infestation with weeds which are not adequately controlled by trash (**Figure 13**); action of insects or larvae (such as the *Bothynus medon*) that feed on trash and expose certain areas of the soil, where weed development can occur (**Figure 14**).

Figure 14

Left - Exposed soil surface due to trash removal at the galleries entrance, excavated by the larvae of *Bothynus medon*;

Right - Weeds developing on the exposed areas

The evolution of weed population was observed in an experiment of unburned harvesting, conducted for six crops without the use of herbicide or physical means to control weeds, except for the trash on the soil surface. Weed population (plants/m^2) increased in this period at a rate of 75:1 in the treatment without trash, 45:1 in the treatment with 33% of the trash, 17:1 in the treatment with 66% of the trash, and 7:1 in the treatment with 100% of the trash on the soil.

3.5.2. Experiments with 100%, 50% and 0% of the initial trash

Unfortunately not all experiments carried on in the Project extension phase, considering 100%, 50% and 0% of the initial trash continued for three crops (00/01, 01/02 and 02/03), what made it difficult to do a better analysis of these experiments. Nevertheless, the available information indicates that there is no effective weed suppression with only 50% of the initial trash.

The idea of removing only part of the trash for energy generation purposes, leaving in the field enough trash to still keep some agronomic benefits is an alternative. Removing part of the trash with the cane and making the separation at a cleaning station at the mill is a possibility that should be considered. Nevertheless, the remaining trash might not be enough for weed suppression. Therefore, any future decision on trash removal for any utilization must be preceded by technical and economical viability analyses, considering the loss of trash herbicide benefit, besides other agronomic factors. All reported practices that imply in trash removal, leaving the soil partially or totally exposed, especially if less than 7.5 t of trash/ha (dry matter) is left in the field require the use of physical or chemical weed control.

4. Selection and field test of high biomass producing cane

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4.1. Introduction

The process of selecting new sugar cane varieties has always been focused on sucrose production. With the perspective of generating energy at the mill using bagasse and trash (leaves and tops) as fuels, the variety selection process should take into account the trash and fiber that can be produced by the different varieties.

Results indicated that commercial varieties such as RB72454 included in the experiments, were considered an interesting option for biomass production when compared to the clones, since the commercial varieties combined a high millable stalk yield with reasonable biomass yield. This was not the case with high biomass yielding "non-commercial" clones. It was therefore recommended that high biomass varieties be identified or selected within a group of promising commercial "type" sugar cane varieties.

» Objective

To evaluate the potential of biomass production among sugar cane varieties and related species and to investigate the possibility of selecting high biomass producing sugar cane varieties, to be identified or selected within a group of promising sugar cane clones of the Copersucar Breeding Program, from outfield tests.

4.2. Procedure

4.2.1. Experiment 1

Planted in September, 1996, the total biomass volume was estimated based on yield components in 12 months old plant cane in a field multiplication of 107 clones of sugar cane and related species including *Saccharum robustum*, *S. barberi*, *S. sinense* and *Erianthus arundinaceus*. A set of 12 clones was selected for further studies in Experiment 2.

- Yield components: stalk number, weight, diameter and height
- Quality traits: sucrose content, soluble solids, fiber content

4.2.2. Experiment 2

A replicated field experiment was established in October 1997 with the 12 sugar cane clones from Experiment 1 and a commercial check variety (RB72454) and evaluated at first harvest in October 1998.

- Yield components: stalk number, weight and diameter; whole plot stalk weight
- Quality traits: sucrose content, soluble solids, fiber content
- Others: leaf weight, cane top weight, disease reaction, flowering intensity

Three sets of field trials named Experiment 3, 4 and 5 were established to evaluate the potential of biomass production among sugar cane varieties and elite sugar cane clones selected from the Copersucar Sugar Cane Breeding Program, and to investigate the possibility of selecting the ones with high biomass yield.

4.2.3. Experiment 3

Two replicated field tests were established to evaluate biomass production within a group of commercially promising new clones and sugar cane varieties (**Appendix 4**) in March 1998. The tests were planted at Usina Santa Luiza and Usina Cresciumal, on Typic Haplorthox, sandy clay loam texture and Typic Euthorthox, clay texture soils, respectively (Department of Agriculture, Soil Conservation Service. Soil Taxonomy. Washington, 1975. 754p, USDA, Agriculture Handbook, 436). Twenty-five treatments (varieties) were planted in completely randomized block design with three replications. Plots were comprised of 3 rows of 25 meters in length and inter-spaced 1.4 meters. The plots were evaluated in plant cane (harvested in June 1999).

- Yield components: stalk number, weight and diameter; whole plot stalk weight
- Quality traits: sucrose content (pol), soluble solids (brix), fiber content
- Others: weight of dry leaves, green leaves and sugar cane tops

4.2.4. Experiment 4

Two replicated field tests with 25 elite sugar cane clones (**Appendix 5** and **Appendix 6**) at Usina da Pedra (Typic Acriorthox, clay texture soil) and Usina Santa Luiza (at the same field of Experiment 3) were established in March 1998 and evaluated at the second harvest (first ratoon) in July 2000. The 25 sugar cane clones were planted in completely randomized block design with three replications. Plots were comprised of 3 rows of 25 meters in length and inter-spaced 1.5 meters at Usina da Pedra and 1.4 meters at Usina Santa Luiza tests.

- Yield components: stalk number and weight
- Quality traits: sucrose content (pol), fiber content
- Others: trash (leaves + cane tops) weight, moisture content of trash.
- Calculation: total fiber per plot in clean cane stalks and in the trash (green and dry leaves and tops of stalks)

4.2.5. Experiment 5

Two replicated field tests with 16 elite sugar cane clones (**Appendix 7** and **Appendix 8**) at Usina Cresciumal (Typic Euthorthox, clay texture soil) and Usina Santa Luiza (Quartzipsammentic Haplortox, sandy loam texture soil) were established in March 1999 and evaluated at the second harvest (first ratoon) in July 2001. The 16 sugar cane clones were planted in completely randomized block design with three replications. Plots were comprised of 3 rows of 25 meters in length at Usina Cresciumal and 3 rows of 20 meters in length at Usina Santa Luiza, with the rows inter-spaced 1.4 meters for all the tests.

Figure 15

Weighing stalk samples for biomass evaluation.

- Yield components: stalk number and weight
- Quality traits: sucrose content (pol), fiber content
- Others: trash (leaves + cane tops) weight, moisture content of trash and clean cane moisture
- Calculation: total fiber per plot in clean cane stalks and in the trash (green and dry leaves and tops of stalks)

A 3.0 m wide walkway was left in front and behind the plots to permit easy access for evaluations in trials 3, 4 and 5.

For all the tests of Experiments 3, 4 and 5, each plot was evaluated before harvesting for the total number of stalks, and a 30 stalk sugar cane sample was evaluated for fresh weight of stalks, fresh weight of green leaves, fresh weight of dry leaves and fresh weight of cane tops (**Figure 15**). The 30 cane sample was made of 10 cane samples from the three sugar cane rows of the plot.

The estimate of the total amount of each component in the plot was obtained by multiplying the number of stalks in the plot by the mean component weight per stalk, determined from the 30 stalk sample.

The yield estimate in terms of tons per hectare for the cane components was determined from the average plot component weight divided by the area of the plot. According to Copersucar Technology Center experience in this type of estimate, correction to the plot area should be done to compensate for the effect of better development of the cane at the extremities of the plot, adding 2.0 meters to the length of the plot when calculating its area. Therefore, a plot of three rows of 25 meters in length and inter-spaced 1.4 meters should have its area calculated as: 3 rows x (25+2) m x 1.4 m.

For the purpose of verifying the correlation between yield estimated by components (stalk number and stalk weight) and whole plot yield, 30-stalk samples were taken from plots and whole plots were harvested without burning with a chopper harvester and weighed with a load cell equipped truck (**Figure 16**).

The correlation between the total plot weighed stalk yield (measured with the load cell equipped truck) and the estimated stalk yield (calculated from the 30-stalk sample weight and the total number of stalks in the plot) was verified.

The experience gained on Experiment 3 suggested for Experiments 4 and 5 the determination of sugar cane parameters such as: stalk and trash fiber content, clean cane pol (apparent sucrose % cane). For Experiment 5, another parameter was added: clean cane moisture content.

4.3. Results and discussion

4.3.1. Differences between varieties

Significant differences were observed between treatments (varieties) for all parameters evaluated at Usina Santa Luiza in June 1999 (**Appendix 4** – Probability value for varieties PVAR < 0.05). With the exception of fiber % trash in the experiment harvested in July 2000 at Usina da Pedra, all other parameters exhibited significant differences between varieties (**Appendix 5**). The same was observed at analysis of variance for the field test at Usina Santa Luiza in July 2000 (**Appendix 6**), at Usina Cresciumal (**Appendix 7**) and Usina Santa Luiza (**Appendix 8**) in July 2001.

Figure 16

Weighing a mechanically harvested field experiment with a load cell equipped truck.

4.3.2. Biometry

Significant correlation was verified between estimated stalk weight and whole plot weight mechanically harvested (measured with the load cell equipped truck) (**Figure 17**). This suggests that for the objective of the present study, employing the estimated weight of each sugar cane component in the plot, determined from the method of the 30 stalk sample and total number of stalks in the plot, is equivalent of using its real weight.

Low coefficient of determination (R^2=0.34) for the correlation between estimated stalk weight and whole plot weight (mechanically harvested) was observed at Usina Cresciumal-1999 test. This can be attributed to poor harvesting conditions of the lodged cane field test. This test was discharged after the results observed for the tests of Experiments 4 and 5, with the recommendation that these experiments shouldn't be carried on in lodged cane fields.

4.3.3. Stalks, trash and biomass correlation (fresh weight)

No significant correlation was verified between fresh weight of stalks and trash (**Figure 18**). Significant correlation was obtained between fresh weight of stalks and total biomass fresh weight, since the stalks comprise for about 80% of the total fresh weight of the biomass (**Figure 19**).

It's possible to select varieties for high biomass among the high sucrose content commercial varieties. Example of this are the varieties SP80-3480 and SP80-3280, both with high sucrose clean cane content of 16.9 and 17.3%, but with a great difference in the estimated total fiber weight of 331 and 250 kg/plot, respectively (**Appendix 8**, Usina Santa Luiza, July 2001).

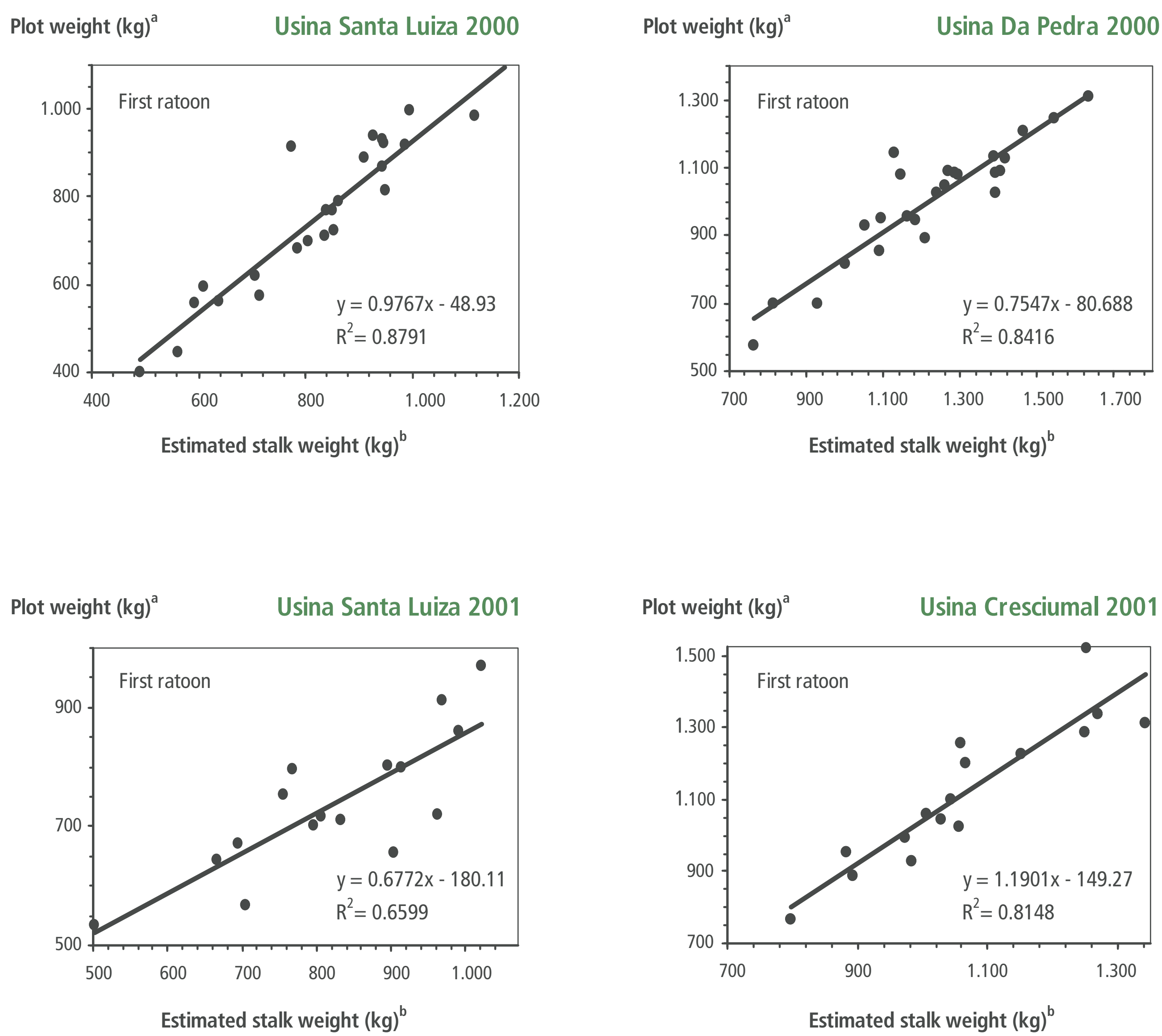
4.3.4. Fiber production

No significant correlation was verified between estimated total fiber of stalks (fiber % fresh cane multiplied by estimated fresh weight of stalks) and estimated total fiber of trash (fiber % trash multiplied by estimated fresh weight of dry leaves, green leaves and cane tops) for all varieties trials (**Figures 20a** and **20b**). Considering that the fiber in the stalks represents between 40% to 50% of the total fiber in the biomass, the correlation between total fiber in the stalk and total fiber in the biomass indicates that selecting high tonnage and high sucrose varieties means choosing varieties with high energy potential (**Figure 21**).

4.4. Conclusions

With the exception of fiber % trash, significant differences were observed between varieties for all parameters evaluated in the experiments. This indicates that it is possible to select varieties considering the total amount of biomass and also the high sugar content. Nevertheless, the selection of a variety should not be done considering only the amount of biomass, since the main product extracted from sugar cane, up to now, is the sucrose for sugar and ethanol production.

Figure 17

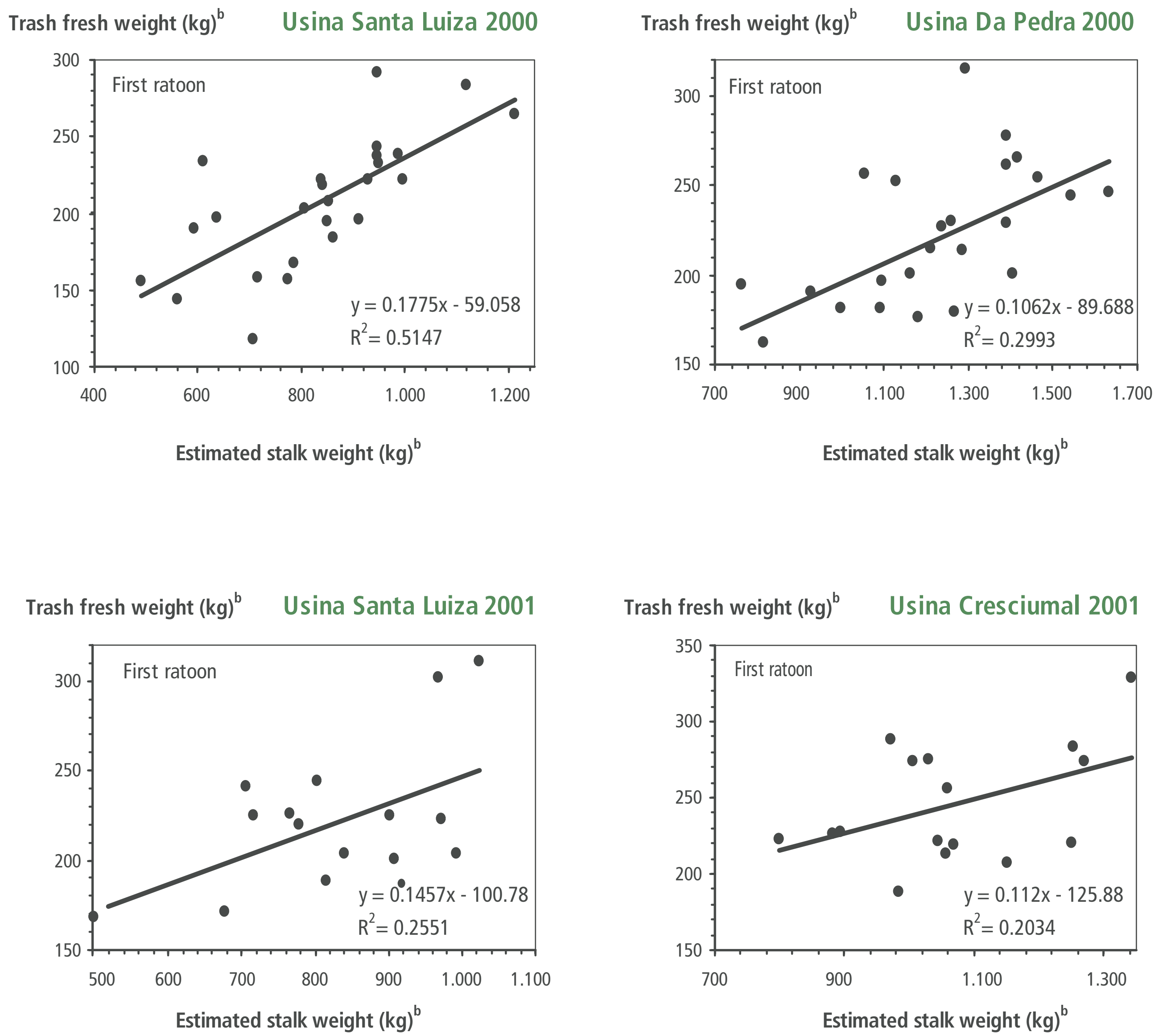


Correlation between yield components in the field tests with varieties. (a) Weight of the plot measured with the load cell equipped truck; (b) Estimated weight of stalks in the plot, determined from the method of the 30 stalk sample and total number of stalks in the plot.

The cane yield can be estimated in the plots by weighing 30 stalks and counting the number of stalks in the plot, with the exception of experiments in lodged cane fields.

No significant correlation was verified between total fiber of stalks and total fiber of trash. This fact indicates that it might be possible to select varieties with high biomass, choosing between more fiber content in the sugar cane stalk or more trash (or both), according to what is more convenient at the time, taking into account cane processing factors and trash recovery costs.

Figure 18

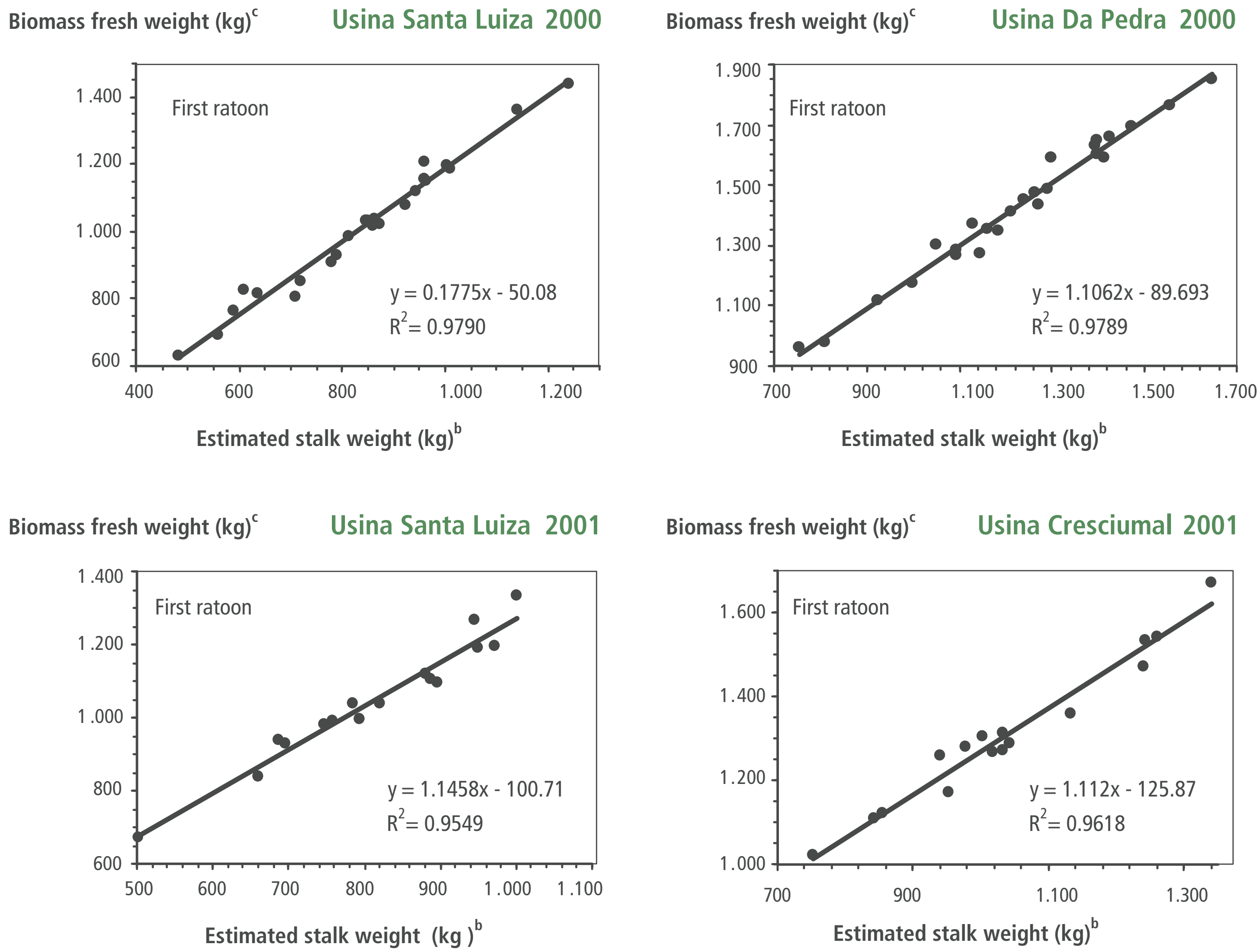


Correlation between fresh weight of stalks and trash. (b) Estimated fresh weight of stalks in the plot; (d) Estimated fresh weight of dry leaves, green leaves and cane tops in the plot (trash).

4.5. Perspectives and future work

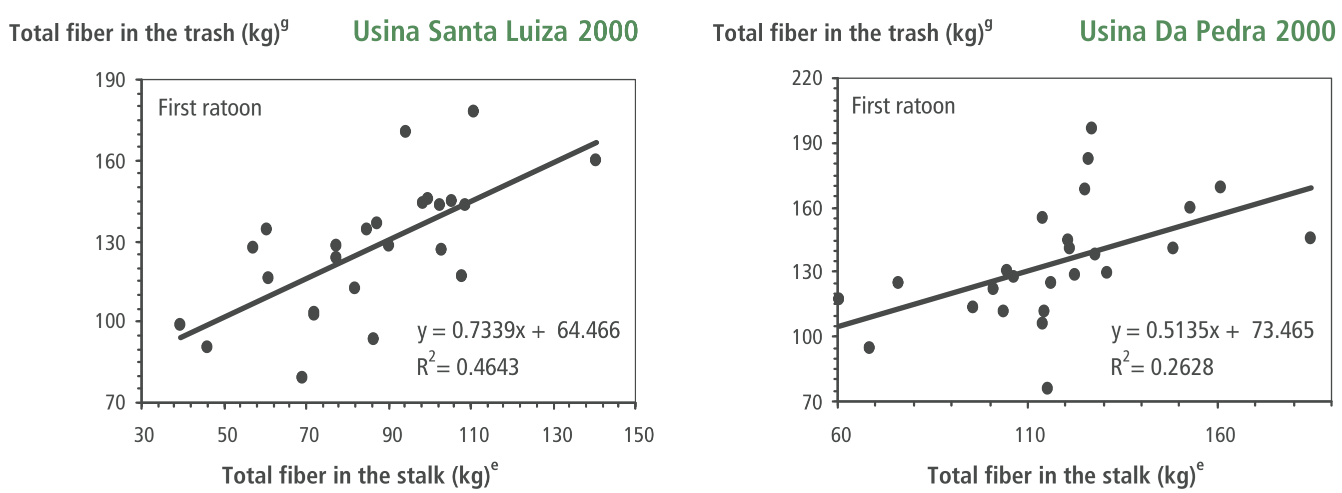
The selection process for the release of new varieties in a breeding program goes through several technical aspects. Besides that, commercial considerations are also involved. The use of the contribution margin calculation classifies the varieties or clones according to economic aspects. This calculation takes into account factors such as the sugar cane production in tons of cane per sucrose content, purity, percentage of fiber, average distance to the mill, and others. This tool, together with other technical ones, is used from the start of the variety selection process.

Figure 19



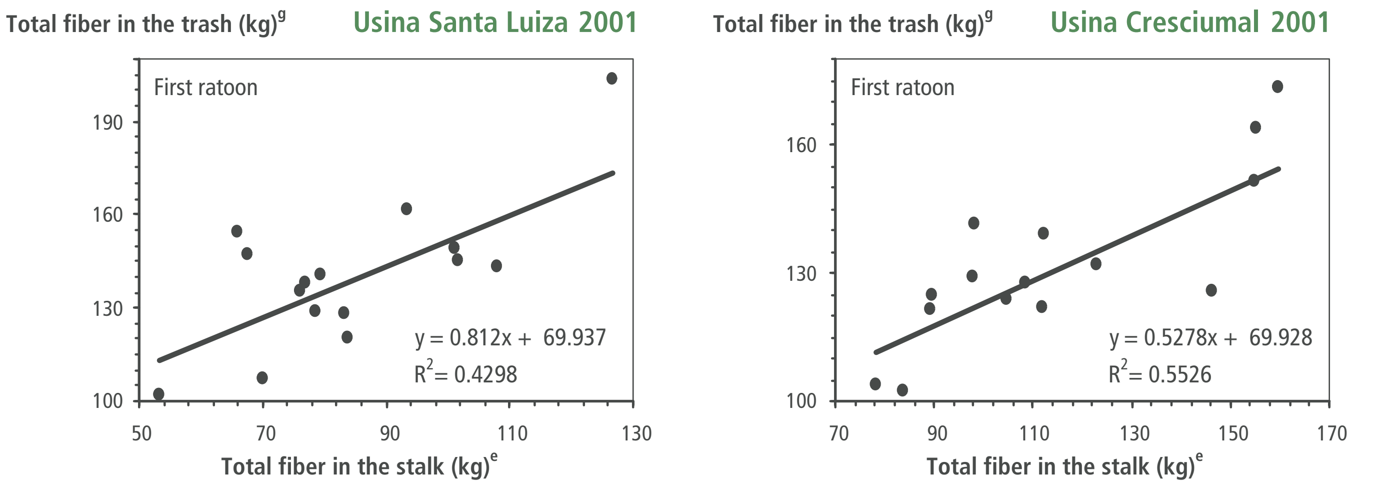
Correlation between stalk weight and fresh weight of biomass. (b) Estimated fresh weight of stalks in the plot; (c) Estimated fresh weight of stalks in the plot plus the fresh weight of dry leaves, green leaves and cane tops in the plot (trash).

Figure 20a



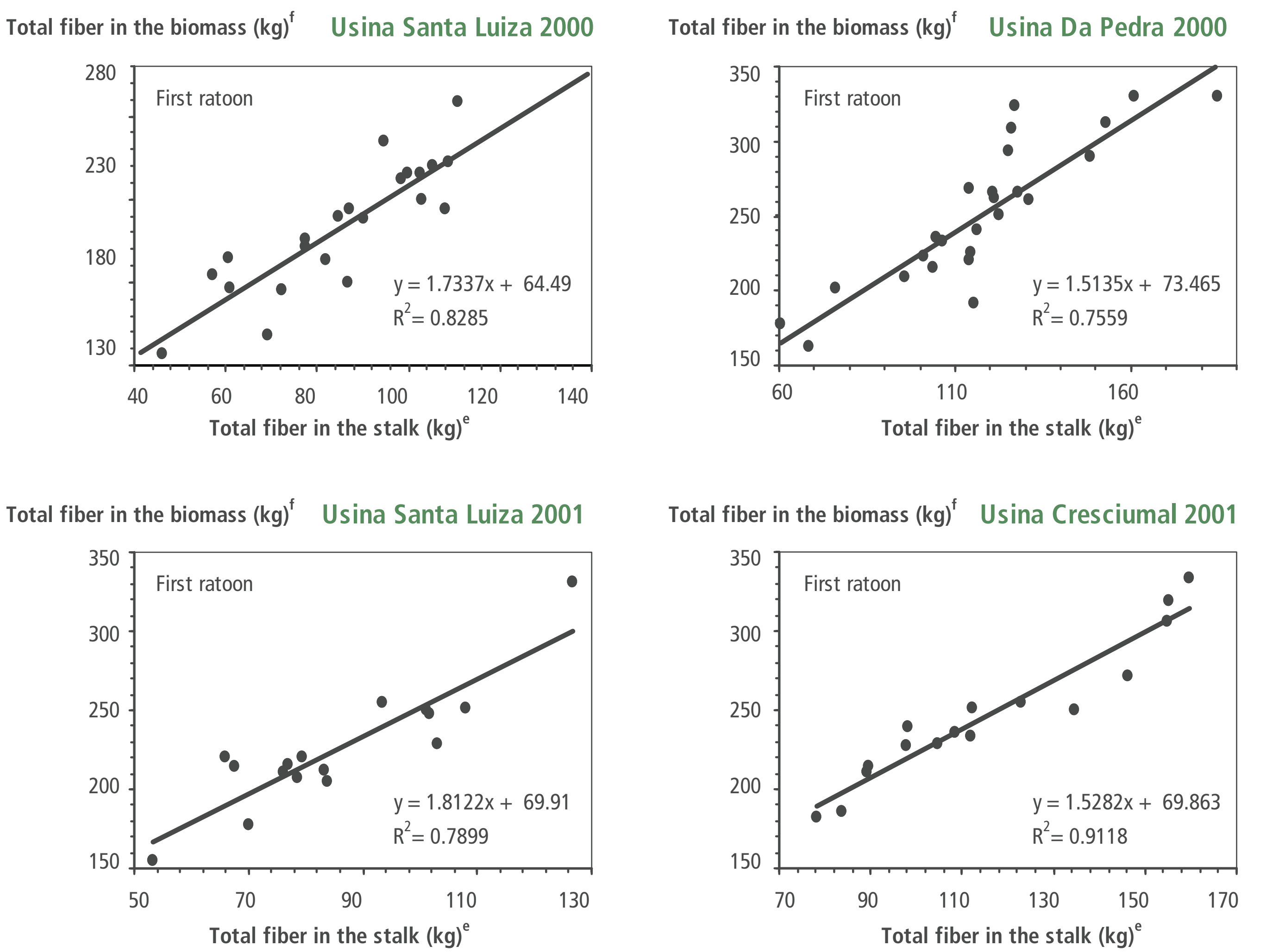
Correlation between total fiber in the stalks and total fiber in the trash. (e) Fiber % cane multiplied by fresh weight of stalks; (g) Fiber % trash multiplied by fresh weight of trash.

Figure 20b



Correlation between total fiber in the stalks and total fiber in the trash. (e) Fiber % cane multiplied by fresh weight of stalks; (g) Fiber % trash multiplied by fresh weight of trash.

Figure 21



Correlation between total fiber in the stalks and total fiber in the biomass. (e) Fiber % cane multiplied by fresh weight of stalks; (f) total fiber in the stalks plus total fiber in the trash of the plot.

The equation for the contribution margin calculation, employed nowadays by the Copersucar Sugar Cane Breeding Program, penalizes the fiber content, since it is detrimental for mill capacity and cane juice extraction. The amount of trash is not considered in the calculation.

Once the bagasse (cane fiber) and the trash are being considered as fuels for electric generation at the mill site, it is necessary to credit them an economic value that should be considered in the contribution margin calculation.

The selection of varieties that would maximize the mill profit in a scenario of energy generation should be done using a new definition of this contribution margin calculation. Besides the parameters already considered, this calculation should take into account the price paid for the energy, the production cost of the energy, the trash cost, and the efficiency of the energy generation process. The contribution margin would take into account the two main components of the total biomass: trash and stalk fiber content, individually, since each one has different recovery cost and different effect on harvesting, transportation and sugar production.

With this new tool, the new contribution margin calculation, simulations can be done, considering several energy market scenarios and select from the tables generated in a breeding program the most suitable varieties.

5. Evaluation of agronomic routes to unburned cane harvesting with trash recovery

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The harvest, loading and transport represent around one third of the cost of cane at the mill in Brazil. Presently, the most common system consists of manual harvest, mechanical loading on trucks, which transport the cane to the mill.

Manual harvest is usually done on burnt cane. An average cane cutter will cut seven metric tons of cane per day. On unburned cane, his yield would be three metric tons of cane per day. The worker cuts the cane from five rows and places it on the middle row, either in a continuous mat or in piles perpendicular to the rows. The continuous mat will usually be loaded on trucks with a grab loader equipped with rotary push pilers, while a conventional grab loader will be used when loading piled cane.

Mechanical harvesting accounts for less than 20% of the harvested cane in Brazil up to year 2003. The machine cuts, chops the cane in 25 cm billets and loads it into trucks. Trucks for this harvest system have closed trailers to receive chopped cane and follow the harvester in the field. The field capacity of a chopper harvester in burnt cane is approximately 700 t/day (24 hours).

Whole stalk cane mechanized harvest is rare and not widespread due to some operational problems. Most machines leave the stalks parallel or diagonal to the furrows, which forces the loaders and trucks to cross the rows during the loading operation. This increases soil compaction and machine wear.

Modifications of the present harvest system on burnt cane are expected. Changes in legislation due to pressure from environmentalists will inevitably lead to unburned cane harvest. Since the yield of the field labor is low on unburned cane cuting and labor accidents are higher, the future will see a substantial increase in mechanized unburned cane harvest.

With the implementation of mechanical unburned cane harvest, cane trash may become an important by-product used in many ways. It can be recovered to be used as raw cellulosic material for paper and pulp, particle board manufacturing, as fuel for the generation of energy or as raw material for ethanol production. On the other hand, trash could be left in the field for agronomic purposes such as weed control, protection of the soil from erosion and soil moisture maintenance

Thus, with the main objective of recovering trash to be used as fuel for energy generation, the structure of the project considered preliminary basic choices for unburned cane harvesting and trash recovery systems.

Four routes for whole and chopped unburned cane harvesting were pre-selected:

Route A: Whole stalk cane harvesting; loading and transporting cane and trash; cane cleaning and trash recovery at the mill.
Route B: Whole stalk cane harvesting; cane picked up, chopped and cleaned in the field; transporting clean cane; baling and transporting trash to the mill.
Route C: Chopped cane harvesting; cane cleaned and loaded in trucks during harvesting; transporting clean cane; baling and transporting trash to the mill.
Route D: Chopped cane harvesting with harvester cleaning extractors off; cane and trash loaded during harvesting; transporting cane and trash; cane cleaning and trash recovery at the mill.

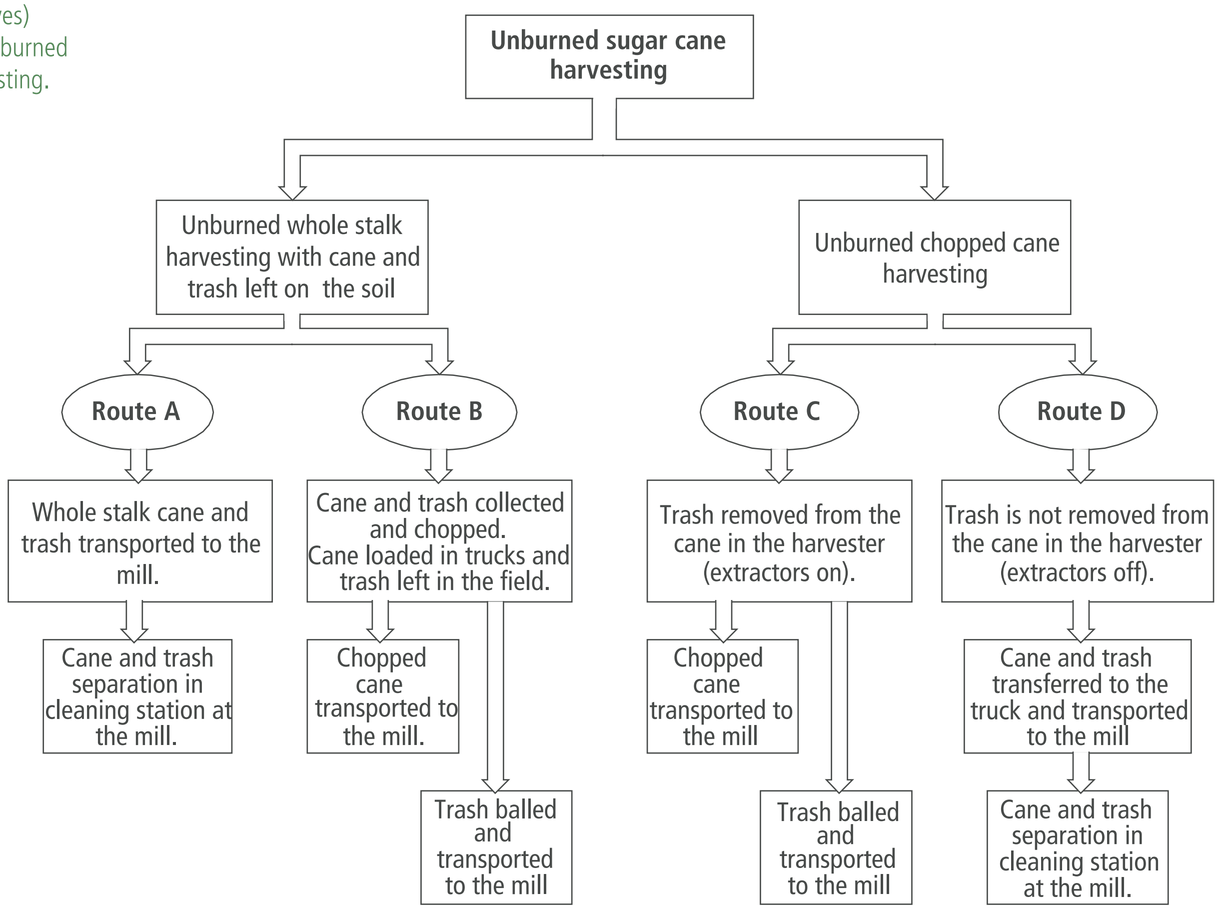
These routes are schematically described in **Figure 22.**

Regarding the four routes described, for some of the operations there has been a need to develop the technology or the equipment:

- Development and test of Copersucar Two Row Whole Stalk Cane Harvester: Under this Project the Copersucar Harvester was modified to improve performance and tested as an alternative for routes A and B.
- Development and test of a sugar cane Dry Cleaning Station: One important item in routes A and D (cane cleaning at the mill) is the Cane Dry Cleaning Station. An existing prototype for 250 tons of cane per hour, already designed and built by Copersucar, was improved and tests carried out.
- Trash recovery with baling machines: A baling machine has been selected for detailed testing, after some preliminary investigation based on previous knowledge acquired during tests carried out in the past.

Figure 22

Routes (alternatives) considered for unburned sugar cane harvesting.



- Trash bale processing at the mill: Shredding equipment manufacturers were contacted to find alternatives technically and economically viable for trash processing, either baled or in loose form.

Field tests were performed to verify the adequacy of the proposed solutions. Trash recovery potential, handling, transportation and processing costs were evaluated for all four routes. To do so, performance was determined for the equipment under development and for those commercially available. The benefits and drawbacks of leaving the trash in the field were also considered for economic purposes and associated to trash removal. Therefore, total trash cost was determined as trash recovery and transport cost plus the cost of the benefits lost with trash removal, minus the cost of the drawbacks caused by the trash when it is left in the field.

6. Development and test of "Copersucar Two Rows Whole Stalk Cane Harvester"

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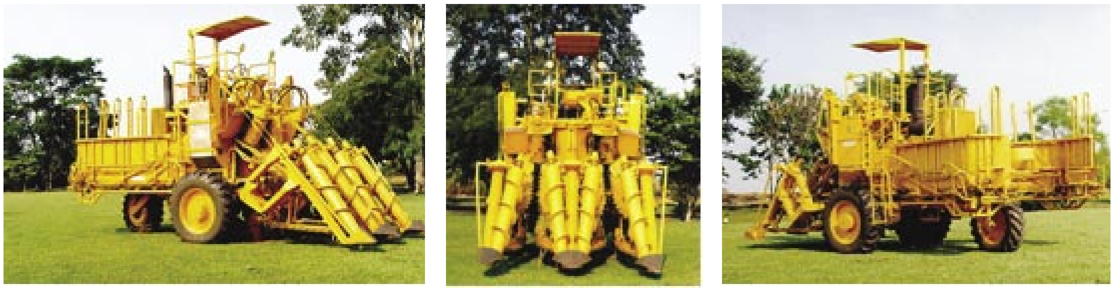
6.1. Introduction

For unburned sugar cane harvesting with trash collection, routes A and B consider mechanized whole stalk cutting of the cane. For this task, there is no commercial machine available in the world market that is suited for the Brazilian field and variety characteristics, that leaves the harvested cane in continuous mats perpendicular to the cane rows. Project description supposes working with the "Two Row Whole Stalk Cane Harvester", under development by Copersucar (**Figure 23**), which has undergone field tests until 1996. Based on the results of these tests, a series of modifications were planned and executed in the scope of the Project.

» Objective

To improve the performance of the Copersucar Cane Harvester to cut unburned cane, so that it could be used in routes A and B of whole stalk cane harvesting with trash recovery.

Figure 23



"Copersucar Two Row Whole Stalk Cane Harvester" improved prototype.

6.2. Methodology

Improvements were introduced to the components and parts of the cane transporting through the machine and cane piling systems. Modifications were basically restricted to the installation of careenage, to avoid the accumulation of trash over the internal combustion engine (to avoid fire hazards) and on the cane piling arms (**Figure 24, A**); and the enlargement and segmentation of the cane piling arms (**Figure 24, B**), to improve cane piling and to reduce choking of the cane transport system through the machine.

Figure 24

"Copersucar Two Row Whole Stalk Cane Harvester".

A) Piling arms with careenage.

B) Piling arm segmented in two parts.

6.3. Results

During the 98/99 harvesting season, field tests were carried out with the Whole Stalk Harvester, in unburned cane fields with yield up to 80 t/ha, with 1.4 meters spacing between lines of cane (**Figure 25**). The machine participated then of the tests of the agricultural routes for trash recovery, considering harvesting of whole stalk cane (**Figure 26**).

Figure 25

"Copersucar Two Row Whole Stalk Cane Harvester" during field tests.

Figure 26

"Copersucar Two Row Whole Stalk Cane Harvester" under operation and a view of the harvested field with the piles of cane

The main parameters determined during the tests with the "Copersucar Two Row Whole Stalk Cane Harvester" were:

• Potential capacity[1]	84.6	(t/h)
• Field capacity[2]	39.9	(t/h)
• Fuel consumption	24.0	(L/h)
• Fuel consumption	0.54	(L/t)
• Speed at work	5.7	(external piling - km/h)
• Speed at work	4.6	(internal piling - km/h)

[1] Considers non-stop work without maneuvers.
[2] Considers total operating time.

Despite several improvements, some of them described here, the Copersucar Harvester had several problems harvesting cane fields with yield above 70 t/ha, or lodged cane.

Difficulties driving the machine while harvesting unburned cane and topping cane longer than 2.4 meters (**Figure 27**) were other problems observed.

Another limitation to cut cane with yield above 70 t/ha in a sugar cane field planted with spacing between rows of 1.4 meters is the length of the cane, large enough to be driven over by the harvester tires. This is better explained in **Figure 28**, **Figure 29** and **Figure 30**.

6.4. Conclusions

The system of harvesting whole stalk cane has several advantages such as fewer losses in chopping cane when compared to the chopped cane harvesting and independence between harvesting and transport.

The main disadvantages encountered during the tests with the "Copersucar Two Row Whole Stalk Harvester" were: difficulties harvesting lodged cane, problems driving the harvester in unburned cane fields and harvesting cane fields with yield above 70 t/ha.

Despite several improvements performed in the machine, it was observed that major changes should be performed in the machine to overcome these problems. In fact, a new machine design would be needed.

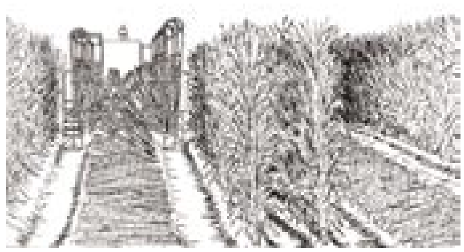
Figure 27

Copersucar Havester working in a field of 80 t of cane/ha. Operator dificulty to see the inter-row to be able to drive the machine properly. In the detail, topper cuts piece of cane for cane longer than 2.4 meters.

Figure 28

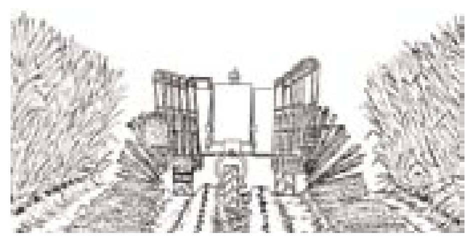
Beginning of the field harvesting, with the harvester cutting two rows of cane and piling this cane behind it.

Figure 29



The harvester drives back in the field, cutting two rows of cane (and piling them behind it) but leaving two standing rows in between the harvested rows. This operation goes on for the entire field.

Figure 30



The harvester proceeds cutting the standing rows, with external piling, forming piles of four rows of cane on the ground.

7. Development and test of a "Sugar cane Dry Cleaning Station"

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7.1. Introduction

Sugar cane harvesting has always been preceded by trash (tops and leaves) burning, in order to have a raw material with low level of vegetal impurities and also to favor the cane stalks hand cutting operation. Current legislation asks for unburned cane harvesting, turning hand cutting unprofitable, as the labor productivity drops, and demanding machine harvesters. The equipment used for unburned cane harvesting are the chopper harvesters. A large volume of trash remains in the field as a residue, which can be used as a fuel for electricity generation.

This Project considered different alternatives for unburned sugar cane harvesting with trash collection. These alternatives consider whole stalk harvesting and chopped cane harvesting with three different modes of trash recovery.

- The trash is removed from cane in the field during the harvesting operation and then collected with proper equipment such as balers.
- Part of the trash is separated from the cane and left in the field for agronomic purposes and the rest of the trash is transported with the cane to the mill where the trash separation is executed by a Dry Cleaning Station.
- The trash is not removed from the cane in the field. Cane and trash are transported together to the mill to be separated there using a Dry Cleaning Station.

The Sugar Cane Dry Cleaning Station was designed with the main purpose of separating vegetal impurities (trash) and mineral impurities (soil) from the cane at the mill site. The trash separated from the cane, after some preparation, can then be used as a supplementary fuel to bagasse for the boilers or even for the gasifier.

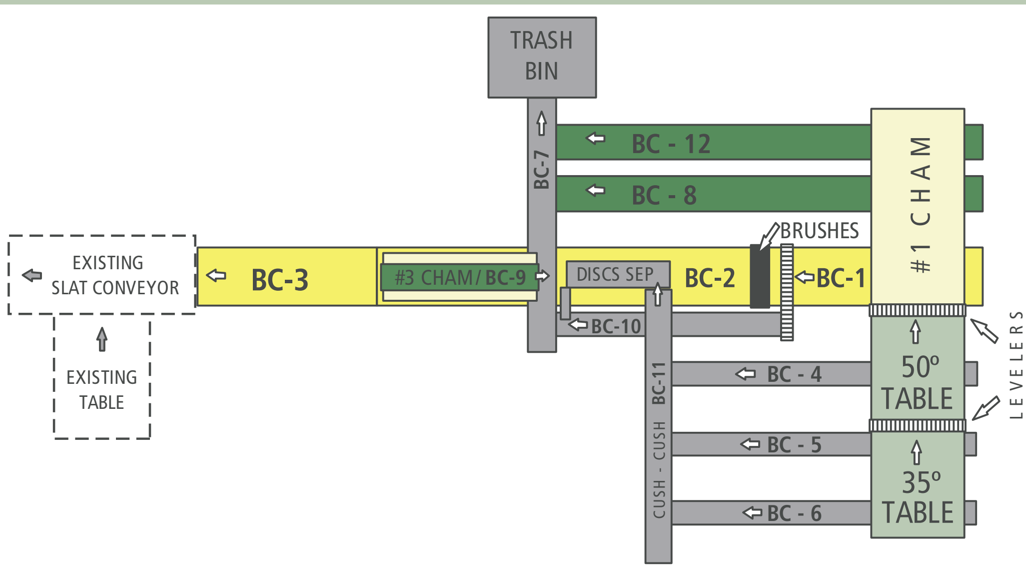
The design of the Dry Cleaning Station admits the processing of whole stalk cane and chopped cane. Nevertheless, during the tests of the different unburned cane harvesting alternatives with trash recovery only the options of chopped cane showed to be operationally viable. Due to this fact, the last evaluation of the Sugar Cane Dry Cleaning Station efficiencies considers only the processing of chopped unburned cane.

7.2. Equipment description

The sugar cane Dry Cleaning Station prototype, designed for a 250 t/h capacity and processing whole stalk or chopped cane, is in operation at Usina Quatá since the 1994/1995 crop. After several evaluations and modifications at the end of 2001/2002 crop, the current system configuration is shown in **Figure 31**.

Figure 31

Scheme of the Sugar Cane Dry Cleaning Station.



Following, the function of each one of the main equipment that constitutes the prototype is described.

Feeder table

It is used for whole stalk or chopped cane reception and transport from this point to the BC-1 belt conveyor.

It has a 45º slope to reduce the cane layer and to increase the blowing efficiency, but in the prototype, due to layout problems, there are two feeder tables, the first one with 35º slope and the second one with a 50º slope. At the table bottom there is a screen made with trapezoidal bars mounted with approximately 13 mm gaps, for the mineral impurities separation. As it will be seen ahead, these trapezoidal bars were changed by perforated plates, that contributed for the reduction of the mineral separation efficiency.

Leveler

This equipment is used only with whole stalk sugar cane. It enables an uniform discharge from the feeder table to the belt conveyor and it promotes an agitation, increasing the impurities separation efficiency, besides optimizing the feeder table operational conditions. At present, Usina Quatá is operating only with the 50º table leveler.

Sugar cane belt conveyors (BC-1, BC-2, BC-3)

They operate with high speed and a thin cane layer, improving the blowing efficiency and making the cane flow easier through the rotary brushes.

Mineral impurities belt conveyors (BC-4, BC-5, BC-6, BC-10, BC-11)

They carry the soil collected at the feeder tables to a trash bin (in the future there should be a soil bin).

Vegetal impurities belt conveyors (BC-7, BC-8, BC-9, BC-12)

They carry the leaves collected at the blowing chambers to a trash bin.

Rotary brushes

This equipment increases the blowing chambers efficiency, detaching leaves and soil from the cane stalks.

Blowing chambers

The blowing chambers are used to separate mainly vegetal impurities (leaves) at the following strategic points: cane discharge from the feeder table to the BC-1 conveyor and cane discharge from the BC-2 conveyor to the BC-3 conveyor, after the rotary brushes. They are equipped with fans for the air blowing through nozzles, promoting the cane impurities (mainly leaves) separation, which are collected using belt conveyors (BC-8 and BC-12 in the # 1 chamber and BC-9 in the # 3 chamber).

Rotary discs impurities separator

This equipment is used to recover cane stalks and cane chips improperly collected together with the mineral impurities at the feeder tables, using a screening process. The recovered material returns to the cane conveyor BC-2 and the mineral impurities are taken to the BC-10 conveyor and directed to a trash bin.

7.3. Review

The sugar cane Dry Cleaning Station prototype installed in Usina Quatá had an evaluation with tests carried through during the end of October, 1997. These tests had shown that the station had reached the expected results of cleaning efficiency, with overall average of 70,3%, confirming the previous results, during the 1996/1997 crop, between 70% and 80%, in its nominal capacity. It is important to point out that the higher efficiencies had been reached during the tests with whole stalk cane, and that the mineral separation efficiency was very high with this type of cane, increasing therefore the total efficiency.

During the 2000/2001 crop some evaluation tests were done that could not be considered here due to the station unsatisfactory operating conditions, which was operating only with the # 1 blowing chamber.

In November and December 2001, after some modifications made in the station, tests were done for its performance evaluation, at this time considering only the chopped unburned cane processing, in three distinct conditions for the harvester's primary extractor speed.

In these analyses, the evaluation of the mineral and vegetal separation efficiency results were done separately. Therefore, the mineral separation efficiency depends much more on the conditions of the existing screening processes, while the vegetal separation efficiency depends basically on the conditions of the blowing processes.

» Objective

The main objective of this work was to evaluate and improve the Sugar Cane Dry Cleaning Station under development.

During tests of different unburned cane harvesting alternatives with trash recovery, only the option of chopped cane harvesting showed to be operationally viable. Due to this fact, this last evaluation of the Sugar Cane Dry Cleaning Station efficiencies considers only the processing of chopped unburned cane.

The evaluation tests considered different levels of vegetal impurities for the determination of the Dry Cleaning Station trash separation efficiency for cane brought to the mill in three different conditions (Routes):

- Cleaned in the field
- With part of the trash
- With almost all the trash

7.4 Modifications in the Dry Cleaning Station prototype equipment

A series of improvements were made in the prototype since the 1997/98 crop, when the evaluation tests had been made. The following modifications have been implemented in the Quatá Sugar Cane Dry Cleaning Station:

Feeder tables

The feeder table bottom screen was modified, changing the trapezoidal bars by perforated plates, reducing considerably the screen open area. This modification was made by the people in charge at Usina Quatá in order to reduce the clogging of the trapezoidal bars gaps. It is believed that this clogging was caused by very fine cane chips that stuck into the gaps and by the use of smaller gaps than the recently specified.

For this reason, the mineral impurities separation efficiencies during 2001/2002 crop were lower than the ones obtained during 1997/1998 crop, decreasing the total impurities separation efficiency.

Figure 32

Rotary brush.

Rotary brush

The current rotary brush version is a modification in relation to that used in 1997/1998 crop. At that time there were two brush sets made with wire ropes, which did the job with good efficiency; however the brushes wear was very high. Later, these brushes were made with SAE 1070 steel wire cold-drawn, and as a result it showed to have a lower wear, due to the higher abrasion resistance, but on the other hand some wire ruptures occurred close to the brushes center.

In the current configuration (**Figure 32**), only one brush set, is being used with SAE 1070 steel wire cold-drawn at the upper rotor and with rugged rubber pins at the lower rotor, where the highest wear and rupture were taking place. Some pins were made with one internal reinforcing ply and others with two reinforcing ply. It could be noted that the ones with only one reinforcing ply had the best performance. The pins with two reinforcing ply presented ruptures near the fitting holes on the rotor drum, certainly due to their lower flexibility. The assembly and change of these pins are very simple; therefore they are easily fitted by hand into holes on the rotor drum.

 # 1 Blowing chamber

The # 1 blowing chamber, used to blow the cane discharged by the feeder table to the BC-1 belt conveyor, didn't have any modification since the 1997/1998 crop, and since then it has been operating with good results. It is important to keep the blowers air inlets and the mesh screens located at the chamber top unclogged in order to have high efficiency.

2 Blowing chamber

The # 2 blowing chamber, which was used to blow the cane discharged from the BC-1 belt conveyor to the BC-2 belt conveyor, was deactivated before the 1997/1998 crop and more recently it was removed from the system. After the rotary brushes assembly, there was no space for the blower installation underneath them, therefore it had to be positioned so that the air flow was laterally crossing the cane flow, and this procedure decreased the chamber efficiency. Due to some modifications on the next (# 3) blowing chamber that would make it more efficient, as it will be seen ahead, it was decided to take # 2 chamber out of the system and operate the station only with # 1 and # 3 chambers.

Figure 33

3 Blowing chamber.

3 Blowing chamber

After the 1997/98 crop, a modified design for the # 3 blowing chamber was made, in an association with CTA (Brazilian Aerospace Technology Center), changing from upward air blowing to downward air blowing, with much more efficiency. Only in the 2001/2002 crop this chamber was in reasonable conditions for testing. This delay happened due to the fact that the conveyor which collects the leaves at the chamber exit (BC-9) was very narrow (36”), when the specification was 60” wide and a new conveyor installation (72”) was only implemented by the mill staff in the 2001/2002 crop. Only then there have been adequate conditions for chopped unburned cane processing without clogging problems (**Figure 33**).

Just before the beginning of the tests, a modification was made on the discharge plate slope from the BC-2 belt conveyor to the # 3 blowing chamber, making the cane flow closer to the air jet, increasing the blowing efficiency.

The performance of this chamber was acceptable and it could be verified that the new air jet positioning, which allows downward air blowing, is much more efficient. However, some minor corrections are still needed to optimize its operation. The BC-9 belt conveyor side guides are very wide, causing leaf accumulation over them, which create clogging, despite the fact of the wider conveyor (72”). Another point of leaves accumulation, is the sliding plate, just before reaching the BC-9 belt conveyor, which needs a higher slope.

Solving these two minor problems, there will certainly be a considerable increase in the chamber vegetal separation efficiency. Despite these problems, it could be noted that the amount of leaves removed by this chamber is already higher than with the previous versions of # 2 or # 3 chambers.

Rotary discs impurities separator

This equipment is used to recover cane stalks and cane chips, improperly collected together with the mineral impurities at the feeder tables, using a screening process. The recovered material returns to the cane conveyor BC-2 and the mineral impurities are taken to the BC-10 conveyor and directed to a trash bin. This separator was installed in place of the cush-cush, which was deactivated due to its low separation efficiency.

The cush-cush was kept in the system, but it is used just as a conveyor, since the layout did not allow its replacement by a belt conveyor. Its presence in the system is harmful, since the measured high pol losses in the impurities result mainly from a leakage of cane chips at the cush-cush, in a region where previously there was a vibratory perforated screen for impurities withdrawal. This screen was eliminated, but an opening remained at the transition region from the fixed part to the mobile part of the cush-cush bottom plate.

The equipment consists of several rotary discs with octagonal profile, spaced to form gaps around 7 mm wide, where the mineral

Figure 34

Rotary discs impurities separator.

impurities flow through, and are directed to the BC-10 impurities belt conveyor. The cane billets are carried by the rotary discs, taking advantage of their octagonal profile, following to the BC-2 cane belt conveyor (**Figure 34**).

The rotary discs separator was first installed during the 2000/2001 crop, when very often it presented choking problems. Frequently some small cane billets were blocked into the gaps between the discs, causing a belt slippage over the pulley in the equipment driver. During the 2001/2002 crop the belts and pulleys have been replaced by chains and sprockets and so this problem was fully solved.

This separator proved to be very efficient for mineral impurities removal, since most of the impurities are removed soon after passing by the first discs and the cane billets returning to the system are very clean. However, the biggest problem to be solved is the excessive wear on the tips of the discs, rounding the discs corners and lowering the cane billets transport efficiency. This problem was reduced during the crop and also along the tests period, with hard weld application over the affected area. More recently, a solution was developed for this problem, using plastic discs (UHMW) with hard surfaced inserts on the tips.

7.5 Dry Cleaning Station prototype evaluation - Test description

During November and December 2001, after modifications made in the prototype, tests have been carried out for its performance evaluation, considering only the processing of chopped unburned cane, in three different levels of vegetal impurities (corresponding to the three chopped cane harvesting alternatives with trash collection considered):

• Chopped unburned cane with normal speed of the harvester's primary extractor fan (trash is removed from cane in the field during the harvesting operation and then collected with proper equipment such as balers);

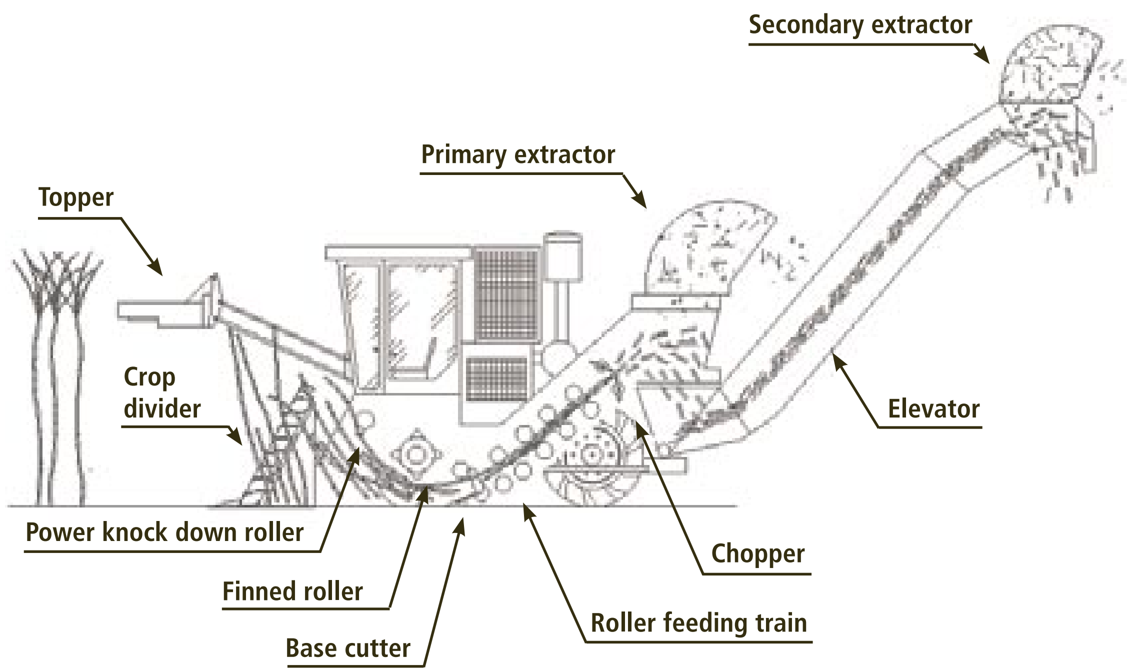
• Chopped unburned cane with low speed of the harvester's primary extractor fan (part of the trash is separated from the cane and left in the field for agronomic purposes and the rest of the trash is transported with the cane to the mill where the trash separation is executed by the Dry Cleaning Station);

• Chopped unburned cane with the harvester's primary extractor turned off (trash is not removed from the cane in the field. Cane and trash are transported to the mill to be separated using the Dry Cleaning Station).

For the alternative of trash recovery where part of it is left in the field and the other part transported to the mill, with the separation executed by the Dry Cleaning Station, setting of the harvester cleaning system is the main

Figure 35

Chopper harvester scheme.



factor determining the remaining trash in the field and, therefore, in the cane load. The harvester cleaning system adjustment for 50% trash left in the field was supposed to be the starting point for the studies.

The harvester's cleaning system (**Figure 35**) is constituted by a topper, used to remove the tops (immature internodes and green leaves attached to the top of the cane stalk) and by a set of extractors, identified as primary and secondary, used to remove the vegetal impurities (trash). The primary extractor has a speed control, while the secondary extractor has only the on/off switch.

The harvester performance and some parameters such as losses, vegetal and mineral impurities, load density, among others, are all influenced by the primary extractor speed. Lowering this speed, increases the vegetal impurities level in the cane load, reducing the load density and therefore raising the transport costs.

On the other hand, recent studies indicate that when dealing with unburned cane, it is convenient to keep an amount of trash coverage over the field, acting as a weed growth inhibiting effect. The minimum trash needed for the herbicide effect was studied in the topic "Benefits and problems of trash left in the field". The conclusion is that for trash levels higher than 7.5 t/ha, a higher than 90% efficiency control was obtained for yearly cycle weed, comparable to the majority of herbicide treatments successfully used in sugar cane plantations.

The most relevant issue is to set adequate primary extractor speed (keeping the secondary extractor turned off) to meet the requirement of the trash level in the cane load and therefore, in the fields. These levels are determined relatively to trash availability in the field, the expected amount of trash coverage over the field, and the transport cost versus trash economic value. The lower limit of speed control is harvester operation with both extractors turned off, carrying almost all field trash with the cane load. The higher limit is the harvester operation with both extractors turned on in normal speed, carrying trash that the harvester cleaning system couldn't remove. **Figure 36** shows aspects of trash remaining in the field after harvesting in three different operating conditions.

During tests to evaluate the Dry Cleaning Station efficiency, the two extreme harvesting conditions were set first:

(A) Harvester conventional cleaning, sending cane with the least amount of trash to the mill (and consequently to the Dry Cleaning Station)

(B) Harvester with the extractors turned off, sending all trash with the cane to the mill

An intermediate condition (C) was also evaluated, adjusting the cleaning efficiency of the harvester to an average point (C) to trace the Dry Cleaning Station efficiency for a partial cleaning condition.

The chopper-harvester used during the tests was the Santal Amazon, which uses a cleaning system different from the one shown in **Figure 35**, with only one extractor. It operated in three different extractor fan speeds, depending on the test condition. In the normal cleaning condition, the speed was 1200 rpm, in the condition without cleaning it was turned off, and in the intermediate cleaning condition it run at 800 rpm.

7.6 Dry Cleaning Station prototype evaluation - Test procedure

Four tests were carried out for each of the three chopped cane harvesting alternatives (three different levels of vegetal impurities). For each of these tests, four cane truck loads in the selected test condition were prepared for processing at the Dry Cleaning Station. When possible, cane from the same variety, age and area was used, which happened in most cases. Moreover, two tests were done per day and it was possible to alternate the three test conditions.

The four cane truck loads for each test added up to around 50 tons and were processed in about 20 minutes. The weight of the processed loads and the time for processing were registered to get the cane rate (tons/hour) of the prototype. The weight of the total impurities collected in the trash bin was also registered in each test.

During cane load processing, a sample of the net cane (around 300 kg) was collected at the prototype exit, and another one of the total impurities collected in the trash bin (around 10 kg). Analyses were done to determine, in dry and wet basis, the percentages in each sample of the mineral impurities (soil), vegetal impurities (leaves), tops and cane billets (or chips).

The sucrose content of all sampled components (mineral impurities, vegetal impurities, tops and cane billets), at the two sampling points, were analyzed.

Figure 36

Remaining trash in the field.

i) Harvesting area without cleaning.

ii) Harvesting area with partial cleaning.

iii) Harvesting area with conventional cleaning.

It is important to note that the analysis was done in the net cane and in the impurities leaving the prototype, and that the total weights were registered for the cane feeding the prototype and for impurities collected in the trash bin. The total impurities in cane feeding the prototype was calculated and not directly determined by sampling at this point. The sampling of clean sugar cane and impurities leaving the station was better than the sampling in the cane feeding system.

It is important to point out that tests performed at the end of 2001 are considered to be more representative of the real operating conditions than those executed in the 1997/1998 crop. In the former there were four tests in each cane/trash condition while in the latter only one test has been performed for unburned chopped cane with extractor fan on and two tests for the unburned chopped cane with the extractor fan off.

7.7 Test results

The mineral separation efficiency results had varied from 45% to 72%, depending on the type of processed cane (**Table 14**) and it had been lower than the results obtained in October, 1997, which varied from 67% to 73% for the same type of cane; therefore the station currently does not present the same screening conditions it had at that time, since the suggested modifications were not implemented.

Table 14

Test results - 2001/2002 crop (average of four tests for each harvester primary extractor speed).

Impurities	Harvester primary extractor speed		
% cane	Normal speed	Low speed	Turned off
		Processed cane (t/h)	
	201	150	111
		Cane impurities (wet basis)(1)	
Mineral	1.4	1.9	2.4
Vegetal	5.7	10.9	21.6
		Separation efficiency (dry basis)	
Mineral	45	63	72
Vegetal	55	56	60
Total(2)	46	45	60
		Pol losses in collected impurities(3)	
Mineral	0.11	0.18	0.32
Cane chips	1.01	2.38	4.58
Total	1.12	2.56	4.90

(1) Cane impurities (%) prior to processing at the Dry Cleaning Station.

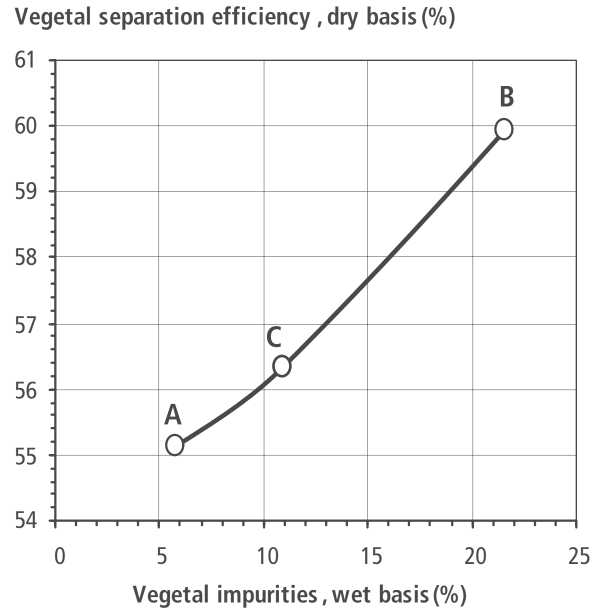
(2) Calculated as the percentage of total dry weight impurities (vegetal plus mineral) removed from initial dry weight impurities (vegetal plus mineral) in the cane prior to processing at the Dry Cleaning Station.

(3) Percentage of losses related to the initial amount of pol in the cane prior to processing at the Dry Cleaning Station.

On the other hand, the vegetal separation efficiencies, varied from 55% to 60% (**Figure 37**), also depending on the type of processed cane and remained above the results obtained in October, 1997, which varied from 48% to 55%, for the same type of cane, showing an operational improvement due to the new # 3 chamber.

High pol losses have been measured in the impurities, mainly due to the fact of a leakage of cane chips at the cush-cush, in a region where previously there was a vibratory perforated screen for mineral impurities removal; this screen was eliminated, but an opening remained at the transition region from the fixed part to the mobile part of the cush-cush bottom plate. Moreover, it also occured a leakage of cane chips through the gaps between the discs of the impurities rotary separator, due to the excessive wear of these discs.

Figure 37



Dry cleaning station vegetal separation efficiency related to the vegetal impurities level in cane. Point A refers to harvester conventional cleaning condition (normal speed of extractor fans) while point B refers to harvester with the extractors turned off, which are the two extreme conditions. Point C is the intermediate condition, where the harvester primary extractor fan was adjusted for a partial cleaning operation (primary extractor fan operating at low speed and secondary extractor turned off).

7.8 Comments

The values of mineral and vegetal impurities in the feeding cane, which were calculated based upon the data of the clean cane and of the collected impurities leaving the system, are consistent with the harvester primary extractor speed, increasing from higher to lower speed.

The mineral separation efficiency may be improved with the reassemble of the trapezoidal bars screen, previously installed in the bottom of the feeder tables.

The vegetal separation efficiency showed an improvement in comparison with the same one obtained in the previous condition of the Dry Cleaning Station. It is believed that the reason for this higher efficiency is the new design of # 3 blowing chamber, with downward air blowing, taking advantage of the gravity force to use less energy to deviate the leaves from its normal trajectory. However, this efficiency can be further improved if the previously mentioned problems in # 3 blowing chamber are solved.

The # 3 blowing chamber efficiency increased very much near the area where the effective leaves separation takes place, since a small deviation of the leaves from its normal trajectory enables its falling into the impurities collecting chamber. The problem is that after falling into this trash collecting chamber (over the BC-9 conveyor) its flow is impaired by the improper sliding plate slope and also by leaves accumulation over the slide guides of the BC-9 belt conveyor. These factors also make difficult the access of a higher quantity of leaves to the impurities collecting chamber, reducing the separation efficiency.

The downward air blowing used in # 3 chamber, should also be used in # 1 blowing chamber, which will certainly increase the separation efficiency.

Due to the high pol losses observed, it was suggested to close the openings in the cush-cush bottom plate. Alternatives are being studied to reduce the wear on the discs of the rotary impurities separator, trying to preserve the ideal gap for the impurities withdrawal during the entire crop to avoid the undue collection of cane chips.

For new cleaning station designs, to be installed in other sugar mills, the technology developed and implemented in Usina Quatá is being used as reference but modifications and improvements are considered, such as: separated collecting systems for mineral and vegetal impurities, more efficient trash blowing chambers (as # 3 chamber) and layout modifications that were not possible to implement in Usina Quatá.

8. Trash recovery: Baling machines

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Figure 38

Examples of the baling systems tested.

Small cylindrical.

Large cylindrical.

Small rectangular.

8.1. Introduction

Trash, the sugar cane harvesting residue and other forms of biomass are considered renewable fuel sources, and are usually found in very low-density forms. Recovery and transport costs are high and the required storage areas in the power generation facilities are large. The needs for equipment, labor and time restrictions inhibit the recovery of crop residues, due to the fact that farmers are concerned with their main product activities (harvesting or tillage). Trash recovery operation will also conflict with the efforts to maintain soil productivity (agronomic benefits) and to minimize soil erosion. Therefore, the interest of the farmer in recovering crop residues is directly dependent on the economic benefits.

Baling is as an alternative for harvesting residues recovery with increase in density and transformation of the biomass in uniform units (bales). Standardization and optimization of equipment lead to a reduction in residue recovery and transportation costs.

Baling studies and tests had the objective to consider the different baling systems, bale recovery and transport operations, baler field performance and mineral impurities (soil), making it possible to estimate biomass cost.

In 1991, Copersucar started a project that had the main purpose of studying the possibility to recover sugar cane trash after unburned cane harvesting. The idea was to test different baler models to verify their performance. The need of modifications or even new equipment development for cane trash recovery would be evaluated after the tests.

Tests were performed with Sode JS-90, Semeato ROL-1518 and New Holland NH-570 balers, the first and second of cylindrical bales (small and large respectively) and the third of small rectangular bales (**Figure 38**). Initial tests allowed an indication of the performance of the three balers, each one with a different bale compaction system (**Table 15**). Some other information about the bales was gathered, like the amount of soil in the bales, bale weight and density.

The choice of a given baling system considered bale characteristics such as: bulk density, integrity (handling/weathering), easiness of recovery and handling (form and size), easiness to stack (transport and storage) and size to optimize truckload.

The results from these preliminary baler tests performed by Copersucar Technology Center (CTC), with the purpose of studying the possibility to recover sugar cane trash after unburned cane harvesting, indicated that the baling system employed by the rectangular balers is the one with the best possibilities to succeed. First because of the higher operational baling performance (t/h), second because of its better ability to deal with the trash and pieces of cane, and third because of the better space utilization by the bales in the transportation truck. However, the difficulty in recovering large amounts of small rectangular bales from the field, and its stacking in the truck, indicated that large rectangular bales should be used.

Nevertheless, the system of large rectangular bales has some disadvantages like: high cost and weight of balers and the fact that rectangular bales have bad weather resistance, and should be moved to a covered area as soon as possible.

Baling operations took place usually 4 to 7 days after harvesting, being preceded by the raking of the trash. It is possible to bale the trash in non windrowed areas, but normally, raking operation is very important to improve baler performance and to reduce damage to the pick up system, that can work without direct earth contact. Another advantage of windrowing is to avoid fire propagation in case of any accident.

In 1997, several balers for large rectangular bales were identified. Two balers were selected, Case 8575 and Claas Quadrant 1200. The selection criteria considered basic characteristics, such as dimension, weight, need of tractor power and bale sizes. Besides machine technical aspects, the interest of the manufacturers (Case and Claas) in developing the market for this type of equipment in Brazil was paramount for this choice.

Both equipments are similar, with the basic difference in the size of the bale. Claas bales are 1.2 m (width) x 0.7 m (height) x adjustable length and Case bales 0.8 m (width) x 0.875 m (height) x adjustable length. Results of preliminary tests carried on by Copersucar indicated similar performance of both machines.

Case's decision to participate in the project of cane trash recovery, sending a machine for the tests, engineering support, implementation of modifications and tests, was essential for choosing Case 8575 baler to be used in the tests.

» Objective

The main objective was to measure large rectangular baler performance and efficiency under different conditions of trash preparation and to estimate the performance of equipment involved in bale recovery and transport for trash recovery cost determination.

Table 15

Baling information.

Type of bale / Baling system		Small round / Fixed drums	Large round / Belts	Small rectangular / Press
Baler operational capacity(1)	(t/h)	1.8	2.7	9.0(3)
Bale weight	(kg)	106	285	15
Bale bulk density	(kg/m³)	118	95	112
Soil in the bale	(%)	5.6	6.2	na
Trash(2) recovery efficiency	(%)	62	52	na

(1) Baling + maneuvers
(2) Green leaves, dry leaves and tops
(3) Preliminary tests – only baling and no maneuvers considered - na Non available data

8.2. Methodology

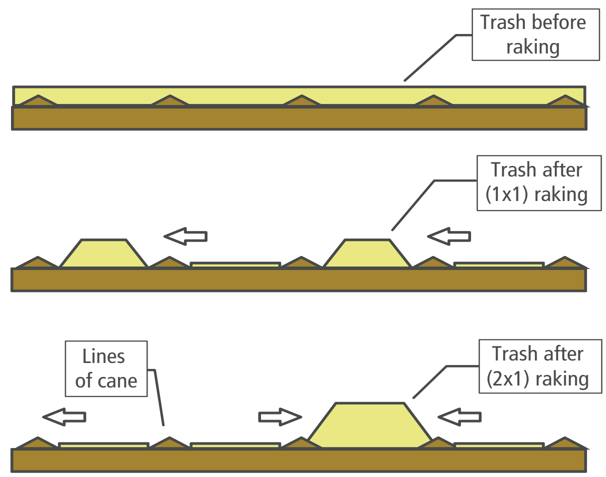
A baling experiment using Case 8575 large rectangular baler was carried out at Usina São Luiz AA (Pirassununga - SP) in a mechanized unburned cane-harvesting field.

Case 8575 baler characteristics:

- Purchase price - US$ 57,258.00 (FOB USA)
- Power needed from the tractor - 90 hp
- Weight - 5.1 t
- Size of the bales - 0.8 m (width) x 0.875 m (height) x adjustable length

During the test, all the necessary operations to recover and deliver the trash to the mill were carried out, such as raking, baling, bale recovery, bale transport to the sugar mill and finally bale unloading.

Figure 39



Raking alternatives tested.

With the purpose of measuring baler performance and efficiency under different conditions of trash preparation, tests were carried out in three areas of the same field. The first with the raking of one row of trash over one row (1x1), the second with the raking of two rows of trash over one row (2x1) and the third with no raking

Figure 40

Area preparation (raking) and baling with Case 8575 Baler.

Figure 41

Area after baling with the bales to be collected and grab loader loading bales on the transport truck.

Figure 42

Transport truck with the bales loaded being tied for transport to the sugar mill.

Figure 43

Bale sampling with a drill and special device for sample collecting.

(**Figure 39**). **Figure 40**, **Figure 41** and **Figure 42** show some of the operations being performed.

The transport trucks were weighed loaded and then empty (at the mill), and the load weight divided by the number of bales in the truck to determine the average weight per bale transported. Bales were then sampled for moisture content and mineral impurities (soil) determination (**Figure 43**).

8.3. Results

The performance of the baler was evaluated in the three areas. **Table 16** presents a summary of the operational baling results and bale characteristics.

Information on bale recovery, loading and transport performance estimate is presented in the topic "Trash recovery cost".

8.4. Conclusions and comments

The experiment showed that it is possible to recover sugar cane trash using conventional balers. Despite some problems addressed in the following paragraphs, the machine had a high operational performance and bale bulk density when compared to the tests originally carried on with other types of balers.

The baler had the best performance in terms of "Baled tons/hour (baling + maneuvers)" in the raking 2x1 (9.1 t/h) and no raking areas (9.8 t/h).

The good performance of the baler in the no raking area can be granted to the surface flatness in the experiment area. In areas where there are surface irregularities, the baler would have a poor performance and very low recovery efficiency if no raking was done. Therefore, this baling condition cannot be always considered an interesting option.

As for the quality, the bales from the no raking area contained the least amount of soil (3.3%) and showed the highest compaction level (dry density of 175 kg/m^3). Moisture content was low for all bales with an average of 13%.

The higher recovery efficiency was 84%, for the 2x1 raking area, as should be expected. Surprisingly, the recovery efficiency, determined for the no raking area (73%), was higher than the raking 1x1 area (56%). Here again, the surface flatness in the experiment area had great influence and this result should not be expected for the typical areas with sugar cane in Brazil.

Several problems associated with trash recovery were observed. Some are related to the baler, suggesting that improvements should be made; others related to the concept of collecting the trash from the ground, such as:

Table 16

Summary of baling tests results.

Bale parameters	Raking 1x1	Raking 2x1	No raking
Size (m)		0.80x0.87x1.9	
Average weight (kg)	242	306	295
Bulk density[(1)] (kg/m^3)	183	231	223
Average moisture content (%)	12.0	15.3	13.1
Soil (%)	3.5	4.7	3.3
Dry trash[(2)] (kg)	185	216	231
Dry density[(3)] (kg/m^3)	140	163	175
Baling operational parameters of dry clean trash			
Baled tons/hour (baling + maneuvers)	6.5	9.1	9.8
Diesel consumption (L/t of dry clean trash)	2.0	1.5	1.6
Recovery efficiency (%)[(4)]	56	84	73

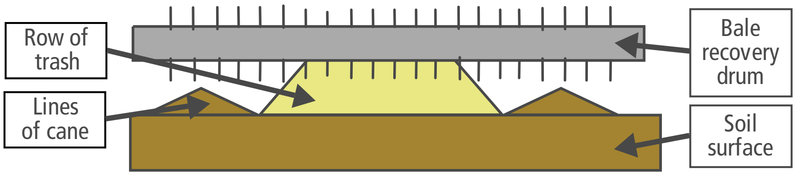
(1) Bulk density: it is the apparent density of the bale, calculated by the ratio: Average weight/volume of the bale.

(2) Dry trash: it is the mass of dry clean trash in a bale calculated by the equation: Average weight*(1 - (Soil% + Cane%)/100))*(1 - Moisture%/100).

(3) Dry density: it is the apparent density of the bale, considering the volume of the bale and the mass of dry clean trash. It is calculated by the ratio: Dry trash/volume of bale.

(4) Recovery efficiency: indicates the percentage of trash recovered in relation to available trash in the field after unburned cane harvesting and before baling.

Figure 44



Picture of the recovery system and a sketch showing incompatibility of width between bale recovery drum and lines of cane.

- Recovery system width not compatible with lines of cane width and soil irregularities (**Figure 44**);
- Time limitations after harvesting due to cane growth and tillage operations;
- Need of longer drying periods if it rains on the trash;
- Soil that is added to the trash during the raking operation and trash recovery;
- Choking problems in the baler recovery system due to the presence of high quantities of whole cane stalk left in the field by the harvesters;
- Premature components wear and bale plugging inside the baler in the presence of high moisture content and soil in the trash;
- Excessive field traffic with soil compaction and sugar cane stool damage;
- Lack of reliability of the baler, specially of the twine tying system;
- Need for twine removal and shredding of the bales at the mill if they are to be burnt in conventional furnaces or used in BIG-GT systems.

It is important to use adequate equipment for bale recovery from the field, loading, transport and unloading. Studies of the layout of the bales in the transportation truck body should be carried out to determine truck and bale length to optimize the transported volume and reduce the number of bales. The truck should tow one or two trailers (the maximum allowed by law to maximize transport load). These are some measures to be taken in order to reduce bale field recovery and transport costs.

9. Trash processing at the sugar mill

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9.1. Introduction

When considering the alternatives of sugar cane harvesting with trash collection, it can be concluded that the cane trash that is brought to the sugar mill (with the cane load or recovered from the field with balers) is not in an adequate form for feeding directly to boilers or to the gasifier. The long trash pieces and low density make it difficult to design a feeding system to handle this residue. When the trash is baled, an additional problem is the bale dismantling or cutting. Therefore, a trash processing system must be foreseen to grind this residue to a particle size and density condition where it can be handled by the gasifier feeding system.

Since bagasse, the other cane residue, is normally handled by the feeding system of the conventional bagasse boiler, it has been decided that bagasse fineness and density should be used as a reference condition for the processed trash.

» Objective

To verify the different existing systems that can process the trash, trying to get a particle size and density condition similar to the one observed for the bagasse.

9.2. Procedure

9.2.1. Equipment selection

Initial contacts with manufacturers of agricultural residue processing equipment have been made, to find out the alternatives already available in the market. Two basic concepts used in equipment design have been identified: knife cutters and hammer shredders. The former consists basically of a rotating cylinder with a series of parallel blades and comb type fixed blades which act like multiple shears, while the latter is a rotating cylinder with a number of hammers, either fixed or hinged, which pulverizes the material by impact.

One of the manufacturers suggested a system consisting of a knife cutter with a hammer shredder downstream; the cutter would reduce the trash to pieces no larger than 50 mm and the hammer mill would reduce the particle size even further.

A decision was made to test the alternatives, before defining the final concept, due to lack of experience of the manufacturers with cane trash and the need to have a processing system that would operate with low cost and low power consumption.

9.2.2. Equipment testing

The concepts of trash processing were tested with small scale equipment, due to the high cost of this equipment in commercial scale. **Table 17** lists the equipments that have been identified and made available for testing.

Table 17

Main characteristics of the equipment tested.

Manufacturer	Máquinas Tigre S.A.	Haybuster MFG	Dedini
Model	TSE-35/20	Big Bite H-1000	-
Type	Hammer Mill	Hammer Mill	Knife/ Hammer Mill
Installed power (hp)	15	110	50*

Only Hammer Mill power

The TSE – 35/20 is a small size hammer mill unit (15 hp) and it has only been used for preliminary testing of the operating principle and the particle size of the product.

The Big Bite H-1000 model of Haybuster MFG is another hammer mill equipment, but in a bigger size, driven by an electric motor of 110 hp, located at the bottom of a cylindrical shaped container for the material to be processed. It is normally used in Brazil to shred corn stalks for animal feed. It was tested with two types of trash bales (15 kg and 200 kg rectangular bales) without any operational problem. **Figure 45** shows the equipment, where the red part rotates while the equipment is in operation in order to force the material toward the rotor.

The Dedini shredding system that is installed at Usina São Luiz AA, in Pirassununga – SP, has been designed and built by Dedini as part of a small-scale prototype of a cane preparation and milling system. It is formed by a 380 mm wide set of fixed knives followed downstream by an oscillating hammer type shredder, both following the designs of conventional knives and shredders normally used in the sugar cane mills (**Figure 46**).

9.3. Test results

The TSE–35/20 machine has been tested with loose trash only as it is too small to handle even the smallest bales available. It proved to be able to produce shredded trash of particle size quite similar to bagasse (**Table 18**).

For the test of the Haybuster Big Bite H-1000 a conventional cane loader was used to feed the bales to the machine and the shredded trash was removed with a belt conveyor (**Figure 47**). The machine maximum capacity has been measured and as much as six 200 kg bales/per hour (~1200 kg/h) have been processed, but most of the time five bales (~1000 kg/h) could be considered as maximum capacity under continuous operation when three people have been required simultaneously (one machine operator, one assistant and one bale loader operator); the power consumption has been measured as 110 hp, but varied from 60 to 112 hp.

The Dedini shredding system installed at Usina São Luiz AA has been tested with and without the set of knives; with the knives in operation a slightly better result has been reached with respect to trash particle size but the capacity of the system was considerably decreased. With only the hammer mill in operation the results have been quite satisfactory. The hammer mill shredder was powered by a 50 hp electric motor.

More recently, preliminary tests have been conducted with an industrial Demuth equipment (**Figure 48**), normally used in pulp and paper industry. This equipment uses a total power of 400 hp and the concept of knife cutters.

The particle size results for the Demuth equipment are presented in **Table 19**, and an analysis of the greater particles is presented in **Table 20**.

9.4. Discussion and comments

Although no uniform data have been obtained in these tests to allow a reliable scale up of the system, they can be considered successful in respect to demonstrating the adequacy of knife and hammer mill shredders to process the sugar cane trash to a particle size similar to bagasse. The processed trash has been tried in the bagasse fired boiler-feeding system of Usina São Luiz AA and presented good results after minor adjustments.

Considering the test results and Copersucar knowledge on cane preparation equipment design – knives and shredders – a detailed design of a trash preparation system has been done for the typical mill based on Copersucar COP8 knives and COP5 shredder, both

Figure 45

Haybuster machine being fed with trash bales.

Figure 46

Knife and shredder system at Usina São Luiz AA.

Figure 47

Trash shredded by the Haybuster Big Bite H-1000.

Figure 48

Demuth shredder during trash test.

Table 18

Percentages of the total amount of trash retained in the screen.

ABNT screen(1)	Screen opening (mm)	TSE–35/20: 13mm back screen	TSE–35/20: 20mm back screen	Usina São Luiz AA, pilot plant: Knives + hammer mill	Usina São Luiz AA, pilot plant: Hammer mill only	Usina São Luiz AA, pilot plant: Haybuster Big Bite H-1000	% total bagasse (reference)
		% total trash					
6	3.36	-	-	21.0	49.0	38.6	34.2
7	2.80	27.8	58.4	-	-	-	-
12	1.68	-	-	12.5	12.9	12.0	11.8
18	1.00	38.2	20.0	12.5	11.8	10.0	11.8
30	0.59	16.1	10.5	17.0	12.4	13.0	24.2
40	0.42	7.7	2.9	16.0	8.3	11.0	10.0
Bottom	-	10.2	8.2	21.0	5.6	15.4	8.0

(1) ABNT – Associação Brasileira de Normas Técnicas (Brazilian Society for Technical Standards).

Table 19

Percentages of trash particles retained in the screen in the Demuth Test.

Screen opening (mm)	% total trash: Before shredding	% total trash: After shredding
12.70	66.2	19.1
6.35	4.9	8.0
4.76	1.8	4.8
3.36	1.9	6.4
2.38	2.1	6.8
2.00	0.9	2.6
1.68	1.2	3.5
1.19	1.6	4.6
1.00	1.2	2.0
0.84	0.9	3.4
0.59	1.2	4.8
0.42	1.6	6.0
Bottom	14.5	28.1

Table 20

Percentages of trash greater particles retained in the screen in the Demuth Test.

Mesh size (mm)	% total trash: Before shredding	% total trash: After shredding
Greater than12.70	66.2	19.1
Between 12.7 and 20	2.3	1.7
Between 20 and 40	5.2	6.5
Greater than 40	58.7	10.9

48 inch wide. The bales are fed to the system trough a feeding table and belt conveyor; the prepared trash is transported via a canvas belt conveyor to the gasifier or storage area.

For cases where the trash comes from the cane Dry Cleaning Station the trash is transported from the cleaning station to the processing system by belt conveyor.

One alternative that should be carefully considered in future studies is the modification of the gasifier feeding system to make it suitable to handle shredded trash, but not necessarily trash processed to bagasse-like sizing. This would save energy, reduce maintenance and investment costs in the trash processing system.

10. Unburned cane harvesting with trash recovery routes

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10.1. Introduction

The four pre selected routes for whole and chopped unburned cane harvesting with trash recovery are described in detail and results from tests performed with related equipment are presented. During the development of the project another alternative has been proposed, considering chopped sugar cane mechanical harvesting with partial cleaning.

» Objective

Test the different machines involved in the harvesting routes with trash recovery, determine their ability to deal with unburned cane and estimate their operational field capacities.

10.2. Methodology and results

10.2.1. ROUTE A

Considers unburned whole stalk harvesting with cane and trash left on the soil, whole stalk cane and trash transportation to the mill and cane and trash separation at a dry cleaning station at the mill site.

Route A consists of unburned whole stalk cane cutting with the Two-Row Whole Stalk Copersucar Harvester, leaving the cane in windrows (mats) on the ground. The recovery of this cane and transport to the field border is done by the Loader Transporter and then, loading of this cane into trucks with a Conventional Grab Loader. The cane is transported to the mill where trash is separated from cane at a Dry Cleaning Station. **Figure 49** until **Figure 54** show the sequence of field operations.

Figure 49

Two-Row Whole Stalk Copersucar Harvester.

Figure 50

Cane mats formed by the Copersucar Harvester.

Figure 51

Loader Transporter recovering cane.

Figure 52

Loader Transporter unloading cane at the border of the cane field.

Figure 53

Cane unloaded by the Loader Transporter at the border of the cane field.

Figure 54

Conventional Grab Loader loading cane into truck.

Figure 55

Set up of one of the plots for losses and trash determination.

This harvesting route presents advantages such as:

- Independence between harvesting and cane loading operations, avoiding to stop harvesting operations due to lack of trucks;
- No trucks traffic inside cane field, avoiding stool and truck damage;
- Optimization of truck loading operation, with the reduction of truck time in the field.

An experiment was performed at Copersucar Technology Center Station to determine the operational performance of the different equipment involved in this route. The determination of the losses and trash left in the field was carried out collecting the material from several plots of 11.2 m x 5 m (8 rows of cane x 5 m), randomly chosen in the field (**Figure 55**).

The collected material was classified (**Figure 56**) and weighed to estimate the amount of cane and trash left in the field per unit of area (tons per hectare). This classification allows the determination of the percentage of cane pieces, whole stalk cane and stumps from the total cane left in field.

At the area where the Conventional Grab Loader loaded cane left by the Loader Transporter into trucks, the losses of cane were weighed and compared to the loaded cane.

Figure 56

Classification of the material collected from the plots for the evaluation of cane and trash left in the field (10 cm segments in the scale).

Stumps Pieces Trash

The main results obtained at the tests for the Copersucar Harvester, Loader Transporter and Conventional Grab Loader are presented in **Table 21**.

Table 21

Results of the test with the system: Copersucar Whole Stalk Harvester - Loader Transporter - Conventional Grab Loader.

Copersucar Harvester	
Potential capacity (t/h)*	84.6
Fuel consumption (L/h)	24.0
Loader Transporter	
Potential capacity (t/h)*	46.8
Fuel consumption (L/h)	13.0
Conventional Grab Loader	
Potential capacity (t/h)*	87.1
Fuel consumption (L/h)	7.0

Impurities with the cane	
Mineral (soil %)	0.2
Vegetal (trash)	
Wet basis (%)	19.9
Dry Basis (%)	11.0
Cane losses	
at the field side (%)	0.22
in the field in relation to the clean stalks harvested (%)	3.5

* Potential capacity considers non stop work without maneuvers.

The experiment was carried out in an area with a yield of about 65 t/ha. Copersucar Whole Stalk Harvester had several problems when harvesting sugar cane fields with yields above 70 t/ha, or lodged cane. It was observed that major changes should be performed in the machine to overcome these problems. In fact, a new machine design would be needed. The Loader Transporter had problems too. Originally, it was not designed to work with unburned cane, so a high occurrence of cane choking was observed due to the greater amount of trash.

10.2.2. ROUTE B

Route B considers unburned whole stalk harvesting with cane and trash left on the soil. After that, cane and trash are collected and chopped. Cane is loaded into trucks and trash is left in field. Chopped cane is transported to the mill, and trash is baled and also transported to the mill.

The Copersucar Harvester cuts unburned whole stalk cane and lays it in windrows comprised of four rows of cane. After that, the continuous loader collects the cane and chops it in billets, removes the trash with a fan system and then the billets are transferred to the truck that follows the continuous loader. **Figure 57** until **Figure 62** show the sequence of field operations.

A summary of the results from the tests carried out at Copersucar Technology Center experimental station is presented in **Table 22**. Losses and trash left in the field were determined according to the methodology described in ROUTE A.

10.2.3. ROUTES C & D

ROUTE C

Considers unburned chopped cane harvesting with trash removal in the harvester (extractors working normally - conventional cleaning). Chopped cane is transported to the sugar mill, and trash is baled and also transported.

Figure 57

Two-Row Whole Stalk Copersucar Harvester cutting cane.

Figure 58

Cane rows formed by the Copersucar Harvester.

Figure 59

Continuous Loader processing cane and transferring it to the truck.

Figure 60

Continuous Loader removing trash and mineral impurities from cane billets.

Figure 61

Trash recovery with Case 8575 Baler.

Figure 62

Truck bales transport.

Table 22

Copersucar Harvester and Continuous Loader system performance results.

Copersucar Harvester	
Potential capacity (t/h)*	84.6
Fuel consumption (L/h)	24.0
Clean cane yield (t/ha)	44.4
Continuous Loader	
Potential capacity (t/h)*	32.0
Fuel consumption (L/h)	41.6
Trash left in the field	
Wet basis(t/ha)	5.5
Dry basis (t/ha)	4.8
Impurities with the cane	
Vegetal (trash)	
Wet basis (%)	19.9
Dry Basis (%)	10.3
Cane losses	
in the field in relation to the clean stalks harvested (%)	4.0

* Potential capacity considers non stop work without maneuvers.

ROUTE D

Route D considers chopped cane harvesting without trash removal (harvester extractors turned off -no cleaning). Cane and trash are transferred to the truck and transported to the mill where cane and trash are separated at the Dry Cleaning Station.

ADDITIONAL ALTERNATIVE

During the development of the project, an additional alternative was proposed, to evaluate chopped sugar cane mechanical harvesting with partial cleaning. This new operational condition considers leaving a certain amount of trash in field (around 50% of the total), and transporting the rest of the trash with the cane.

In some areas, the amount of trash left in field is equal or greater than 7.5 t/ha (dry matter). According to studies carried out by Copersucar (CTC), this amount of trash left in the field is enough to suppress weed growth, avoiding the use of herbicides. The rest of the trash, together with the harvested cane, is loaded on the trucks and transported to the mill where it is separated from the cane at a Dry Cleaning Station, to be used for energy purposes.

Figure 63

Chopped sugar cane harvesting.

Figure 64

Sugar cane transfer from haul-out units to road transport equipment.

To operate with partial cleaning, leaving 7.5 t/ha of trash on soil, it is necessary to adjust the speed of the harvester primary cleaning extractor fan. The secondary cleaning extractor should be turned off. The amount of trash left on the soil varies according to the speed of the primary extractor fan, characteristics of each cane variety, harvesting area and trash moisture.

To evaluate this new harvesting condition, an Austoft A7700 chopped cane harvester was used in a harvesting experiment in an unburned area at Usina São Martinho (**Figures 63** and **64**). Three distinct situations were tested: (1) harvesting with total cleaning, (2) harvesting with partial cleaning and (3) harvesting with no cleaning, in three different experiment areas located side by side (**Figure 65**).

This procedure attempts to reduce the influence of the characteristics of the area. Infield transport units were used to collect the harvested cane and transfer it to the trucks. In all three harvesting situations, three haul-out units were loaded in each truck trailer.

The results of the experiment for the three harvesting conditions are shown on **Table 23**. Here again, the methodology used to determine cane losses and trash left in the field was similar to that used for Route A. The main difference is relatated to the amount of trash left in field (**Figure 66**).

The experiments were carried out in a short period of no more than a week. Despite the short period, all the parameters were very well controlled. Previous tests performed with the different machines evaluated could guarantee confidence of the obtained data.

All described routes were analyzed from the operational point of view. The

Figure 65

Diagram of chopped sugar cane harvesting routes.

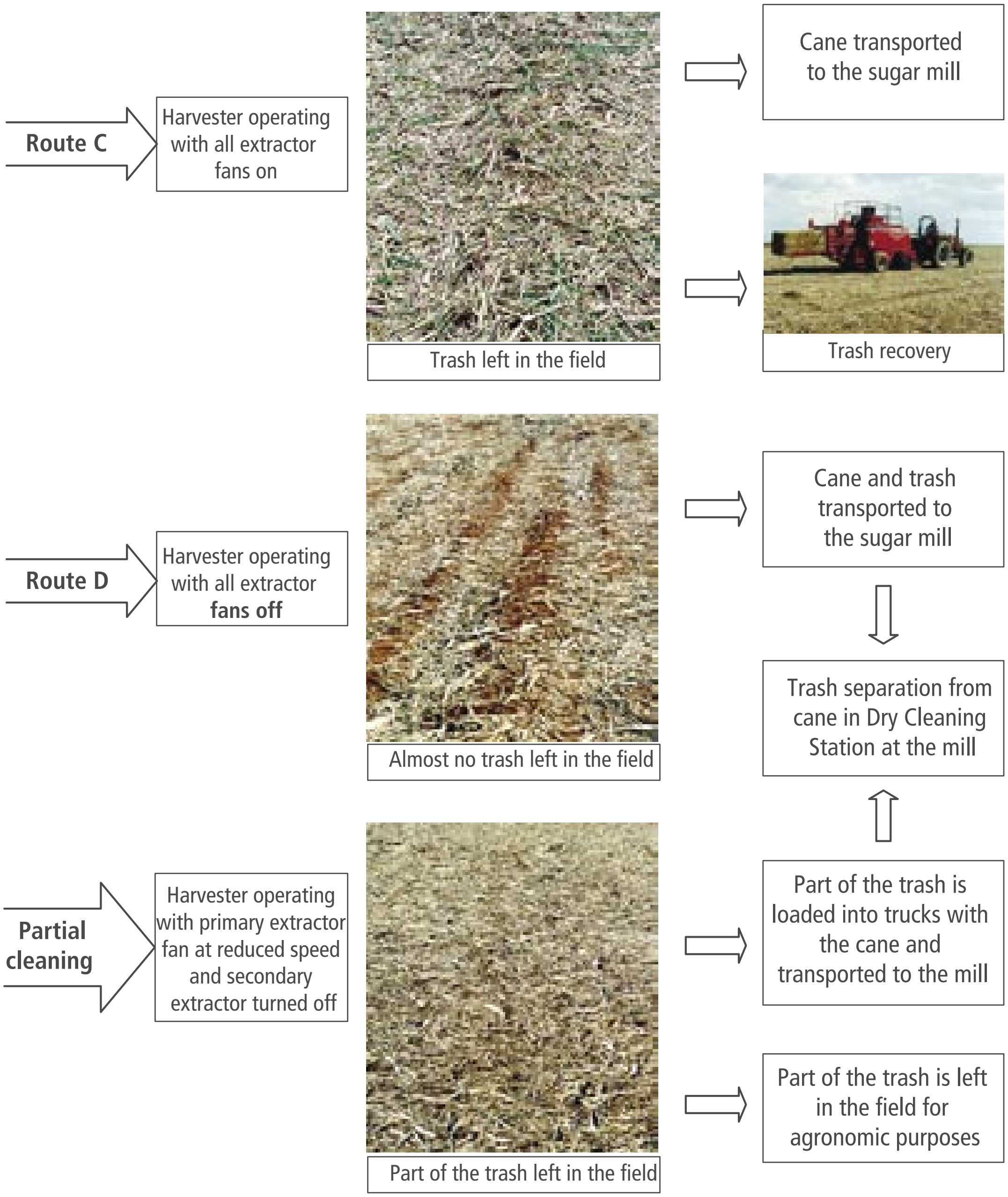

Figure 66

Trash collection and weighing from the selected plots for losses and trash evaluation.

Table 23

Field test results of chopped cane harvesting with conventional cleaning, partial cleaning and no cleaning.

Parameter	Conventional cleaning	Partial cleaning	No cleaning
Potential capacity – harvester (t/h)[1]	63	63	57
Sugar cane field yield (t/ha)[2]	139	148	156
Vegetal impurity			
Wet basis (%)	4.8	16	20
Dry basis (%)	2.3	11	15
Moisture content (%)	52	31	27
Mineral impurity (%)	0.10	0.22	0.38
Percentage of clean cane (%)[3]	95.1	83.8	79.6
Visible losses (t/ha)	3.7	2.0	1.7
Visible losses % clean cane	2.7	1.6	1.4
Clean cane yield estimate (t/ha)[4]	136	126	126
Average load per infield transport unit (t)	6.0	3.6	2.8
Truck load density (kg/m^3)[5]	410	270	240
Trash left on the soil			
Wet basis (t/ha)	17	7.7	1.5
Dry basis (t/ha)	16	7.0	1.4
Moisture content (%)	7.6	8.3	7.0
Harvester cleaning efficiency[6] (%)	83.4	30.1	5.7
Adjusted harvester cleaning efficiency[7] (%)	75.7	29.2	5.5

1 Potential capacity of the harvester (t/h): harvested material by the harvester per hour (t/h), considering non stop operation.

2 Sugar cane yield (t/ha): it is the load of cane harvested per hectare, including vegetal and mineral impurities.

3 Percentage of clean cane (%): it is the percentage of stalks of harvested cane, that is, 100 - vegetal impurities wet basis (%) - mineral impurities (%).

4 Clean cane yield estimate (t/ha): relates to the harvested stalks plus the losses left in the field, that is, [productivity of the sugar cane field (t/ha) x percentage of clean cane (%)] + Visible losses (t/ha).

5 Truck load density (kg/m^3): determined from the volume of the cane inside the trucks and trailers and its weight.

6 Harvester cleaning efficiency (%): percentage from the total trash that is left in the field by the harvester, calculated as: 100 x Trash left on the soil dry basis (t/ha)/ [Sugar cane yield (t/ha) x percentage of vegetal impurity dry basis (%) + Trash left on the soil dry basis (t/ha)].

7 Adjusted harvester cleaning efficiency (%): The analysis and use of the data described must take into account that the results were obtained with plant cane (1st cut), of high yield and high quantity of trash. In fields harvested after the first cut, with cane of medium or low yield, the operational conditions would be different. During the Project, other tests were performed with the harvester operating in different varieties and yield conditions. Despite the fact that these tests were not so complete as the presented, they allowed to adjust the harvester cleaning efficiency parameter, considering an average sugar cane yield of 83 t/ha.

operational restrictions of Copersucar Whole Stalk Harvester unabled it to be considered a reliable machine for Routes A and B. The machine could not harvest sugar cane fields with yield above 70 t/ha which are a great percentage of Brazilian fields. Therefore, further Routes analyses will consider only chopped cane harvesting (Routes C, D and Partial Cleaning).

The data obtained in these tests were used to perform the trash cost analyses. Not only the recovery and transport costs of the trash itself were taken into account. The different aspects of a given harvesting with trash recovery system were considered, such as the losses of cane in the field, mineral and vegetal impurities in the cane load (and the consequences at the mill) and field impacts (soil compaction, herbicide application, tillage operations, soil erosion, etc.).

10.3. Conclusions

All considered routes had their equipment tested for operational performance. It was verified that Copersucar Whole Stalk Harvester was not able to deal with lodged cane and cane with yield higher than 70 t/ha, that accounts for a high percentage of the Brazilian sugar cane fields. Therefore, Routes A and B that consider whole stalk cane can not be considered for the moment, until an appropriate machine for whole stalk harvesting is developed.

Routes C, D and the Partial Cleaning Route, which consider chopped cane harvesting, must be verified for cost and economic potential.

11. Potential trash biomass of the sugar cane plantation, including trash recovery factors

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11.1. Introduction

The amount of trash (green leaves, dry leaves and tops) in the sugar cane field, before harvesting, was designated as the potential trash availability. Tests were carried out with three sugar cane varieties (SP79-1011, SP80-1842 and RB72454), in two different regions in the State of São Paulo – Brazil (Piracicaba and Ribeirão Preto) and in three stages of cut: plant cane, 2nd ratoon and 4th ratoon (**Table 3**).

The average potential of sugar cane trash (dry matter) was determined as 14% of the mass of stalks (See item 1: "Potential trash biomass of the sugar cane plant"). This means that for each ton of sugar cane stalks there are 140 kg of dry trash. **Table 5** shows an estimate of the potential trash availability for the main sugar cane producing regions of the country.

The potential of sugar cane field residues is an estimate of the amount of trash in the field prior to the harvesting operation. The determination of the real availability of residues, which is the effective amount of trash that will reach the mill and become a biomass fuel, depends on the percentage of area of unburned sugar cane harvesting and of the recovery system efficiency.

» Objective

To estimate the amount of sugar cane trash available to be used for power generation in Brazil, considering the trash recovery alternatives of baling (Route C), whole cane harvesting (Route D) and partial cleaning (See item 10: "Unburned cane harvesting with trash recovery routes").

11.2. Considerations

The determination of the real availability of field residues at the mill depends on:

a) Considerations for the estimate of future field residue availability regarding the percentage of area of unburned sugar cane harvesting:

I. All unburned harvesting areas will be mechanized.

II. Unburned sugar cane harvesting: 100% in the State of São Paulo and 50% in the rest of the country, compelled by environmental laws.

b) Considerations for the estimate of future residue availability regarding the trash recovery system efficiency:

During the studies and tests of the different harvesting alternatives with trash collection (harvesting routes), three alternatives were considered operationally viable, with the cleaning and recovery efficiency determined during the tests:

1) Route C: Unburned chopped sugar cane harvesting with separation of trash from the cane by the harvester in the field (extractors on) and recovery of trash from the ground with balers.

2) Route D: Unburned chopped sugar cane harvesting, with harvester extractors turned off, and separation of trash from cane stalks at the mill site in a Dry Cleaning Station.

3) Partial Cleaning Route: Unburned chopped sugar cane harvesting, with partial cleaning done by the harvester, and the rest of the trash separation from cane stalks accomplished at the mill site in a Dry Cleaning Station.

Taking into account considerations I and II, the real availability of field residues (effective availability) was estimated for the three alternatives considered.

Table 24

Available million tons of biomass (dry matter) considering Route C for trash recovery.

Region	Dry residues potential	Baled* trash	Total trash at the mill*
São Paulo	25.4	16.3	22.4
Center South**	35.0	19.4	26.6
North - Northeast	7.2	2.3	3.2
Brazil	42.2	21.7	29.8

* Dry basis
** The Center South includes the State of São Paulo

11.3. Results

11.3.1. Route C

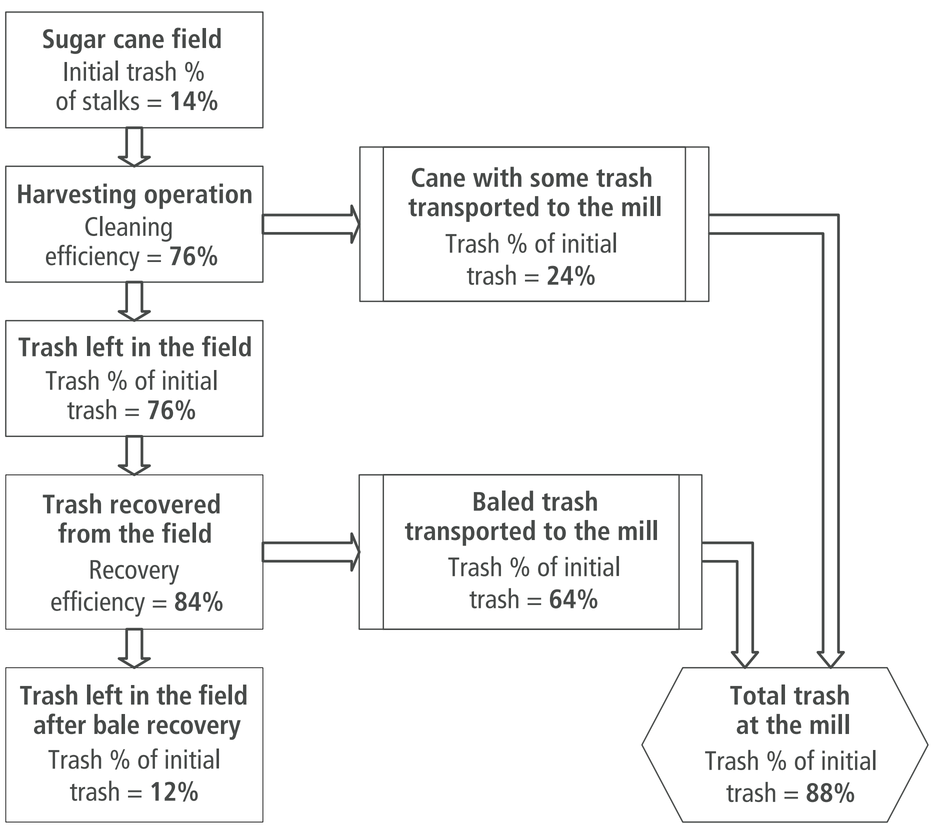
Chopped sugar cane is harvested from unburned fields, with cane trash removed in the harvester (topper, primary and secondary extractors turned on – cleaning efficiency of 76%) and trash recovered from the field using balers (recovery efficiency of 84%, raking two rows in one row). **Figure 67** describes the different operations and the related amount of trash (dry matter) for Route C. **Table 24** presents the total biomass recovered (total trash at the mill - dry matter) based on the potential of dry residues, the percentage of unburned cane harvesting area and Route C recovery efficiency.

11.3.2. Route D

Chopped sugar cane harvesting of unburned fields, without cane trash removal at the harvester (topper, primary and secondary extractors turned off – cleaning efficiency about 5%) and trash separation from cane at the mill with Copersucar Dry Cleaning Station (estimated achievable vegetal cleaning efficiency of 70%). **Figure 68** describes the different operations and the related amount of trash (dry matter) for Route D. **Table 25** presents the available biomass (dry matter) based on the potential of dry residues, percentage of unburned cane harvesting area and Route D recovery efficiency.

Figure 67

Diagram of Route C, with the associated operations and amount of trash.



11.3.3. Proposed Route: Partial Cleaning

Chopped sugar cane harvesting of unburned fields, with partial cane trash removal at the harvester (topper and secondary extractor turned off, primary extractor turned on but at reduced speed of approximately 700RPM – cleaning efficiency about 29%) and trash separation from the cane at the mill with Copersucar Dry Cleaning Station (estimated cleaning efficiency of 70%). **Figure 69** describes the different operations and the related amount of trash (dry matter) for the Partial Cleaning Route. **Table 26** presents the available biomass (dry matter) based on the potential of dry residues, the percentage of unburned cane harvesting area and Partial Cleaning Route recovery efficiency.

11.4. Comments and conclusions

It is important to remember that whatever is the form of trash separation from the cane, a certain amount of vegetal impurity (trash) will still remain with the cane and it will be crushed with the cane at the mill. This vegetal impurity should be considered in the industrial process as it influences the amount of bagasse produced.

It is therefore estimated that the potential of agricultural field residues for the sugar cane produced in Brazil is around 42.2 millions of metric tons, and most of it is nowadays burned before harvesting. Depending on the unburned sugar cane percentage

Table 25

Available million tons of biomass (dry matter) considering Route D for trash recovery.

Region	Dry residues potential	Trash separated from the cane*	Total trash at the mill*
São Paulo	25.4	16,8	24,1
Center South**	35.0	20.0	28.7
North - Northeast	7.2	2.4	3.4
Brazil	42.2	22.4	32.1

* Dry basis
** The Center South includes the State of São Paulo

Table 26

Available million tons of biomass (dry matter), considering Partial Cleaning Route for trash recovery.

Region	Dry residues potential	Trash separated from the cane*	Total trash at the mill*
São Paulo	25.4	12.7	18.0
Center South**	35.0	15.1	21.4
North - Northeast	7.2	1.8	2.6
Brazil	42.2	16.9	24.0

* Dry basis
** The Center South includes the State of São Paulo

Figure 68

Diagram of Route D, with the associated operations and amount of trash.

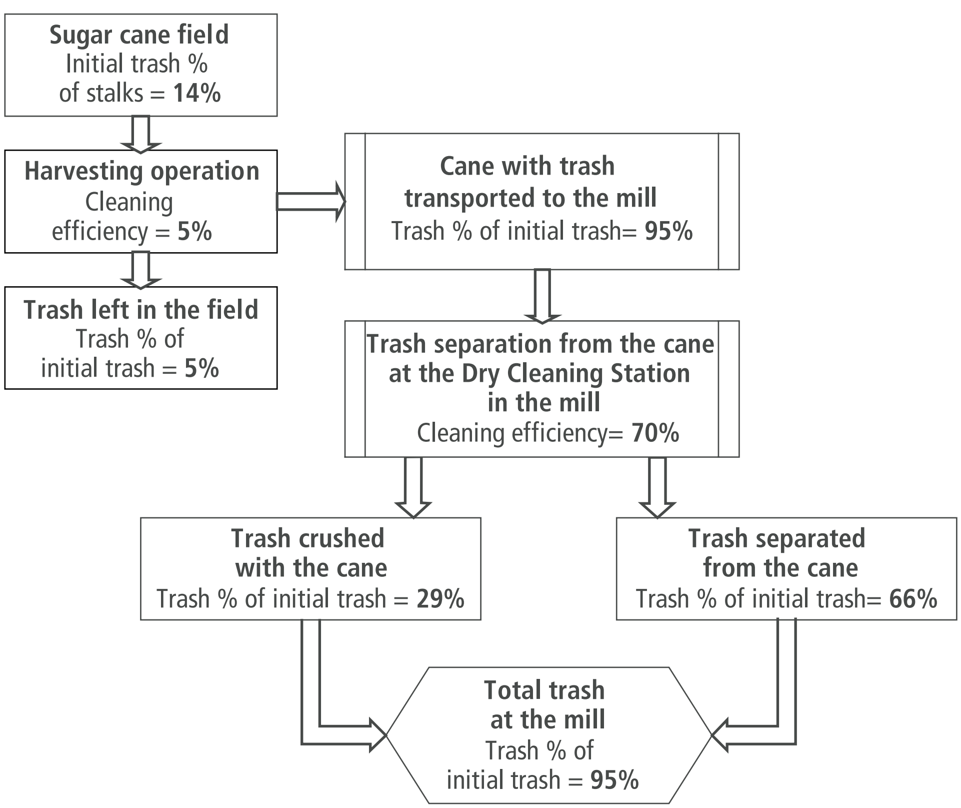
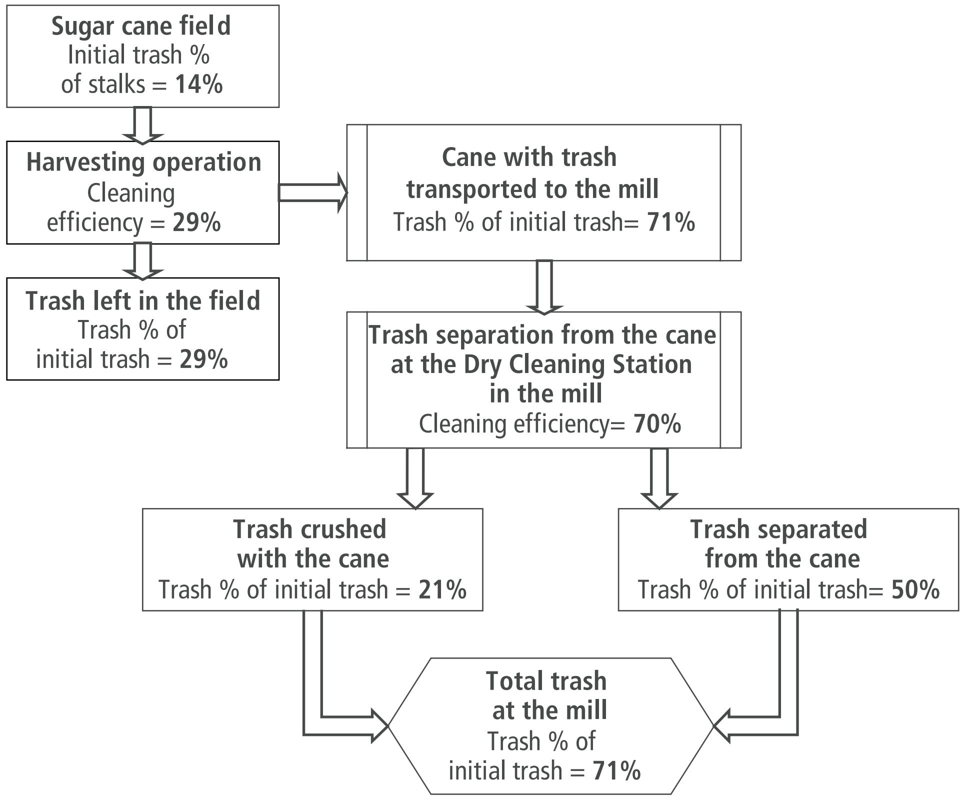


Figure 69

Diagram of the Partial Cleaning Route, with the associated operations and amount of trash.



and the recovery system employed, the collected amount of trash will vary. Considering the collected trash for the three-chopped sugar cane routes, the Partial Cleaning Route is the alternative bringing the least amount of trash to the mill (24.0 millions of metric tons), while with Route C and D is possible to get 29.8 and 32.1 millions of metric tons respectively.

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12.1. Introduction

The economic model for trash recovery cost assessment has been conceived to cover the three potential routes of cane harvesting with trash recovery. These alternatives assume that some trash is recovered and made available at the mill as supplementary fuel to bagasse, namely:

Alternative 1: the trash left in the field is baled, transported to the mill and shredded.

Alternative 2: the cane harvester is operated with the cleaning fans turned off; the trash is transported to the mill together with the cane and the trash/cane separation process takes place in the cane Dry Cleaning Station installed at the mill.

Alternative 3: the cane harvester cleaning system has the secondary cleaning fan turned off and the primary fan set at a convenient rpm; therefore, only a partial cleaning of the cane occurs during the harvesting operation, leaving a thinner trash blanket on the ground and the trash transported with the cane is separated in the cane Dry Cleaning Station at the mill.

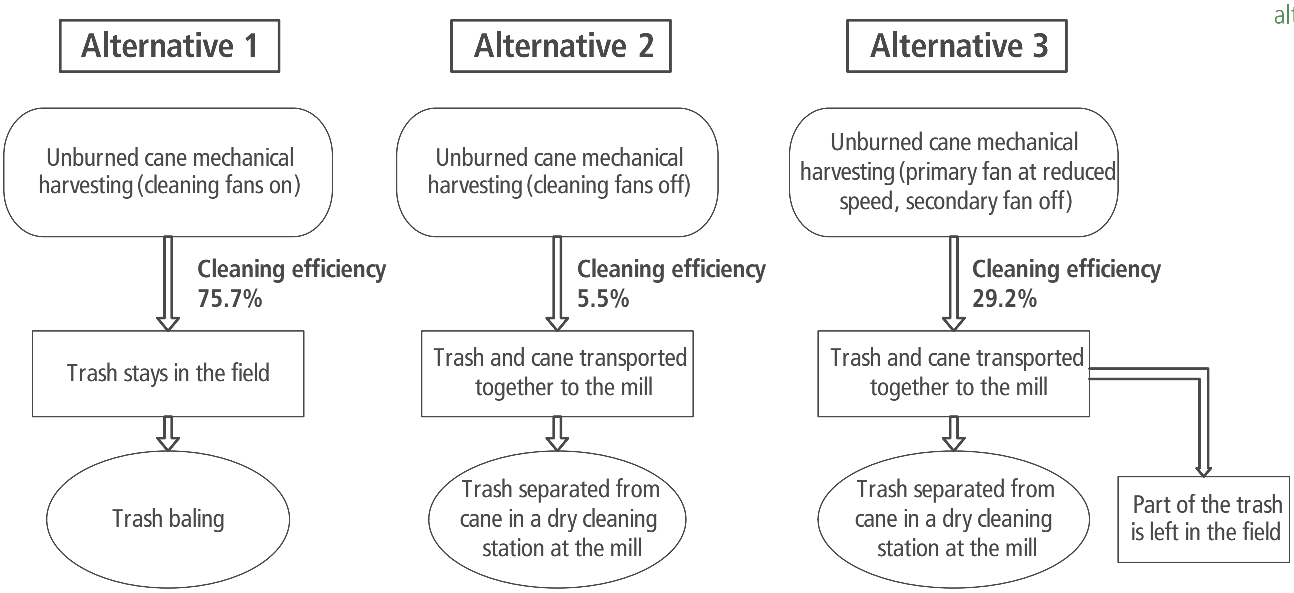
Figure 70 shows in simplified block diagrams the three trash recovery alternatives considered in this report. Two reference (baseline) harvesting conditions have been investigated:

- Manually harvested burned cane;
- Mechanically harvested chopped unburned cane, with normal cane cleaning by the harvester (cleaning fans on); the trash remains on the ground.

Both alternatives above assume that the only biomass available at the mill is the bagasse, residue of the cane juice extraction process. In this section, only the second baseline alternative is considered in the cost estimates, as most of the mills are being obliged by environmental laws to harvest unburned cane.

Figure 70

Trash recovery alternatives.



12.2. Considerations and methodology

The concept behind the economic model used to determine the trash cost at the mill was such as to take into account the several levels of details that could, somehow, interfere in the final cost of this biomass. It was sought that it had the capacity to take in account all economic effects caused by the generation, collection and delivery of the biomass to the mill.

The effects, positives or negatives, are quantified in the incremental form starting from the baseline, or the initial basic configuration, obtaining in this way the cost of the trash for each technical alternative considered.

In other words, the mill would start from the baseline configuration and it would make all technological modifications required to recover the biomass and deliver it to the mill to be used as fuel by the BIG-GT system. These modifications are identified separately and have the corresponding costs charged to the biomass depending on their impacts in sugar cane production and processing.

Some of these economic effects are:

- The mill has its harvesting process totally mechanized, harvesting chopped unburned cane, leaving the trash in the field, with the costs for operations such as baling, transportation, processing, agronomic impacts, herbicide use, cane productivity difference, soil compaction effects, etc, charged to the trash.
- Changes in activities to be performed for soil preparation, planting and tillage, either by the simple elimination of any activity or by the difference in equipment performance when executing these activities.
- Reduction of milling capacity due to the increase in fiber, due to the trash added to the cane.
- Decrease in juice extraction efficiency, due to carryover of sugar by this additional fiber from the vegetal impurities milled with the cane.

It is easy to see that the trash cost, as it does not result from a specific production process, can have different values as a function of the technology required to go from the baseline to the alternative being evaluated; therefore there can be a broad range for the trash cost due to the particularities of each case. The economic model used has been structured to take these differences into account either derived from the technologies used or from the effects of the different amounts of trash being left in the field or taken along with the cane to the mill.

The several routes for cane harvesting with trash recovery present different values for cane and sucrose losses as well as for equipment performance that must be taken into account in the economic analysis. The criterion used consists in determining the contribution margin of the lost cane, which is represented, in this case, by the difference between the income that the mill did not receive due to lost cane and the specific variable costs that have not been incurred due to the same reason.

Of course, in the cases being analyzed what is considered is the incremental contribution margin with respect to the basic technological situation – the baseline. In this study all incremental values determined will be charged to the biomass taken to the mill.

For the assessment of the capital costs, that includes the depreciation of assets and remuneration of the invested capital, the model adopts the concept of Capital Recovery Factor (CRF), calculated by:

$$CRF = [(1 + i)^n * i] / [(1 + i)^n - 1]$$

CRF Capital Recovery Factor
n Quantity of periods (years)
i Interest rate (15% per year has been adopted)

The economic model quantifies in the incremental form the effects (positives or negatives) of the trash blanket that remains in the field after unburned cane harvesting, always having as reference the technical configuration of the baseline, calculating in this way the trash cost for each alternative challenging the baseline.

The cane harvesting with trash recovery causes a series of modifications in the operations of soil preparation, planting and tillage. The efficiency and productivity of the harvesters are also affected by the speed of the cleaning fans that determines the amount of trash that is left on the ground or taken to the mill mixed with cane.

Besides the variation of the operating parameters of each activity performed, among the technical alternatives being economically compared, it has been noticed that the amount of trash being handled is a function of other "non-controllable" parameters that have some influence in the calculation of the trash cost of that route under analysis, such as:

- The quantity of trash depends on cane variety, age and other factors;
- The sprouting of the cane under the trash blanket is slow;
- The trash blanket inhibits weed growth; some types of weeds such as Cyperus rotundus are not affected by the trash blanket;
- The trash blanket increases microbial activities in soil surface layers;
- The trash blanket may decrease necessity of nitrogen fertilizers;
- The trash blanket in humid regions may cause ratoon rotting;
- The trash blanket helps to prevent soil erosion and hinders the photodecomposition of the organic matter;
- Unburned cane harvesting reduces local emissions of smoke and soot as well as loss of water;
- The trash blanket increases fire hazards.

These effects are hard to quantify but, nevertheless, in this work a series of experiments were planned and executed, in an attempt to put figures in what has been considered to be the major impacts. Although the parameters determined in those tests are affected by specific local conditions, they can be considered as reliable preliminary estimates. The data and assumptions used in this analysis are the following:

a) Cane field data

• Average cane productivity	83.23 t cane/ha
• Pol % cane	14.32%
• Fiber % cane	13.44%
• Trash % cane (dry basis)	14% (on the stalks)

The resulting average trash availability is, therefore, 11.65 t of trash/ha (dry basis).

b) Trash blanket effects

The noticed effects of the trash blanket on the ratoons are that the sprouting is slower and the quantity of sprouts smaller, but on the other side the diameter and length of the stalks seem to increase. No conclusion has been reached on the net effect, and it is highly dependent on local conditions of temperature and humidity. For this study, it has been assumed that the trash blanket has no direct effect on cane yield.

It is known that the trash has a significant amount of nitrogen and phosphorus, very important nutrients for cane; however, it could not be determined in the field tests if these nutrients are made available for the cane. This effect has also been disconsidered in the analyses.

Unburned cane harvesting eliminates smoke and soot from cane field burning. The trash blanket causes an increase of microbial activity in the soil top layers; it protects the soil from erosion and from direct sunshine. The possibility of reducing herbicide usage decreases the corresponding pollution.

In spite of these environmental benefits no economic credit has been given to them.

c) Herbicide effect

The use of herbicides in the cane fields, in areas free of trash, is a normal practice. The studies performed in the project have indicated that a certain minimum amount of trash uniformly distributed on the ground permits the control of weeds without application of herbicides, except for the most infested areas. These field tests, performed for several years, have shown that an uniform trash blanket of a minimum density of 7.5 tons/ha (dry basis) is sufficient to control weeds with an efficiency above 90% under most conditions; this density corresponds to about 66% of the total trash in the field, on the average. Below this value, weed control effect starts to deteriorate.

Due to the above, it has been assumed that the herbicide effect of the trash blanket and its influence on the performance of agricultural equipment and changes of agricultural practices should be included in the economic analyses, leading to the trash cost at the mill, in the form of **agricultural impacts – cost differences.**

12.3. Simulation model for equipment/system sizing

The need for a simulation model derives from the fact that the large number of cane harvesting and transportation interdependent activities makes it difficult to establish an adequate and manageable set of equations. Besides, the time required to execute each event has a stochastic distribution and the resources needed for some operations could be disputed according to logic criteria. In this way, the simulation tool presents itself as a viable technique to take all these parameter into consideration and to give a good support for the equipment and systems sizing.

The application of the simulation model for the sizing of harvesting and transportation fleet requires a large quantity of information obtained during field trials; these trials consist in the measurement of the time required for each specific event that occurs during the activities of the processes that somehow interfere with the efficiency of the activity.

The software ARENA (Systems Modeling) has been used as the simulation tool and has been set up to permit the simulation of each activity of the process of cane harvesting, transportation, weighing, sampling, unloading, milling and several others related to the flow of cane.

The results quantified by the simulation of the cane harvesting and transportation, for the three harvesting fronts, as close as possible to the assumed weighed average distance of 19 km, with the minimum quantity of equipment is summarized in **Table 27**.

Analyzing the figures presented in **Table 27** it can be seen that Alternative 2 - no cleaning - resulted in large deviations from the baseline, when compared with the other two. These deviations are consequences of the difference in cleaning efficiencies considered for Alternatives 1, 2 and 3 as 75.7%, 5.5% and 29.2%, respectively. The larger amount of vegetal impurities, or extraneous matter, in the sugar cane in Alternative 2 results in considerable reduction in the density of the transported cane and an increase of total tonnage of the material delivered to the mill (cane + impurities) causing a large impact to the number of tractors, transloaders (infield side tipper cane-transport equipment) and trucks required.

Table 27

Simulation technical parameters.

Items	Baseline	Alternative 1 (normal cleaning and baling)	Alternative 2 (no cleaning)	Alternative 3 (partial cleaning)
Harvested cane (t/day)*	6,474	6,474	7,231	7,265
Delivered cane (t/year)*	1,301,290	1,301,290	1,511,275	1,445,744
1. Harvesters				
Total quantity	10	10	13	10
Operating capacity (t/h)	24.1	24.1	24.1	25.7
Efficiency (%)	43.0	43.0	42.2	47.8
2. Towing tractors				
Total quantity	21	21	30	20
Operating capacity (t/h)	12.9	12.9	10.4	15.1
Efficiency (%)	32.2	32.2	74.5	55.8
3. Transloaders				
Total quantity	42	42	60	40
Operating capacity (t/h)	6.4	6.4	5.2	7.5
4. Trucks				
Total quantity	21	21	33	23
Average trips/day-vehicle	10.46	10.46	10.68	11.19
Operating capacity (t/trip)	29.59	29.59	21.31	28.09
Weighed average distance (km)	18.93	18.93	19.02	18.84
Technical coefficient (km/t cane)	1.279	1.279	1.785	1.341

(*) Cane + vegetal impurities (trash)

All Alternatives considered transport trucks with three trailers, with dimensions and load within the legal highway limits. For Alternative 1, load limits allowed accommodating 2 transloaders load per truck trailer (the cane loaded in the transloaders in the field by the harvester, during the harvesting operation, is transferred to the truck trailer at the side of the field), while Alternatives 2 and 3 accommodated three loads (where the limitation of volume was achieved before load limitations).

12.4. Data base

The following data for the agricultural and industrial areas have been determined with field tests specifically planned and executed for the project or obtained from Copersucar existing data base.

12.4.1. Agricultural area

The aim is to specify all parameters that affect in some way the total amount of cane and trash delivered to the mill. The technical data used in the simulations, related to the agricultural area are detailed.

Sugar cane - The typical mill considered in the analyses had the following conditions:

- Cane field useful life — 5 years
- Average distance from the harvesting fronts to the mill — 19 km
- Number of fronts harvesting simultaneously — 3 fronts
- Cane field yield, average 5 cuts — 83.23 t/ha
- Total cane in the fields, as clean cane stalks — 1.3 million t/year

The technical parameters for the cane harvesting with trash recovery alternatives selected for this study are shown in **Table 28**. The general data for the mill operation during the harvesting crop is presented in **Table 29**.

Table 28

Technical parameters for sugar cane harvesting with three trash recovery alternatives.

Items	Alternative 1	Alternative 2	Alternative 3
Mineral impurities (%)	0.11	0.30	0.19
Vegetal impurities (%)[a]	3.37	11.30	8.85
Moisture content (%)[b]	55.0	38.0	41.0
Cleaning efficiency (%)[c]	75.7	5.50	29.2
Visible losses (%)	3.45	1.20	1.60
Invisible losses (%)	3.40	3.40	3.40

(a) Dry basis;

(b) Moisture content in trash delivered to the mill with the cane;

(c) Harvester cleaning efficiency during harvesting.

Table 29

General data for sugar cane and impurities.

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Material delivered to mill (t)[a]	1,301,209	1,301,209	1,511,275	1,445,744
Vegetal impurities (t)[b]	97,577	97,577	275,418	216,837
Mineral impurities (t)	1,431	1,431	4,534	2,747
Clean cane at the mill (t)	1,202,282	1,202,282	1,231,323	1,226,160
Harvesting losses (t)	88,413	88,413	59,372	64,535
Cane in field (t)[c]	1,290,695	1,290,695	1,290,695	1,290,695

(a) Clean cane (stalks) + mineral and vegetal impurities;

(b) Total vegetal impurities (wet basis) delivered to the mill with the cane;

(c) It has been assumed the same amount of clean cane (stalks) in the fields to be harvested.

The total cane harvesting area can be estimated as 15,509 ha. Considering that 20% of this must be made available for planting (3,102 ha) and 10% of the planting area must be assigned to nursery (310 ha), it can be concluded that the total area required for the cane field is 18,921 ha.

Sugar cane trash - The basic parameters estimated for the average conditions of the trash recovery operations are:

• Baling machine trash recovery efficiency	84%
• Bale weight wet	305.8 kg
• Bale weight dry	215.5 kg
• Mineral impurities	4.70%
• Moisture content	15.3%
• Dry Cleaning Station efficiency	70% for vegetal impurities* and 80% for mineral impurities*

* Figures to be achieved after improvement of the Dry Cleaning Station.

With these data the trash balance can be summarized as shown in **Table 30**.

Table 30

Sugar cane trash (t dry basis).

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Trash in cane field	180,697	180,697	180,697	180,697
Trash transported with cane	43,909	43,909	170,759	127,934
Trash on the ground after harvesting	136,788	136,788	9,938	52,764
Baled trash	-	114,902	-	-
Quantity of bales in the field	-	533,187	-	-
Trash left in the field	136,788	21,886	9,938	52,764
Trash removed by the cleaning station	-	-	119,531	89,554
Total trash available at the mill	-	114,902	119,531	89,554

12.4.2. Industrial area

The parameters that affect any of the cane processing operations, specially milling, and have some impacts on the final amount of sugar, alcohol and bagasse produced are detailed in this item.

Cane preparation and milling:

• Sugar losses in cane washing operation	0.81%
• Loss of sugar in Dry Cleaning Station	1.69%
• Fiber % trash	50%
• Fiber % cane	13.44%
• Daily milling rate	7,110 t cane
• Cane milling % time available	90%
• Milling extraction efficiency	96.24%
• Pol of bagasse	1.89%
• Moisture % bagasse	48.67%

The only assumption made for this section is that the milling capacity of the mill tandem is a function of fiber of the milled material; this relationship can be expressed by the following equation:

MR= MN*[1–0.5*((FMM–FP)/FP)] t cane/day

MR= Milling capacity (t cane/day) for the average fiber of the milled material

MN= Milling capacity for standard cane fiber (7,110 t/day)

FMM= Average fiber of the milled material (cane + impurities)

FP= Standard average fiber for the typical mill (13.44%)

With this information, the situation for each alternative is summarized in **Table 31**.

Table 31

Characteristics of the material processed by the milling tandem.

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Quantity of cane at the cleaning station (%)	-	-	100	100
Pol % material at the mill (%)	14.32	14.32	14.08	14.08
Mineral impurity at the mill (%)	0.11	0.11	0.07	0.04
Vegetal impurity at the mill (%)	7.50	7.50	6.28	5.04
Fiber % vegetal impurity (%)[a]	45.0	45.0	62.0	59.0
Fiber % material at the mill (%)	15.81	15.81	16.49	15.73
Fiber variation (%)[b]	17.6	17.6	22.7	17.1
Quantity of milled material (t/year)	1,301,290	1,301,290	1,314,855	1,291,761
Effective milling rate (t/day)	6,484	6,484	6,302	6,503
Effective milling season (days)	201	201	209	199

(a) Wet basis (b) Related to Fiber % cane

Sugar and ethanol fabrication:

The cane juice extracted by the milling tandems is sent to the sugar and ethanol factories as 48% and 52%, respectively. The following parameters have been considered for the performance analysis of the two factories:

- Overall sugar fabrication efficiency 96.43%
- Overall alcohol fabrication efficiency 90.30%
- Alcohol grade (%w/w) 99.5%
- Conversion factor of TRS to sucrose 4%
(TRS = Total Reducing Sugar)
- Conversion factor of alcohol to sucrose 1.467
- Bagasse consumption by the mill 231 kg/t material at 48.67% moisture content

With the parameters characterized as above the production of sugar, alcohol and bagasse can be determined for each alternative, as summarized in **Table 32**.

Table 32

Mill production data.

Items	Baseline	Alternative 1	Alternative 2	Alternative 3
Bagasse production (t/year)[a]	416,037	416,037	438,591	411,104
Bagasse consumption (t/year)[a]	300,806	300,806	303,942	298,603
Bagasse surplus (t/year)[a and b]	115,230	115,230	134,649	112,501
Sugar production (t/year)	79,092	79,092	79,455	79,355
Alcohol production (m^3/year)	54,969	54,969	55,221	55,151

(a) Wet basis; (b) Bagasse surplus = Bagasse produced – bagasse consumed in the boilers

12.5. Price data and unit costs of activities and processes

The cost to be assigned to a byproduct is normally difficult to characterize and involves subjective criteria in the attempt to split some of the processing costs between the main products and the by product.

The biomass resulting from cane harvesting and processing, bagasse and trash, is a good example of this situation. To obtain the preliminary economic results it has been assumed that the initial reference condition (baseline) would be when the mills are mechanically harvesting chopped unburned cane, with the harvester separating the trash from the cane and leaving the trash in the field.

The economic analysis has also been performed considering as baseline the present situation (year 2003) where burned cane is harvested manually, which reflects the condition of approximately 80% of the cane milled in Brazil. However, it has been also realized that the change from manually harvested burned cane to mechanically harvested unburned cane would not be primarily driven by the necessity or interest to recover and use the trash, but by other reasons such as environmental, legal and population pressure, labor shortage, cost and others. This change will probably take place gradually, independent of the interest in using or not the trash.

For the sake of simplicity, this report will present only the cases where the baseline is mechanically harvested chopped unburned cane with the trash left on the ground in the form of a uniform blanket. The mills that are today partially in this situation are the ones that have shown interest in recovering and using part of the resulting trash.

Starting from the baseline, all the specific changes introduced in the sugar cane production and processing activities to recover the trash are determined and the corresponding incremental costs, either positive or negative, are charged to the total cost of this byproduct – the trash. The concept adopted is to divide the two quantities:

a) The difference between the economic results of the baseline situation and those of each alternative analyzed;

b) The quantity of trash recovered in each alternative.

12.6. Costs of the production processes in the sugar cane agribusiness

Since the activities that form the processes are well known as well as the corresponding equipment, machines, vehicles and accessories required to perform them, the unit cost of each activity can be obtained and, consequently, the unit cost of each process. The sugar cane production processes are: soil preparation, planting, harvesting, transport and tillage.

In the alternatives evaluated here there are variations in the activities as well as in the operating capacity of the equipment involved. The processes listed in the preceding paragraph can be executed in two ways: first without the trash blanket and second with the trash blanket. **Table 33** shows the unit cost for each of these processes in the alternatives being evaluated.

Table 33

Unit cost of cane production processes.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Soil preparation	US$/ha	215.22	183.37	183.37	215.22
Planting	US$/ha	482.84	482.84	482.84	482.84
Harvesting	US$/t material	4.82	4.82	5.99	4.51
Tillage	US$/ha	86.41[a]	144.74	144.74	86.41[a]

(a) Without the herbicide effect of the trash this value is US$ 130.90/ha

12.7. Economic and financial data

The following selling prices, free of taxes, have been assumed for the products:

- Sugar US$ 120.00/t
- Alcohol US$ 145.00/m^3
- Bagasse US$ 5.00/t (wet basis)

The production variable costs have been considered as:

- Cane washing US$ 0.60/t material
- Cane milling US$ 1.00/t material
- Sugar fabrication US$ 40.00/t sugar
- Alcohol fabrication US$ 55.00/m^3 alcohol
- Taxes on milled cane US$ 0.60/t cane

12.8. Cane field loss of productivity

It has been estimated that the average loss of productivity of the cane fields is around 11% and 5% in areas of clay or sandy soils, respectively, due to the effects of soil compaction and rotoon damage resulting from the operations to recover the trash in Alternative 1 (baling).

Considering that in the State of São Paulo the cane fields are 72.7% in clay soil areas, we would have a weighed average productivity loss of 6.23 t cane/ha, already assuming that the loss will happen after the first cut and an average cane yield of 83.23 t cane/ha.

This results in an additional cost of US$ 17.85/ha-year, charged to the trash, corresponding to US$ 2.41/t (dry basis) namely for the **agricultural impacts – loss of productivity** (due to soil compaction and ratoon damage).

12.9. Opportunity cost of the trash in the field – cost difference in soil preparation and tillage

This effect refers to the changes in activities related to soil preparation and tillage, when they are performed with and without the trash blanket. These costs are detailed in **Table 34** for all alternatives. The planting cost has been assumed to be US$ 482.84/ha, the same for all alternatives analyzed.

12.10. Trash processing

The sugar cane trash as it is found in the fields or separated in the cane Dry Cleaning Station comes in pieces of lengths too long to be handled by the gasifier feeding system. Therefore, it must be reduced to pieces smaller than two inches and with density above 60 kg/m^3.

The trash preparation system designed to produce a condition that the trash can be fed to the gasifier has an estimate investment cost of US$ 453,400. Considering an useful life of 15 year, residual value of 10% and an interest rate of 15% per year results in annual capital recovery cost (CRC) of US$ 76,586. The system will operate 24 hours/day during 222 days/year with an annual maintenance cost estimated in 20% of the CRC and an administration cost of 10% of the total cost; the resulting annual trash preparation cost is US$ 102,115. **Table 35** shows the unit trash preparation costs for each alternative.

12.11. Sugar cane cleaning at the mill

The trash recovery process for Alternatives 2 and 3 takes place in the cane Dry Cleaning Station located at the mill. This process that separates the trash from the cane prior to the milling operation is necessary to avoid the deleterious effects that the excessive impurities in the cane would create during its processing in the factory.

Table 34

Technical parameters and costs of agricultural processes.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Soil preparation costs	(US$/ha)	215.22	183.37	183.37	215.22
Tillage costs					
– with herbicide effect	(US$/ha)	86.41	144.74	144.74	86.41
– no herbicide effect	(US$/ha)	130.96	144.74	144.74	130.96
Trash in the process?		Yes	No	No	Yes
Is there the herbicide effect?		Yes	No	No	No
Cane field useful life	(years)	5	5	5	5
Change in preparation costs	(US$/ha)	-	-31.85	-31.85	-
Change in annual preparation costs	(US$/ha-year)	-	-7.75	-7.75	-
Change in tillage cost	(US$/ha)	-	58.32	58.32	44.55
Change in annual tillage costs	(US$/ha-year)[a]	-	49.14	49.14	37.53
Difference in preparation costs	(US$/t of trash db)	-	-1.05	-1.01	-
Difference in tillage costs	(US$/t of trash db)	-	6.63	6.38	6.50
Opportunity cost of trash	(US$/ t db)	-	5.59	5.37	6.50

(a) Only for the last four years of useful life of the cane field.
(db) Dry basis

Table 35

Unit trash preparation costs.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Total recovered trash	(t db)	-	114,902	119,531	89,554
Annual trash processing cost	(US$)	-	102,115	102,115	102,115
Unit preparation cost	(US$/t of trash db)	-	0.89	0.85	1.14

(db) Dry basis

The technical parameters related to the cane Dry Cleaning Station that are necessary to determine the cost of this activity are:

- Annual capital recovery cost (CRC) US$ 186,939
- Annual maintenance cost 20% of CRC
- Annual administration cost 10% of total annual cost
- Electric power consumption 228 kW
- Power cost US$ 47.06/MWh
- Labor 1 person per shift at US$ 1.78/h

Considering that the cane Dry Cleaning Station will operate as long as the milling tandem is in operation, the total operating costs of the station assigned to the trash are shown in **Table 36.** The benefits of processing a cleaner cane are taken in account in the final production data.

Table 36

Trash separation costs.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Total operating days/year	-	-	-	233	222
Operating capacity	(t db/h)	-	-	23.83	18.75
Trash separation cost	(US$/t db)	-	-	2.79	3.69

(db) Dry basis

12.12. Cost of trash placed at the mill

The cost of taking the trash to the mill in Alternative 1 can be obtained in a very straightforward manner, just by adding the cost of each activity along the process. However, for Alternatives 2 and 3 the trash is transported together with the cane, interfering in the normal process parameters. This can become clear if the data in **Table 37** are analyzed.

The economic model used establishes that the differences in costs of the activities of harvesting and cane transportation between the Alternative in question and the baseline shall be charged to the trash and not to the cane. With this concept, the trash transportation costs for the different Alternatives are shown in **Table 38**.

The delivery cost of trash in Alternative 1 has been determined as US$ 9.61/t dry basis as result from adding the various activities costs for the whole process, since there is no change in the characteristics of the material (cane + impurities) delivered to the mill as compared with the baseline. The unit costs (US$/t of trash) of Alternative 1 are:

- Windrowing US$ 0.60/t dry basis
- Baling US$ 3.94/t dry basis
- Bale loading US$ 1.43/t dry basis
- Trailer towing US$ 1.18/t dry basis
- Bale transportation US$ 1.95/t dry basis
- Bale unloading US$ 0.51/t dry basis

Table 37

Technical parameters and cost of material (cane + vegetal and mineral impurities) at the mill.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Mineral impurity	(%)	0.11	0.11	0.30	0.19
Vegetal impurity	(%)[a]	7.50	7.50	18.22	15.00
Moisture content of vegetal impurity	(%)	55.00	55.00	38.00	41.00
Quantity of material	(t)	1,301,290	1,301,290	1,511,275	1,445,744
Material transportation cost	(US$/t)	4.82	4.82	5.99	4.51

(a) Wet basis

Table 38

Trash transportation costs.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Total transportation cost	(US$/year)	6,275,197	6,275,197	9,052,092	6,520,401
Difference charged to trash	(US$/year)	-	-	2 776,896	245,204
Total trash at the mill	(t/year db)	-	114,902	119,531	89,554
Cost of trash at the mill	(US$/t db)	-	-	23.23	2.74

(db) Dry basis

12.13. Effects of differences in the industrial process

Knowing the final expected production of sugar, alcohol and bagasse and the corresponding selling prices and production costs, the changes in the industrial processing results can be determined. This difference, in terms of margin of contribution, in comparison with the baseline, for each Alternative, is shown in **Table 39**.

Table 39

Trash cost (US$ thousand/year) – Industrial effects.

Items		Baseline	Alternative 1	Alternative 2	Alternative 3
Income		18,037.7	18,037.7	18,214.8	18,082.0
Sugar		9,491.1	9,491.1	9,534.5	9,522.7
Alcohol		7,970.5	7,970.5	8,007.0	7,997.0
Bagasse		576.2	576.2	673.2	562.5
Costs		7,488.3	7,488.3	7,530.2	7,499.3
Milling		1,301.3	1,301.3	1,314.9	1,291.8
Sugar fabrication		3,163.7	3,163.7	3,178.2	3,174.2
Alcohol fabrication		3,023.3	3,023.3	3,037.1	3,033.3
Mixed margin of contribution		10,549.5	10,549.5	10,684.6	10,582.8
Difference from the baseline		-	-	-135.2	-33.3
Total trash delivered	(t/year)	-	-	119,531	89,554
Trash cost	(US$/t db)	-	-	-1.13	-0.37

(db) Dry basis

Table 40

Total trash cost (US$/t dry basis)

Items	Alternative 1	Alternative 2	Alternative 3
Deliver trash to mill	9.61	23.23	2.74
Loss of productivity	2.41	-	-
Opportunity cost of trash in field	5.59	5.37	6.50
Trash separation from cane	-	2.79	3.69
Trash processing	0.89	0.85	1.14
Difference of industrial results	-	-1.13	-0.37
Trash total cost	18.49	31.12	13.70

12.14. Trash total cost

The trash total cost determined under the conditions described earlier, detailed in all phases of the processes of sugar cane production and processing, is shown in **Table 40**.

It is important to point out that the total cost includes a margin of 10% assigned as administration costs to be on the conservative side.

For all alternatives, it has been considered that the trucks would have to obey the truckload limitation by Federal and State Laws. In cases where trucks travel mainly on private or side roads, sugar cane truck load would be increased for the baseline, resulting in an increase of trash costs for Alternatives 2 and 3.

Table 41

Trash summary results.

Items	Alternative 1	Alternative 2	Alternative 3
Trash available in the cane field (t db/year)	180,697	180,697	180,697
Trash recovered (t db/year)	114,902	119,531	89,554
Recovery efficiency (%)	64	66	50
Cost of trash (US$/t db)	18.49	31.12	13.70

(db) Dry basis

12.15. Conclusions and comments

It is worth to notice that in the cost estimates for each alternative it has been tried to take into account all known interference of the trash recovery activities with the normal agricultural and industrial operation, especially those related to losses in sucrose, equipment performance and process efficiency, such as:

• Difference in milling rates and loss of pol in the bagasse due the differences in vegetal impurities in the cane.

• Difference in the operating capacities of the equipment executing the same operation with different amount of trash in the process.

• Agronomic effects, positives and negatives, due to the trash blanket in the field or the influence of introducing new activities (such as baling) on the ratoon.

All the costs have been determined considering the baseline of a mill mechanically harvesting chopped unburned cane and leaving the trash blanket in the field.

A summary of the results for all alternatives is presented in **Table 41**.

Alternative 3 has been introduced during the development of project and seems to be the winning option considering that it can be further optimized. The main reason for its introduction has not proved to be true: it was a tentative to recover part of the trash and still maintain a trash blanket in the field to obtain the herbicide effect; for the average conditions the trash blanket density of 5.36 t dry basis/ha has not been considered adequate to accomplish this effect.

13. Test of "Atmospheric Circulating Fluidized Bed" (ACFB) gasification process with sugar cane bagasse and trash

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13.1. Introduction

One of the most important immediate objectives of the project is to test the sugar cane residues – bagasse and trash, as gasifier fuels. These tests required large amount of those residues, in adequate conditions, at the test site in Nyköping, Sweden; these samples were collected in mills in Brazil and shipped to Sweden, in quantity and conditions required for the several types of test planned.

The planned tests were intended to supplement those performed in the Brazilian Woodchips Project (WBP) in such way that all points of concern were thoroughly investigated and that all information required to define the gasifier operating conditions and plant scale up was obtained.

Initially the pilot plant tests were limited to bagasse and consisted of one shake down and two performance tests. Due to limitations in the gasifier feeding systems, at the time, the tests were performed with pelletized bagasse. Later on, the gasifier feeding system was upgraded to be able to handle low density loose residues such as sugar cane bagasse and trash; additional funds were provided by the European Commission (EC) and the Swedish National Energy Agency (STEM) making it possible the execution of four more pilot plant tests.

The fuels tested were loose shredded trash (one shake down and two performance tests) and a mixture of bagasse and trash (one performance test).

The total of seven successful pilot plant tests were considered sufficient for the assessment of the adequacy of the two biomass fuels in question and the gathering of information for the BIG-GT plant scale up and simulations.

» Objective

To characterize sugar cane bagasse and trash as fuels, to determine the operating windows for the gasifier, and to generate the information required for the plant scale up and process simulations.

13.2. Methodology

The activities planned for this immediate objective can be grouped in four sets:

- Test sample preparation: The large size of the test samples, mainly due to the pilot plant tests requirement, and the limitations of the gasifier feeding system demanded a careful planning of this activity to minimize the transportation costs and difficulties in material handling and feeding.
- Laboratory tests: These are physical and chemical analyses aiming to determine the biomass characteristics that are important for the combustion process; they consisted mostly of standard procedures such as proximate and ultimate analysis, ash melting temperatures, that are widely used for fossil fuels, adapted for biomass – TPS performed these tests for the samples received to confirm the results obtained by Copersucar Technology Center (CTC) in more extensive tests.
- Bench scale tests: These tests were performed to determine safe operating windows for the pilot plant and to anticipate potential problems such as ash agglomeration.
- Pilot plant tests: These are the tests that defined the real adequacy of the sugar cane residues as gasifier fuels, the fuels preprocessing requirements and provided the information required for the scale up of the BIG-GT plant and to perform the process simulation for the integration of the gasifier/gas turbine and BIG-GT plant and mill. The details of the above activities are provided below.

13.3. Test sample preparation

In the scope of work of the Project BRA/96/G31, laboratory, bench scale and pilot plant tests have been included for both bagasse and trash to verify the adequacy and characteristics of these two sugar cane residues as fuel for “atmospheric circulating fluidized bed gasifiers” (ACFBG). TPS – Termiska Processer AB has been contracted to perform these tests which initially included laboratory and bench scale tests for bagasse and trash and three pilot plant tests for bagasse only; later on four additional tests, three with trash and one with a mixture of bagasse and trash have been included. These additional tests have been made possible by funds coming from the European Commission and the Swedish National Energy Agency.

Copersucar was in charge to supply the test samples of bagasse, trash and Brazilian dolomite.

For the first batch of pilot plant tests, the bagasse had to be supplied in the form of pellets due to the fact that the TPS pilot plant feeding system was not capable of handling low-density materials such as loose bagasse. The corresponding set of samples was:

• Loose bagasse	10 m^3
• Moisture % bagasse	50%
• Shredded trash	10 m^3
Particle size	Similar to bagasse
• Pelletized bagasse	180 metric tons
• Pelletized bagasse dimensions	
Diameter	11 – 12 mm,
Length	10 – 15 mm

• Pelletized trash	500 kg
Diameter	12 mm
Length	30 mm
• Baled trash	660 kg
• Trash from cane dry cleaning station	330 kg
• Dolomite*	7 samples
Total	310 kg

* From different suppliers.

These materials have been submitted to a preliminary proximate analysis and heating value determination (**Table 42**).

It is important to point that the preparation of these samples was made possible due to the extensive collaboration

Table 42

Material analysis.

Parameters	Units	Pelletized bagasse	Loose bagasse	Shredded trash	Pelletized trash
Moisture content	%	5.31	46.90	10.05	7.17
Ash content*	%	3.56	6.53	8.15	9.84
Volatile matter*	%	88.20	81.42	76.23	81.77
Fixed carbon*	%	8.24	12.05	15.62	8.39
Higher heating value*	MJ/kg	18.10	18.46	16.98	16.82

* Dry basis

of the Usina Barra Grande, in Lençóis Paulista-SP, Brazil. The mill executed the trash baling and trash shredding activities and made extensive modifications in its hydrolyzed bagasse pelletization facility to make it possible the preparation of the 180 tons of raw pelletized bagasse samples. A dedicated pneumatic pellet transportation system was designed and built and several bagasse belt conveyors were modified to bypass the bagasse hydrolyzer. All the costs were supported by the Usina Barra Grande.

The samples were packed in polypropylene bags of approximate volume of 1 m^3, normally used for sugar. The bags were put inside containers and shipped to Sweden; the two 10 m^3 loose bagasse and trash samples were sent by plane for the advanced laboratory and bench scale tests and the rest of the samples were sent by ship.

The second batch of test samples also required extensive preparation work but from another nature: they had to be baled, stored, put in containers and shipped.

A Case 8575 baling machine, operated by people from the Usina São Luiz AA, was used to prepare around 1000 bales totaling approximately 200 tons, wet basis, of sugar cane trash. This activity was used also to collect additional field test data for the balling operation, and was conducted during the months of October and November, 1999, at the beginning of the rainy season. The good field conditions in terms of slope and surface smoothness facilitated the execution of this activity in spite of the occasional rains.

Due to the slow administration process of the project, the samples had to be stored for several months during the rainy season (November – April). Circus type canvas tents were rented to protect most of the bales from the rain.

This activity was used also to establish the logistics for commercial scale baling operation; the partial storage of bales in the field for later loading and transportation to the mill and direct loading in the trucks was tested.

The decision to send the trash in the baled form, instead of shredded, was based on the optimization of the transportation and processing costs; in bales the trash density was around 150 – 200 kg/m^3 while shredded it would be below 100 kg/m^3.

The bale characteristics were:

- Average length 2.1 m
- Width 0.85 m
- Height 0.90 m
- Weight 180 to 280 kg
- Average moisture content 12%

Due to the size of the tent, around 15% of the bales had to be stored in the open; as a consequence of the rains a considerable part of these bales had deteriorated and could not be used.

Considering the long period of storage the trash quality was monitored via sample collection and proximate analyses (**Table 43**).

The bales were shipped to Sweden, on May 2000, in 29 containers. In Sweden, TPS had to discard several bales due to the presence of mould and had many difficulties in processing the trash to adequate conditions of particle size and density. This process will be described in details ahead in this chapter.

Table 43

Stored trash conditions (dry basis).

Parameter	14/Jan/00 Open air covered 1st layer	14/Jan/00 Open air covered 2nd layer	14/Jan/00 Open air uncovered	07/Dec/99 Inside tent shredded	30/Nov/99 Inside tent shredded	30/Nov/99 Inside tent shredded
Moisture (%)	9.84	11.6	60.53	13.2	17.5	15.0
Fixed C (%)	16.82	16.42	16.29	17.98	18.29	17.2
Volatils (%)	78.97	77.08	66.55	74.56	71.95	76.6
Ash (%)	4.21	6.50	17.36	7.46	9.76	6.2
LHV (MJ/kg)	17.98	17.27	16.78	17.18	16.84	17.03

13.4. Gasification test runs

Gasification tests - laboratory, bench scale and pilot plant

13.4.1. Laboratory tests

A laboratory and bench scale test program was performed prior to the pilot plant programs for bagasse and cane trash, respectively. The purpose of the laboratory program was:

- To have analytical data regarding the composition and other properties of the bagasse and sugar cane fuels;
- To obtain tar and ammonia yields from pyrolysis and gasification reactivity data;
- To test Brazilian dolomites as a tar cracker catalyst and compare the results with those of the Swedish reference dolomite.

Analyses

Samples were obtained in two separate batches, one in 1998, containing both bagasse and also cane trash samples from a baling and dry cleaning operation, respectively. In 2000, a sample of baled cane trash was received prior to the pilot plant test on this fuel. The most important analytical results of the sugar cane fuels are in **Table 44**.

The ash content could vary considerably for biomass depending on the growth speed of the plants, which affects the intrinsic ash content, and on harvesting and processing methods, contaminating the biomass in different degrees. The ash of the pelletized bagasse is rich in silica while the ash of the "cane leaves (trash), baled" sample is rich in Al_2O_3 and Fe_2O_3. Fast growing grass species are usually rich in silica which is stabilizing the stem. The operation of the dry cleaning station resulted in that separated inorganic and organic material was remixed. This

Table 44

Fuel analysis.

Determination dry basis % weight	Pelletized bagasse 1998	Trash, dry cleaning 1998	Baled trash, baled 1998	Baled trash, 2000
Ash contet	3.6	29.1*	10.1	9.6
Moisture content	8.7	7.6	9.6	8.1
Volatile matter	82.9	57.1	73.5	76.0
Fixed carbon (by difference)	13.5	13.8	16.4	14.4
Carbon content	46.4	35.1	43.6	44.2
Nitrogen content	0.26	0.36	0.47	0.5
Lower heating value, d.b. MJ/kg	17.44	13.33	16.09	16.63
Ash initial deformation °C	1230	1560	1260	1200

(*) The high ash fraction of this sample is not reflecting a representative sample.

material is therefore not representative any fraction from a dry cleaning station, for which an ash content less than for baled cane trash can be expected.

The initial deformation temperatures of the ash fuels were all relatively high, >1200ºC, thus several hundred degrees above the working temperature of the gasifier and cracker (i.e. approx. 900ºC). The constituent of the "trash dry cleaning" ash apparently consists of a high melting substance, most probably silica. However, in practice the methodology used for determination of ash melting point is too blunt, often being far higher than the temperature where ash related problems are encountered in gasification reactors.

The carbon content for biomass fuels is typically 45-50% on a dry and ash free basis, which is considerably lower than for coal. Bagasse have values in between 35 to 45% on dry basis and 48 and 50% on dry and ash free basis, thus in the upper part of biomass carbon contents when ash content is disregarded.

The nitrogen contents are in the order of 0.2 – 0.3% for the cane leaves fuels thus comparable eucalyptus wood and other wood species. The "pelletized bagasse" consisted of 0.26% of nitrogen and the cane leaf samples in 0.36% (dry cleaning) and 0.47% to 0,50% (baled). According to TPS experience, most of the nitrogen species will be converted into ammonia during gasification and tar cracking.

The heating values of the fuels as analysed by TPS show a span ranging from 13 to 18 MJ/kg on a dry basis, mainly because of the differences in ash content, but also to a minor extent in the elemental composition. Recalculating to a moisture and ash free basis, the span closes down to 19.4 – 20.2 MJ/kg, showing that the organic portion has a similar constitution.

The chlorine content was fairly high in the cane trash. The chlorine content varies considerably between the different biomass samples and the span is 0.04 to 0.49%, thus one order of magnitude. The low value was found in the pelletized bagasse, while the high values were connected to cane leaves baled. This difference indicates a high fraction of water-soluble chlorine salts that are leached out as a result of the milling.

The sulphur content is generally very low for biomass fuels, in comparison with fossil fuels. There is usually no need for any treatment to reduce SO_2 emissions from normal biomass fuels, like wood chips. However, compared with the wood fuels, the bagasse fuel is rich in sulphur, with values between 0.04 and 0.12%.

13.4.2. Tar conversion

The definition of tar is not unambiguous when comparing tars from different sources. In the case of TPS, condensable tars are defined as components of a molecular weight in excess of 100 kg/k mole. The most predominant component is naphthalene. Lighter hydrocarbons are lumped together as BTX (benzene, toluene, xylene), components that are not condensable at ambient conditions. The term "tar", when used in this report, refers to the condensable tar hydrocarbons.

The condensable tar yields from pyrolysis of bagasse and sugar cane residues in a laboratory reactor, without any cracking of tars, became between 9.3 and 14 g/kg of fuel. These yields were reduced to 0.55 to 4.4 g/kg after cracking in a bed of dolomite.

When pelletized bagasse was treated with Swedish dolomite the reduction of condensable tars was 91%. When this dolomite was substituted by a particular Brazilian dolomite, the reduction decreased to 77%. However, at an increase of the cracker temperature up to 900ºC the reduction reached 90%.

For trash (cane leaves), dry cleaning the reduction of condensable tars became 91–93% using the Swedish dolomite. The same result for the Brazilian dolomite (identified for the WBP eucalyptus tests) was 77%, but also here an increase of the temperature to 900ºC increased the conversion to 90%.

For baled trash (cane leaves), the Swedish dolomite decreased the condensable tars by only 77%, while for the Brazilian dolomite the reduction was only 63% at 850ºC and 72% at 900ºC, respectively. The lower conversions seen for the baled trash (cane leaves) could be associated with its higher chlorine content. Both dolomites tested were affected in the same way, but the higher activity of the Swedish dolomite was more sensitive to this effect.

13.4.3. Dolomite tests

From the above data, it could be concluded that the Swedish dolomite used was superior in activity to the Brazilian one, but a slight change in temperature would even out this difference. To further try to identify suitable dolomites locally available in Brazil, CTC sent samples of such materials for scooping tests. Out of six potential Brazilian bed materials, of which five were dolomites and one was silica sand, only one showed catalytic activity comparable to the Swedish reference dolomite when tested on Swedish wood chips fuel. In comparative tests on the bagasse related fuels the Brazilian dolomite identified for the WBP eucalyptus project also showed activities comparable to the Swedish reference dolomite.

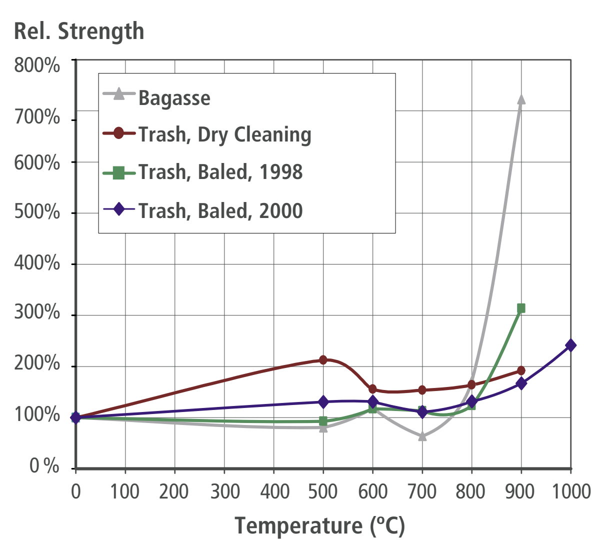
13.4.4. Ash agglomeration and sinter tests

Bio-fuels of agricultural origin are in general well known for their problematic ash melting (agglomeration, sintering) behaviour during gasification and combustion. Experience has shown that ash melting points, as determined by fuel analysis, are indicative only as to whether ash agglomeration or sintering may occur, but they are not sensitive enough to predict the "safe" operating conditions in a gasifier. One reason for this is that this test is performed on an ash residue, such that volatile components can already have been lost as part of the ashing procedure, and therefore not present in the sample or surrounding gas when the ash melting is performed. In the case of biomass, various salts are lost, such that standards for coal show too little ash for biomass, and the standard ashing temperature is therefore only 550°C for such fuels. Also the onset of melting is visually observed on a sample in the shape of a cone or cylinder; the temperature when this can be clearly visually detected is higher than when some first viscous eutectica is formed on the micro level. As this is an important problem in the operation of boilers and gasifiers operating on agroenergy fuels, development work is going on to find more relevant methods to detect and predict the onset of viscous behavior.One such method has been developed at Åbo Akademi in Turku, Finland. This method estimates the sintering tendency of an ash by measuring the compression strength of a heat treated sample, under selected conditions of atmosphere, temperature and pressure, cylindrical ash pellet. The method gives information about the influence of time, gas composition and temperature on the sintering of a given ash sample depending on which parameter is studied. After the heat treatment, the compression strength of each tested pellet is measured, using a standard strength testing device. The average strength the pellets retain after the heat treatment at a certain condition is taken as the degree of sintering. A sintering temperature, defined as that heat treatment temperature at which the strength increases significantly from a baseline value, can be read from the curve. The baseline strength value for a strength curve is determined by measuring the strength value from four untreated ash pellets.

Figure 71 shows the result using the ash sintering tendency laboratory test method for the three fuels samples tested in 1998, and also the trash sample used for the pilot plant test in 2000.

The bagasse sample shows a clear increase in strength, say a doubling, around 800°C, and baled trash at 850°C, while the curve

Figure 71



Sinter tests of the three fuels.

for the dry cleaning trash is less easy to interpret. The high ash content, partially being of soil origin in this sample may mask any changes in this respect. The result of the test on the trash received in 2000 shows more similarity to this latter material, and has no indication of very defined changes.

Compared to fuels like miscanthus and switch grass (canary reed grass) this is still 100 – 150°C higher in temperature, while some wood residues, having high ash content and soil, etc. are in the same region as bagasse. Clean wood and Salix are more similar to the dry cleaned trash, i.e. no effect below 900°C. The data show changes to the ash, at several hundreds of degrees lower temperatures than in the conventional tests.

13.5. Bench-scale tests

As discussed above the ash agglomeration tendencies under practical conditions are not easy to predict from a simple analysis. In addition, there may be synergetic effects, both positive and negative, when mixing a fuel ash and the bed materials used in the gasifier. Experimental tests aimed at mapping suitable operating conditions is therefore of importance to avoid ash agglomeration problems during gasification in larger plants causing large operational costs. This also holds true at pilot plant scale, such that information on this subject is essential for the planning of the pilot plant tests.

The general objective of this activity was to investigate the actual gasification behavior of the bagasse and sugar cane trash residues in a nominal 20 kW bench-scale, air blown, fluidized bubbling bed gasifier. The operational information was used in the planning of the "circulating fluidized bed" (CFB) pilot plant tests at a scale of 12 tpd or 2 MW thermal.

Experimental tests have been performed with three different bed materials, olivine sand, Brazilian dolomite and quartz sand, to establish the possible interactions between the fuel ash and the bed material. The fuels tested were selected by CTC and in the first set of tests in 1998 were pelletized bagasse, cane leaves baled and dry cleaning. In 2000, also the same large cane trash sample used for pilot plant tests was used in preparation for the pilot plant tests. Apart from the ash fusion behavior, the tests also gave information on carbon conversion and gas quality.

13.5.1. Bench-scale fluidized bed gasification Test-Rig

The experimental tests were performed in a nominal 20 kW air blown bench-scale bubbling bed fluidized gasifier equipped with gas cleaning facilities. This apparatus is generally used for gasification experiments but can also be used in gas cleaning experiments, as well as in experiments where it is feeding other equipment with gas, for example, in catalytic combustion and re-burning studies. A schematic picture of the apparatus is shown in **Figure 72**.

The fuel feeding system consists of a fuel reservoir with a volume of ~0.4 m^3, a variable-speed controlled dosation screw at the bottom of the reservoir and a fuel feeding transport screw rotating at constant speed that transports the fuel to the reactor. The system is dimensioned for pelletized fuels or uniformly cut chippings with a maximum size of 12 mm. It is possible to supply bed material via locks though the fuel feeding screw or by using variable-speed controlled dosing equipment.

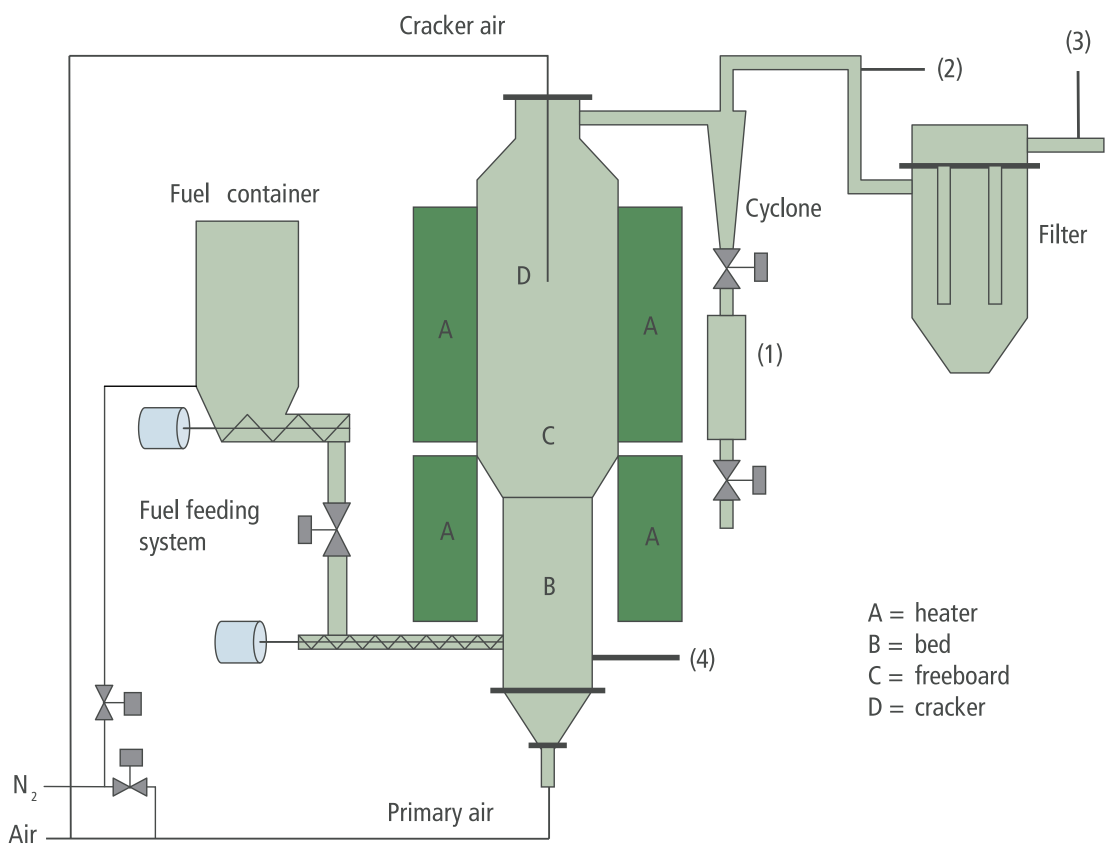
The height of the reactor is 2 m, excluding the top-cone and air distributor, with diameters of 0.2 and 0.27 m, respectively. The reactor is equipped with an electrical heater for the primary air, and two high temperature heaters situated on two levels around the reactor casing. These heaters can be controlled continuously up to a total heat input of 9.4 kW. That heat input allows the reactor heat losses to be fully compensated; giving the gas produced a realistic composition and heating value representative of large scale installations.

Dust is first removed in a cyclone dust collector followed by a filter. The filter element consists of ceramic fiber useable to a maximum temperature of 400ºC. Cleaning of the filter is performed manually.

A pneumatic control valve, placed downstream of the filter, is used to control the amount of product gas to the downstream gas burning equipment.

A PC and PLC based control and data acquisition system controls the electrical heaters, flow of air and feeding of fuel, and also collects process data, such as temperatures and the pressure drop over the bed.

Figure 72



The bubbling bed fluidized gasifier at TPS. The cyclone ash sample is collected at point (1), the gas composition analysed before and after the particulate filter at points (2) and (3), respectively.

The experimental tests were aimed at investigating the gasification characteristics and ash behavior during gasification of the three fuels.

13.5.2. Test procedure and main results

A typical test started with the filling of bed material, while pre-heating the bed in the reactor to obtain a temperature of around 350°C, which is the approximate ignition temperature of the fuel. This heating is achieved by using the two electrical heaters enclosing the reactor and the heater for the primary air. At the point of ignition, the fuel feeding is started at a low rate and relatively high flow of primary air is used. The temperature increases rapidly from combustion of the fuel and at close to 750°C the fuel feeding rate and the air flow is adjusted to obtain stable gasification conditions and a low heating value (LHV) of the gas around 5 MJ/Nm^3. The gasification process is operated at stable conditions for two hours before the temperature is increased to the next set point at 850°C. The airflow is adjusted to stable conditions in the same way as for the previous temperature. The procedure is then repeated for additional temperature set points.

The bulk components of the product gas produced during the gasification are analyzed by using a HP 5890 gas chromatograph (GC) equipped with a thermal conductivity detector (TCD). Samples of cyclone ash and bed material were collected in the end of each temperature period. Filter ash was only collected after the end of each experimental test, i.e. after 900°C, as the amount of material collected is very low. The ash content is determined for the cyclone and filter ash, respectively, and also for some bottom ash samples. The bed ash sample is visually inspected for agglomerates using a light microscope. The carbon content of the bottom ash is normally very low, consisting of discrete fairly large char particles. The ammonia content is sampled by bubbling the gas though impinger bottles containing sulphuric acid. Tar samples are collected by passing the gas though impinger bottles containing acetone. The HCN and HCl contents are sampled using impinger bottles containing NaOH-solution and distilled water, respectively. All these samples are sent to an external laboratory for analysis. The moisture content in the product gas is analyzed by the condensation of water in a small vessel for a measured period of time. This vessel is weighed before and after sampling. The water content is calculated from this weight and the integrated gas flow.

The gas yields ranged from 2.2 to 2.5 Nm^3/kg of fuel, moisture and ash free (maf), in the bench scale tests. The composition varied depending on bed material and ash content of the fuel. In **Table 45** four typical gas analyses are shown. It should be noted that in the bench scale unit, electrical heating is used to compensate heat losses such that the gas composition more resembles a full-scale capacity plant than the pilot plant. The primary carbon conversion to gas ranged from 78 to 97% in a fluidized bed without recycle of elutriated fuel fine particles, with values above 90% for pelletized bagasse and below for the cane leaves fuels.

Table 45

Gas analyses (% volume). Bench scale tests.

Fuel dry basis	Pelletized bagasse	Pelletized bagasse	Cane leaves (dry cleaning)	Cane trash 2000
Bed material	**Olivine sand**	**Dolomite**	**Dolomite**	**Dolomite**
H_2	8.5	14.8	12.2	12.5
N_2	53.3	49.0	51.8	54.0
CO	14.6	18.1	14.1	14.5
CH_4	4.6	3.2	3.6	2.5
CO_2	16.4	13.8	16.0	14.3
C_2H_4	1.7	0.7	1.4	0.8

The tar yield, expressed as condensable tar per kg of fuel, maf, was 13 – 14.5 g when sand was used as bed material. By application of the most active dolomites this amount was reduced to 1 to 1.3 g/kg for pelletized bagasse and cane leaves (dry cleaned) at 850 – 900°C, the first temperature valid for Swedish dolomite and the second for Brazilian dolomite. The reduction was smaller for cane leaves (baled) with a resulting tar amount of 3.1 to 4.9 g/kg of dry and ash free fuel. However, the tar yields in this gasifier are difficult to convert to another system. First, the feed fuel is in the shape of pellets that will float around in the bed during pyrolysis having good contact with the bed material, such that the dolomite can be effective in cracking the tar. If a finer particle size is used, or mixed in, pyrolysis will also occur in the freeboard, causing less contact between the tar evolved and dolomite bed material, such that the tar yield would increase.

13.5.3. Detection of ash agglomeration

As mentioned before, conventional ash melting analyses does not give an answer that can be easily and safely interpreted to gasifier operating conditions. The laboratory sintering tests reported above showed some changes occurring for bagasse at around 800°C, and for baled trash at 850°C, while the curve for the dry cleaning trash did not change very much, nor did the trash sample received in the year 2000.

Figure 73

Photo of a bed material collected at a temperature of 900ºC.

To validate these data, ash samples from the benchscale tests were collected at the end of each stable period. These samples were closely examined visually using a light microscope equipped with a camera. A photo illustration of a bed sample was collected at 900ºC (**Figure 73**). In the case of bagasse, the silica-rich ash particles, when increasing the temperature, first were seen as opaque sharp-edged particles which at higher temperatures started to attain a droplet shape, and then, at even higher temperature, became sticky and formed agglomerates also containing bed material particles. In the case of trash, the growth of agglomerates was more limited, and the effect of temperature was less pronounced. One plausible explanation for the limited growth of the agglomerates compared to bagasse is that the trash ash itself is more heterogenous than the bagasse ash, which is basically the internal, water non-soluble ash of the plant material without any external soil contamination. The ash from trash is a mixture of the soil contamination of the organic material and both its water soluble and non-soluble fractions. It can be expected from the high ash content, that the soil fraction is high and less susceptible to agglomeration compared to the plant ash fraction itself, and hence the effect is limited.

The accumulation of ash in the gasifier bed, for both bagasse and trash, also indicates that withdrawal of bottom ash is necessary in both a pilot and commercial scale gasifier, using bagasse and trash as a fuel.

13.5.4. Conclusions

The main conclusion is that a fluidized bed can be operated with bagasse and cane trash in combination with sand and dolomites up to a sufficiently high operating temperature in the gasifier to have a good carbon conversion without detecting agglomeration of any significance. Testing of ash mechanical strength showed that the bagasse had a sharp increase in compression strength at 800 – 850°C when external forces were applied, while trash was less affected. This indicates a good resistance towards sintering and melting. However, the photographs taken of the bed material show that fuel ash particles are increasing in size to become larger than other particles in the bed. This limited effect is possibly attributed to the presence of both soil and plant ash in the fuel ash, and that probably only a fraction of the plant ash is susceptible to agglomeration. In the case of bagasse, the ash has been leached in the milling process, leaving only the non-solvable plant ash in the bagasse, explaining the more drastic changes for this fuel.

Gas analysis and other data are mostly in agreement with what could be expected. Mass balances and carbon balances have reasonable agreement. The results indicate that the Brazilian dolomite considerably reduces the condensable tar yield during the gasification in a bubbling fluidized bed gasifier, whereas olivine or silica sand does not have this effect.

13.6. Pilot plant test

13.6.1. Description of the pilot plant

The test campaign was carried out in TPS's ACFBG pilot plant. The capacity of this pilot plant is roughly 2 MW fuel or approximately 500 kg dry fuel per hour.

Fuel pretreatment (e.g. chipping and drying) is handled in advance. The pilot plant has approx. 360 m^3 covered storage facilities, of which 250 m^3 is used for fuel and the remainder for other materials used in running the plant, e.g. dolomite, olivine sand, etc. There are also open storage facilities to accommodate approximately 1 000 m^3 of fuel.

During plant operation a front-end loader loads a fuel bin (approx. 7 m^3 capacity) with screw discharge to a pneumatic transport system. The fuel is sent to a day fuel bin (approx. 20 m^3 capacity) with a live bottom and screw discharge. The fuel is fed from the hopper to a weigh belt conveyor which measures the feed rate, it then passes though a rotary valve system equipped with sealing air and into the gasifier though a screw feeder. The screw feeder controls the fuel feedrate.

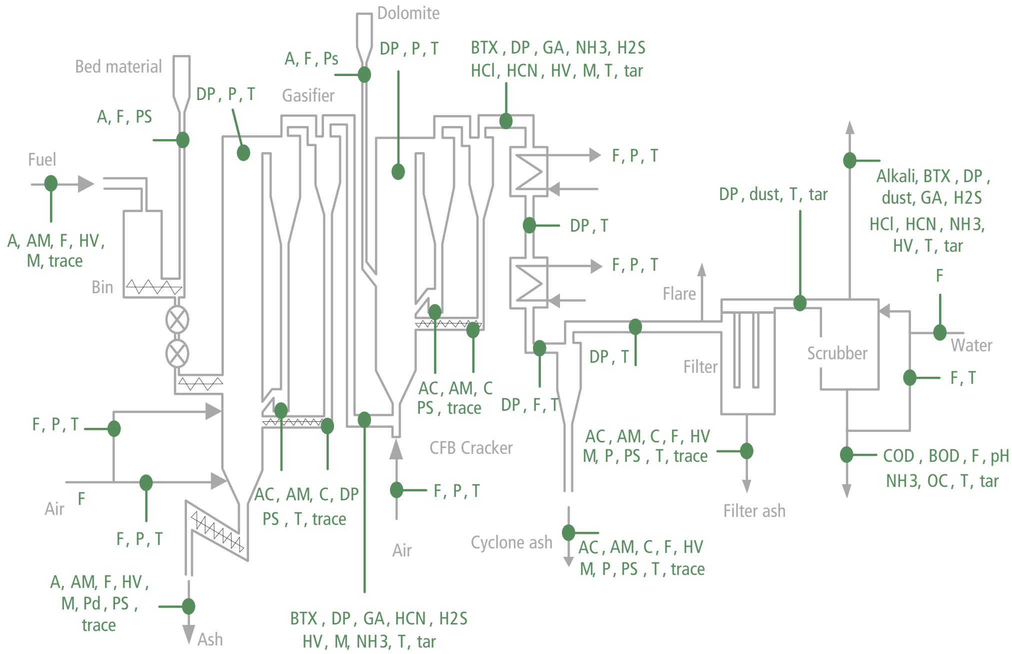
In parallel to the system described above, a second system, which is designed to handle lowdensity material, was installed in the pilot plant just before the test series for bagasse. After commissioning, this second system was used for the tests on loose cane trash in 2000 and 2001.

The gasifier is of circulating fluidized bed (CFB) type. Mediumsized fuel particles and bed material elutriated from the gasifier are captured in the solids separators placed at the exit of the gasifier and recycled to the bottom section of the gasifier. At the bottom of the gasifier, a sparger type distributor provides primary air to the fluidized bed. An ash drain is located below this distributor.

Downstream of the second cyclone and on the pipe taking the gas to the tar cracker bottom, a rupture disc is located as a safety precaution. The gas leaving the gasifier's secondary solids separator enters the bottom section of the "tar cracker". The cracker is of CFB type and it operates in a similar manner to that of the gasifier. The gas leaving the cracker's secondary solids separator passes though heat exchangers before it enters a "cold cyclone". The gas leaving the cyclone can be flared. Downstream of the cold cyclone, the gas passes though a filter and a wet scrubber.

Figure 74

TPS pilot plant.



The test campaign reported here covered all equipment from the feeding of the prepared fuel up to, and including, water scrubbing of the fuel gas. Possibilities for semi-continuous gas analysis and sampling of tar and water in different parts of the plant exist. **Figure 74** is a schematic flowsheet of the pilot plant; this figure also shows the main measurements and sampling points.

13.6.2. Description of the program and its objectives

The objective of the pilot plant test program was to verify that sugar cane bagasse and trash are suitable fuels for a CFB gasifier, and to demonstrate the operating regime of the gasifier under which this fuel can be stably gasified with an acceptable gas quality, after cleaning, under campaigns of duration of approximately five days. When in stable operation, an objective is also to validate input parameters for modeling of the gasification system on this fuel.

The program for bagasse was planned, already in 1995, to include three pilot plant tests, a first so-called shake-down test followed by two tests. These tests were performed in 1998-99. In the case of the tests with trash, four tests were planned, of which one would also co-gasify bagasse and trash. The latter sets of tests were made in 2000/01.

13.6.3. Operating data for the pilot plant on bagasse

Overall performance

The three tests on pelletized bagasse went very well. The only problems that occurred and also solved during the program were some circulation problems in the tar cracker standpipes and occasional clogging of the spray nozzles of the water scrubber. Bed agglomeration of the gasifier did not occur as long as the temperature was maintained below the threshold defined on the basis of the results of the benchscale tests. Only when a high temperature was purposefully tested, agglomeration was encountered. The outcome of the tests was as expected, both from the fuel ash analysis and the benchscale tests made to determine the gasifier's upper temperature limit for this fuel.

Fuel pretreatment and feeding

In the case of bagasse, the fuel was received in pellet form, such that no pre-treatment was necessary on site. Thoughout the tests, the pelletized bagasse was shown to be an excellent fuel concerning its feeding properties. Initially, a disintegration of the pellets in the pneumatic transport of the fuel from the ground level to the day hopper took place. The fine dust caused segregation in the silo and problems in the rotary valves below the day hopper at low hopper levels. The disintegration could be minimized by a decrease of the pneumatic transport air pressure and the rotary valve then operated normally. During the last test, bags were emptied directly into the hopper thereby avoiding the use of the pneumatic transport completely, improving the situation further.

Table 46

Operating performance of the pilot plant on bagasse.

Week nº	Total time	Downtime	Onstream
9835	68h	0h 35m	99.1%
9838	93h	0h 30m	99.5%
9915	95h	3h 20m	96.5%

The excellent feeding properties resulted in a high and even fuel feeding during all three test campaigns. A lower feedrate, 400 – 450 kg/h, was used only on a few occasions. The cause for this was not to be found in the fuel properties or feed system, but in the circulation problems in the gasifier and tar cracker cyclone standpipes. The filter was operated during all tests, without disturbances, while the scrubber was only operated in the last two tests, and sometimes nozzle blockages disturbed the water circulation. The hours of operation of the whole plant (i.e. disregarding the time to start from cold condition and to stop the plant), excluding the scrubber, on a full fuel feedrate, i.e. 500 – 550 kg/h, downtime and the onstream factor are shown on **Table 46**.

13.6.4. Pilot plant tests on bagasse

Gasifier

The gasifier was operated at temperatures from 820°C and upwards during the test campaigns on bagasse. The first test was planned to validate the agglomeration predictions from laboratory and bench scale tests, by gradually increasing the temperature, until, finally, at a temperature above the threshold found in smaller scale test, an agglomeration was provoked.

All tests were performed with a makeup feed of dolomite to the gasifier bed, the purpose being mainly to counteract agglomeration. Although the tests at benchscale and the initial tests in the pilot plant had indicated an upper temperature limit for safe operation it was believed that dolomite could improve long term effects of accumulation or temporary excursions.

The test indicated that no agglomeration occurred using this strategy, but on the other hand, it was not shown that these fears were unfounded. When operating the gasifier with a low dolomite feedrate, the solids circulating in the bed and first cyclone loop will consist of approx. 10 – 20% dolomite. At higher dolomite feedrates, this fraction will increase. To control the bed level of the gasifier, regular bottom discharge of ash was necessary.

Tar cracker

The tar cracker was mostly operated at a temperature in the vicinity of 900°C. For about 20 hours at the end of the second test a higher temperature was used. The tar cracking results are discussed below. The bed material used was Swedish and Brazilian dolomites.

During the first test on pelletized bagasse the bed behavior was irregular. After the test it was found that damage of interior parts of the standpipe had caused the circulation problem. A flow of tar cracker gas had passed upwards in the standpipe. The damage was repaired before the second test campaign. During the second test the recirculation problems remained initially in spite of the repair, but adjustments of the fluidization gas flow to the standpipe solved the problem. During the third test the establishment of the tar cracker bed was easily achieved and the recirculation in the standpipes operated excellently. This resulted in a slowly increasing bed pressure drop from which a steadystate consumption of make up dolomite could be calculated.

Gas cooling

The cooling of the product gas in the fire tube steam boilers was satisfactory during all tests. Soot blowing of the boilers was made by a sonic horn that was used occasionally with good results. This showed that the decreases in heat transfer rates are mainly due to the dust layer on the interior of the tubes.

Particle separation and gas filter

The particulate removal part of the process consists of a cold cyclone operating at approx. 250°C, and a baghouse filter operating at between 170 and 220°C. From an operational viewpoint, these parts have worked without any trouble. No signs of blockage of the cyclone outlet or increased pressure drop across the filter bags have been seen.

Scrubber

The water scrubber has the task of removing residual tar and water-soluble gases, i.e. ammonia and hydrochloric acid, from the product gas. In addition, it condenses the main part of the gas moisture content.

During the first test in September 1998, the water scrubber was rarely in use as the gas was used for a combustion experiment that did not require scrubbing.

During the second test period the water scrubber was operated but suffered occasionally from blockages on the outside of the water spray nozzles. The nozzles were cleaned either mechanically during a halt in the operation of the scrubber or by shutting down the cooling of the scrubber water.

During the third test the scrubber was operated in a fairly stable manner, but occasional shutdown for cleaning of the spray nozzles was again necessary, which were blocked by condensing naphthalene crystals. By applying tracing of the spray nozzles, this would be avoided in a commercial plant.

13.6.5. Results and discussion

Analysis of solids

Solid samples were regularly collected from the following parts of the plant:

- Gasifier bottom;
- First gasifier cyclone standpipe;
- Second gasifier cyclone standpipe;
- First tar cracker cyclone standpipe;
- Second tar cracker cyclone standpipe;
- Cold cyclone;
- Baghouse filter.

In the tests on bagasse, the initial bed of the gasifier was established by injecting dolomite, followed by a continuous feed at low rate. This is reflected by high initial contents of CaO in the bottom ash and the first gasifier cyclone solids. The values successively decreased and the CaO was substituted by SiO2 from the fuel ash. This resulted in that the bed, in addition to a low carbon content, < 1%, had also a low dolomite fraction, 10 – 15% of the bottom ash. The dust remaining in the gas after that cyclone is finer than for the bottom ash and the fraction of dolomite is increased considerably. No reaction between ash and dolomite has been indicated. The fraction of the ash entering that is necessary to drain as bottom ash was determined in the tests, the remainder will have a size distribution such that it will leave as flyash.

The solids circulating in the second cyclone loop of the tar cracker consisted predominantly of and a minor fraction of fuel ash. A small fraction of carbon was also present. The mean particle size was 0.07 mm. This proves that it is possible to maintain a high dolomite concentration in the tar cracker, and that the bagasse flyash particles that are not captured in the gasifier cyclones are so fine that they are not recovered or even accumulated in the tar cracker cyclones. This dust probably passes directly to the second tar cracker cyclone, where a small part is separated but the main part continues to the cold cyclone and the baghouse filter. This is supported by the fact that the particle size curve for dust collected in the second tar cracker cyclone has a slightly higher mean particle size than the dust from the corresponding gasifier cyclone. The dolomite fed to the tar cracker circulates both in the first and second loops. The finest particles leave the tar cracker system and pass to the cold cyclone and the baghouse filter.

The dust collected in the cold cyclone consisted of 35 to 50% carbon. The dust from the baghouse filter consisted of 50 – 55% carbon.

A number of ash samples from the tests were examined using light microscopy. Photographs were taken using Polaroid techniques. In the first pilot plant test on bagasse a successive increase of the size of the fuel ash particles were seen in the bottom ash. In the second and third tests already the first bottom ash samples showed fuel ash particles as opaque, droplet or eggshaped particles. A likely explanation to this could be that the first test was started on coppice wood chips, the ash of which contained some sand and soil, which was clearly visible in the first bottom ash sample, whilst the other tests were started on bagasse directly. It seems that the bagasse ash particles were formed already from the pellet fragments directly in a size of 0.1 – 0.4 mm, i.e. approximately the same size as the bed material. The argument to support this is that the ash particles seem to be very "pure", i.e.

they do not show traces of dolomite particles being incorporated into the structure. If they were formed as very small particles, the growth by a sintering process in the bed to this size would cause "contamination" of these particles to a higher degree than seen in these samples. As only a fraction of the ash is drained from the bed, ash fractions being generated from a porous structure or which do not rapidly reach a large enough particle size will be in the remaining ash finding its way to the cold cyclone and baghouse filter.

Apart from the dominating fraction of fuel ash particles, some dolomite particles were also seen. Only a rare few agglomerates between dolomite and fuel ash were seen, and then often having much smaller dolomite particles attached to the larger fuel ash particles. This indicates that the fuel ash particle may be a bit sticky at some points, but not sufficient to capture larger particles having more inertia and where the contact point is a low fraction of the particle surface. The capture of these small particles may act as a growth inhibitor for the agglomerates as the sticky part will not be in direct contact with other particles when this layer is covering a large fraction of the surface.

Now and then black particles, which are fuel char particles were seen. The bottom ash sample from the second test contained a piece of char. This char particle was a bit glossy and some extremely small particles of ash were seen on the surface. This could be an indication that the fuel ash particles were formed as a densification of the char structure, as opposed to wood ash that has a brittle and porous structure.

13.6.6. Gas production and composition

A V-cone differential pressure measurement device was used during all three tests to measure the gas flow from the tar cracker. Unfortunately, the pressure taps were shown to be very sensitive to fouling by dust and also by tar. Mass and energy balances have therefore been made on the basis of both this measured gas flowrate and also a rate calculated from a nitrogen balance.

In **Table 47** typical gas analyses from the three tests are shown. Based on nitrogen balances, the gas production in the pilot plant from 1 kg of dry bagasse pellets fuel was 2.5 to 2.7 Nm^3. At larger scale, or when the heat losses are compensated as in e.g. the benchscale tests, less gas will be produced per kg of fuel. Depending on gasifier and tar cracker temperatures, the bulk composition of the gas exiting the tar cracker the main gas constituent are in Table 47.

Table 47

Gas analyses in the pilot plant, dry bagasse pellets.

Test (% volume)	9835	9838	9915
H_2	9.0	10.4	10.0
N_2	58.0	57.1	56.4
CO	12.1	10.9	12.7
CH_4	3.5	3.5	3.7
CO_2	16.6	17.6	16.7
C_2H_4	0.7	0.5	0.5
LHV, MJ/Nm^3	4.2	4.1	4.3

The differences in LHV and composition are not significant considering analytical errors and minor variations between the tests, e.g. purge rates, etc. The methane content is not affected by the dolomite in the tar cracker but higher hydrocarbons, including BTX and tar compounds, are decomposed and thereby compensate the loss of chemical energy connected with incremental oxidation necessary to keep a higher temperature. In a commercial size plant, where heat losses are substantially less, the LHV will increase to the levels used for the process engineering and also seen in the bench scale tests, where heat losses are compensated electrically.

The yields of some other gas components, e.g. aliphatic hydrocarbons, BTX and naphthalene were estimated on the basis of the gas and tar analyses. These are essential inputs to the model calculations.

Minor components and constituents in the gas

Some minor constituents of the gas, that is; gas components present at below 1 000 ppm, were measured at numerous occasions during the tests. The components of interest are ammonia (NH_3), hydrogen cyanide (HCN), hydrogen sulphide (H_2S) and hydrogen chloride (HCl).

Ammonia and hydrogen cyanide emanate from the nitrogen content of the bagasse fuel. Normally, the main part, 50–80%, of the fuel nitrogen is converted to ammonia and a very small portion (parts of percent) to hydrogen cyanide. In the three tests **Table 48** shows the following approximate conversions to ammonia and hydrogen cyanide and ammonia and hydrogen cyanide contents, respectively, of the gas after the tar cracker.

Table 48

Ammonia and cyanide conversion.

	Conversion NH_3 (%)	NH_3 (mg/Nm^3)	Conversion HCN (%)	HCN (mg/Nm^3)
9835	60-70	540-670	0.1	0.2-1.4
9838	60-70	540-620	<0.1-0.3	0.1-4.6
9915	75-99	565-750	<0.1	<0.04-0.5

Table 49

H_2S in gas (mg/Nm^3).

Week nº	Gasifier	Bag house filter	Scrubber
9835	20-110	-	-
9838	27-88	-	46
9915	-	92	70-81

Table 50

HCl in gas. (mg/Nm^3)

Week nº	After tar cracker	After bag house filter	After scrubber
9835	<6-7	no data	<5-7
9838	<30	no data	<6
9915	no data	11	8

Inorganic and organic sulphur of the fuel is released as hydrogen sulphide in the reducing atmosphere of the gasification system.

The calcium part of the dolomite, and also the ash, has the ability to retain a part of the sulphur in the solid residues as calcium sulphide (CaS) at low temperatures, i.e. below 800 °C. A complete conversion of the fuel sulphur content of the bagasse, which is approx. 300 ppm weight, would result in a hydrogen sulphide content of the gas of around 120 mg/Nm^3. The actual measured values during the tests after the gasifier, after the baghouse filter and after the scrubber are in **Table 49**.

Analyzing these measurements it seems that the main part of the fuel sulphur is initially released as H_2S in the gasifier. The tar cracker values are not representative of the bulk gas composition as hydrogen sulphide reacts with the dolomite in the filter cake in the gas sample filter. The values measured after the baghouse filter and the scrubber are of the same order as the values measured in the gasifier gas showing that the retention of sulphur in the system is in the order of 30 – 50%. Most of this sulphur is found in the flyash.

The bagasse pellets had a mean chlorine content of 300 ppm weight. Part of chlorine was converted to hydrochloric acid which in the stable chlorine containing substance in a reducing atmosphere. The measured values are in **Table 50**. Thus, it can be stated that the main part of the fuel chlorine is retained in the solids leaving the process, most probably as $CaCl_2$.

13.6.7. Mass and energy balances, carbon conversion

Mass balances have been calculated during stable operating periods in all three tests. The direct gas flow measurements were unreliable and therefore balances were also calculated using a nitrogen balance as base. Some of the mass and energy balances have been subjected to minor modifications of the measured values to adjust for known errors in calibrations etc.

The mass balances concerning carbon, hydrogen, nitrogen and oxygen, which are the main elements of the gas, all showed deficits in the balances from the first test week using the measured gas flow. This indicates that during that test the flow meter constantly showed too low a gas flow. Making use of nitrogen balances instead resulted in an overbalancing of carbon and hydrogen whilst the values for oxygen narrow to around 100%. Also, during the second test period, the carbon balance especially became overbalanced using nitrogen based gas flows. Hydrogen and oxygen show quite reasonable values. During that test the gas flowbased balances showed good agreement for carbon whilst the nitrogen and oxygen balances were underbalanced. The third test gave very good agreement on carbon using nitrogenbased gas flows. In the first one hydrogen and oxygen are overbalanced but this could be the result of an overestimation of the moisture content of the product gas.

Table 51

Carbon conversion and energy balance.

Date	Carbon in gas with calculated gas flow	Carbon in gas with adjusted gas flow	Heat loss with calculated gas flow	Heat loss with adjusted gas flow
25-Aug-1998	106%	95%	6%	15%
26-Aug-1998	97%	97%	15%	15%
27-Aug-1998	109%	95%	5%	16%
15-Sep-1998	101%	96%	10%	15%
16-Sep-1998	100%	87%	3%	13%
17-Sep-1998	108%	98%	5%	13%
14-Apr-1999 00.00h	98%	97%	15%	16%
14-Apr-1999 17.00h	95%	96%	20%	19%
15-Apr-1999 12.00h	97%	96%	23%	24%
15-Apr-1999 21.00h	97%	96%	17%	18%

The ash balances are mostly underbalanced but during a few periods they are highly overbalanced. These results could be explained by positive and negative accumulation of solids in the gasifier and tar cracker beds and in the circulation loops. Based on the mass balances, energy balances have been made. The quality of an energy balance is reflected by the value of heat loss. This term is calculated as balance and should be in the order of 12 – 13% of the total energy supply. This corresponds to the convective and radiative heat loss of the vessels and piping. The carbon conversion to gas and heat loss of the energy balances are shown in **Table 51**.

As can be seen from the table, the carbon conversion to gas, on a normalized basis, narrows to between 95 and 97%, which is quite reasonable taking into account that the fixed carbon part of the fuel is approx. 12.5%. The low value of 87% was from a period where the ash output was 50% higher than the input, thereby representing an unstable period.

As the gas flow values were uncertain an approach using the carbon amount lost from the gasifier system in solid samples could be used. This was made and the carbon conversion could be estimated at 95 to 98%. If the carbon balances are normalized, a probable gas flow can be calculated. This then becomes, as mean values, 2.4 Nm^3/kg of fuel on a moisture free basis and 2.6 Nm^3/kg of fuel on a moisture and ash free basis.

As discussed earlier, the gas flow values used in the balances were unreliable. By normalizing the carbon balance, the heat loss in the balances could be modified (Table 51). Calculated in this way the actual heat losses were between 13 and 16%, i.e. slightly higher than predicted. The cause for the high losses during the third period, 16– 24%, is to be found in a lower gas quality than during the two first tests.

During these first tests the LHV of the cracked gas was 4.2 – 4.4 MJ/Nm^3 compared with 3.6 – 4.0 MJ/Nm^3 during the third test. As this test was made in April, however, the ambient temperature was less than in the other tests made in August and September under summer conditions.

13.6.8. Tar cracking

The tar production from the gasifier, and the amount of tar conversion in the cracker, depends on several parameters. These are:

- Fuel contaminants;
- Gasifier temperature;
- Gasifier bed pressure drop;
- Dolomite quality;
- Dolomite feedrate to the gasifier;
- Bed material circulation performance in gasifier system;
- Tar concentration in gasifier gas;
- Tar cracker temperature;
- Tar cracker bed pressure drop;
- Dolomite feedrate to the tar cracker;
- Bed material circulation performance in tar cracker system.

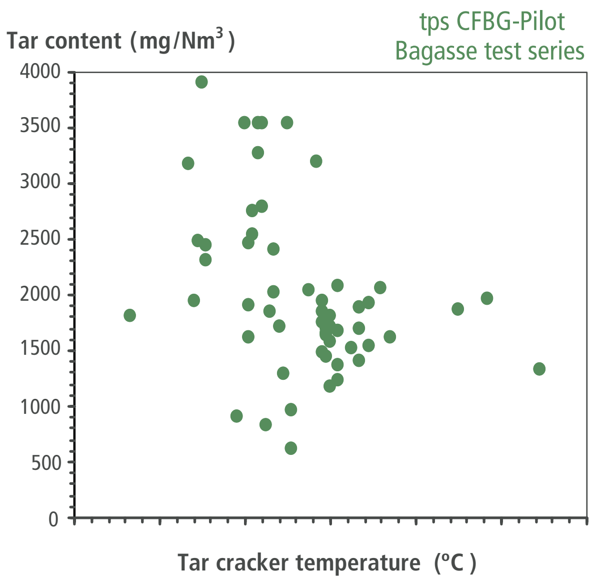
Trends showing the influence of temperature, bed pressure drop and dolomite feedrate on the content of tars in the tar cracker exit gas showed decreases with increasing temperature and bed pressure drop which could be expected, but a dependence on the dolomite feedrate did not exist. This can be expected because the holdup in the tar cracker bed is high compared to the make-up feedrate, thus the impact of the fresh dolomite on the total bed activity is small if no inhibiting effects are present which reduce the activity of the "old" bed.

As a high tar content of the gas entering the tar cracker could result in an increased content in the exit gas, conversion values were calculated. The conversion showed an increase with increasing tar cracker temperature and bed pressure drop. These parameters should thus be maximized to yield a low tar content at the exit of the tar cracker.

From the analysis of the tar measurement the following strategy concerning parameter setting can be proposed:

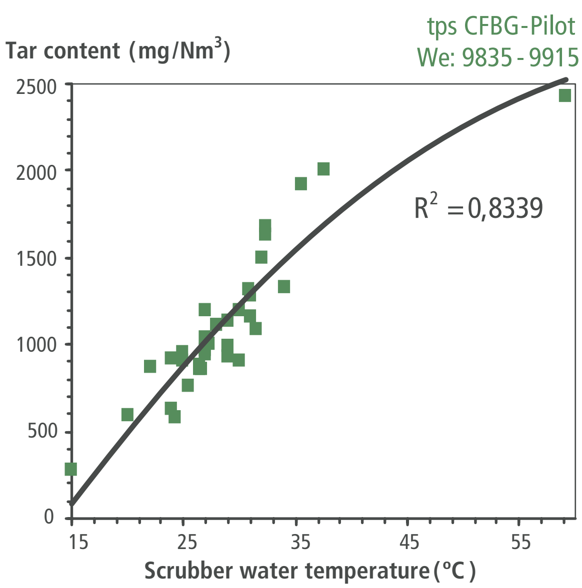
- A high dolomite feedrate to the gasifier;
- Moderate temperature in the gasifier;
- A high and stable bed of dolomite in the tar cracker;
- A dolomite feedrate which only compensates for the bed loss in the tar cracker;
- As high a temperature as possible in the tar cracker.

Figure 75



Condensable tar in gas vs. temperature of the tar cracker. (actual numbers are masked).

Figure 76



Tar in the scrubber exit vs. gas exit temperature.

Against these conclusions the following aspects must be considered:

- A high dolomite feedrate to the gasifier results in high bottom ash loss of dolomite;
- Low or moderate temperature in the gasifier limits the carbon conversion;
- High tar cracker temperature decreases the overall energy efficiency and the gas heating value.

A relationship of the condensable tar still contained in the gas after the water scrubber with the scrubber water temperature was seen. Operation at a low scrubber water temperature condenses more of the tar then operation at a higher level.

As the naphthalene compound is of special interest, the vapor pressure curve of this substance was considered and this indicates that the tar remaining after scrubbing is predominantly in the vapor phase, i.e. the water scrubbing is efficient in removing tar droplets and aerosol from being carried over to the downstream equipment.

The tar data indicate a tar concentration in the gas leaving the tar cracker of 1 – 4 g/Nm^3, disregarding the different operating conditions. These values represent a 40-65% conversion of the tar coming from the gasifier. In **Figure 75**, the temperature dependence is shown, indicating a slight reduction with temperature.

In terms of yield, this is 3 to 8 times higher than the results of the laboratory tests, which indicates that the "real life" efficiency is far lower than in the controlled tests in the laboratory reactor. The main deviation is probably the contact between the bed material and the gas, but also other factors are involved. The average tar content was 2 g/Nm^3, i.e. most values were in the lower end of the scale when the conditions were optimized. The predominant component in the tar was naphthalene.

It should be noted that the vapour pressure of the gas components, in particular under Brazilian conditions, is quite high, whereby the remaining tar after the tar cracking will stay in the gaseous phase completely, or only generate a limited condensation of tar components in the scrubber. The tar content downstream of the gas scrubber is related to the gas exit temperature (**Figure 76**). This tar is in the vapor phase, and concentrations are higher or similar to the concentrations in the previous figure showing the tar in the gas entering the scrubber, i.e. no or very limited condensation of the tar will occur.

13.6.9. Water condensate

Water condensate after the baghouse filter and scrubber water samples were collected from the second and third tests. The pH value of all samples was above neutral. Normal values are between 8.0 and 8.5. The main pH affecting gases absorbed are ammonia and carbon dioxide, the absorption of which results in a buffered solution of ammonium and bicarbonate ions. The ammonium content was typically 4-5 g/Nm^3. The BOD, COD and TOC values for the scrubber water mostly increased with elapsed operating time, thus reflecting that the levels had not reached steadystate. COD was ranging from 200 – 800 mg/Nm^3, while BOD was about 20% of these values. The scrubber was operated with recirculation of water only and the withdrawal of water balanced the condensation of gas moisture. The highest values thus reflect the levels that could be reached at steadystate. The aromatics found in the scrubber water are mostly benzene and naphthalene, the magnitude being tens of ppm. The other three components analyzed showed low values, in the order of a few ppm.

13.6.10. Dolomite consumption

The dolomite consumption is important for the operating cost. A high consumption results in high transportation and calcination costs and huge amounts of solid residues. It is therefore desirable to keep the consumption low whilst still obtaining sufficient tar conversion. Using the Brazilian dolomite, which was also used for the WBP eucalyptus project, consumption could be kept within bounds.

13.6.11. Comparison of test results and modeling parameters

The computer model used for the process integration work requires inputs of empirical nature in order to predict the gas composition and the process performance correctly. These parameters depend on the process conditions, but even more so on the fuel. Thus, for a new fuel, pilot plant tests are necessary to accurately predict the process performance. As the process integration work started prior to the pilot plant tests, default values on the basis of other fuels were used for these parameters.

One objective of the pilot plant tests was to generate such data. Most main items were found to stay uncorrected, whereas for some items a small correction has been made. In the case of the gasifier temperature, the tests have shown that a slightly higher temperature is feasible. The tar cracker temperature used was higher to achieve a conservative value with respect to obtaining sufficient tar removal. It is suggested to retain this higher temperature to maybe more easily accommodate also the use of cane trash.

13.6.12. Conclusions

The properties of the pelletized bagasse make it excellent as a feed for a gasification process. The physical properties of the fuel in the case of pellets makes it easy to feed and no problems are expected in a full scale feeding system when operating on pellets as long as it is designed to limit the disintegration of the pellets. Loose bagasse and cane trash can be handled if the design of the handling and feed system are made specifically for these fuels. As a result of the feed system performance and the fuel properties, an excellent availability for the gasification system was observed during the tests, ranging between 91 to 99% for the three weeks. The chemical reactivity of the organic part of the fuel results in a high carbon conversion to gas, (above 95%). This value should also be achievable for loose material, although this should be verified by testing. The bottom ash, being about two thirds of the total ash entering with the fuel, is low in carbon.

The ash properties of the bagasse limit the temperatures to be used in the gasifier to below a threshold value that was established from tests of up to one week duration as higher temperatures seem to result in extensive bed agglomeration. Examination of the ash revealed no tendencies for agglomerate formation below this temperature and in spite of this limitation a high carbon conversion was still attainable.

As the gas cleaning is achieved in a separate stage, i.e. the tar cracker using dolomite as catalyst, the operating conditions of the gas cleaning are decoupled from the gasifier operating conditions. A reasonably low tar content of the product gas was achieved, whilst still not interfering with operation of the gasifier. The tar content could be lowered further but at this point the tar level, 1 – 2 g/Nm^3, is manageable. However, despite the separation of tar in the scrubber being excellent, some localized operating problems from condensed tar resulted in more downtime in the scrubber than for the gasification section. The composition and heating value of the gas generated was typical for the pilot plant operating on a dry biomass fuel.

The fuel was low in other undesirable components such as nitrogen; yielding ammonia, chlorine; yielding hydrochloric acid and sulphur; yielding hydrogen sulphide. The sulphur released is lower than the emission limits in Sweden. HCl is decreased by contact with spent dolomite and by scrubbing. The fuel ash contains a lot of alkali, but alkali salts will be separated in the flyash and also removed in the scrubber to sufficiently low levels for a gas turbine.

The ammonia content is high and requires removal upstream of the gas turbine to reduce NOx emissions to below acceptable limits.

Parameters used for modeling have been validated by the tests, and only in a few cases was adjustment deemed necessary.

Thus, the main objective of the tests, to show that sugar cane bagasse can be used as a fuel in the gasification process was achieved. Also the other objectives, namely, to find a stable operating regime and validation of the data and parameters used for modelling and scaleup were achieved. Thus, the gasification process, utilizing bagasse as the fuel, can now be scaledup with reasonable confidence to a size consistent with an LM 2500 gas turbine. Also, the successful tests on sugar cane bagasse give us good hopes to also use sugar cane trash in the process.

13.7. Preliminary operating data for the pilot plant on cane trash

13.7.1. Overall performance

The data in this section is only preliminary, as the last test is still being evaluated, and the total program evaluation is thus still pending.

In the case of the cane trash the initial tests suffered from feeding problems which were mainly due to the quality of the fuel resulting from shedding of the bales. In the first test the shedding produced a too large particle size fuel of too low bulk density for the feed system.

In the second test, the fuel quality was improved but adjustments to the feed system were still necessary. However, in the third and fourth test the feeding of loose trash worked well with just a slightly higher variability than observed with pelletized fuel. Thereby the stable periods increased in duration. Also feeding both bagasse and trash simultaneously caused no disturbances.

Table 52

Operating performance of the pilot plant on cane trash.

Week nº	Total time	Downtime	Onstream
0036	84h	48h	43%*
0047	78h**	4h	95%
0117	98h	28h	71%
0117	74h	7h	91%

* On stream time does not reflect full capacity operation, and steady conditions

** Heating-up is not included, as switch-over was made from another fuel

No bed agglomeration was detected under any condition when using trash; however, there was a certain accumulation of ash fines in the gasifier. The filter and scrubber were only operated during periods of the tests, in particular during the fourth test. The reason for this was not related to the trash fuel, except for the first test. On one occasion, a tube leak in the gas cooler decreased the gas temperature below the operating window of the filter, and in yet another test the start-up heating system of the filter itself broke down and spare parts were not available within time. When operated, both the filter and the scrubber were performing satisfactorily.

The preliminary hours of operation of the whole plant, excluding the scrubber, in gasification and, with the exception of the first test, at full fuel feedrate, i.e. 500-550 kg/h, downtime and the onstream factor, are in **Table 52**.

Figure 77

Kverneland KD832.

During the tests, both pelletized and loose trash were used, and also pelletized bagasse in combination with loose trash. This gives data that can be used to asses the difference between a pelletized and loose fuel, such that operating data for using loose bagasse can be extrapolated from the data for pelletized bagasse, and also the effect of mixing the fuels in the gasifier can be judged.

13.7.2. Fuel pre-treatment and feeding

Unlike the tests on bagasse pellets, the pre-treatment of the cane trash proved more difficult than anticipated.

The sugar cane trash arrived at TPS in July 2000 in 0.9*0.9*2 meter bales. Each bale weighed approximately 250 kg. The quantity delivered was 640 bales, packed in 27 containers that were sent to TPS over a period of one week. The containers were unloaded and the bales stored in an indoor storage area on the TPS site specifically rented for this purpose. Some bales contained mould, and these were disposed off.

Before the baled cane trash could be used in the lowdensity fuel feeding system installed in 1999, it had to be pretreated. The main purpose with this activity was to decrease the particle size and to increase the fuel density to better fit the fuel feeding system, which was designed for a fuel density of approximately 50 kg/m^3.

Earlier preliminary cold tests with loose bagasse and loose cane trash had showed that the fibrous structure of the fuels caused them to form long strings, which were difficult to feed. This problem was believed to be manageable by shredding. Without shredding of the cane trash the density was very low, only between 10 and 15 kg/m^3, which could be increased to about 25 – 30 kg/m^3. This was believed to be sufficient for this test series. However, the shredding itself proved to be more difficult than foreseen because of a lack of access to suitable equipment.

CTC had recommended a shredder named "Haybuster" being of a hammer mill type. This machine was unknown in Sweden, and similar types of machine were not found, possibly because straw is easier to shred than cane stalks.

To try various shredders, 1 to 2 bales were loaded onto a cart, and transported to the shredder site for testing. A suitable shredder, when found would be towed to the TPS site and used there.

At a local farm a Kverneland KD832 bale cutter was available. This machine was initially considered to be very suitable for the purpose (**Figure 77**). The reason was that the machine in itself contained many functions and inbuilt flexibility. It has a feed table with a hydraulic feed chain, and the back door to the bale chamber can be used as a lift, for loading the bales, and also be tilted, thereby pressing the belt towards the shredder. At the far end of the feed chain, two co-rotating rollers cut material from the bale and force it into the exhaust fan via a discharge screen. The lower roller has 21 knives as a standard and also feed fingers, while the upper roller has a scraper, and can be adjusted in height to adjust the capacity.

The experience with this machine was that it produced a far too stringy material at too low bulk density, even with an additional 10 knives fitted. This was the case also after all adjustments possible had been made, and also at the lowest capacity, requiring approx. 10 minutes per bale.

Following this disappointing experience, several other lines of action were pursued. This resulted in a test at a fixed shredding installation in a barn. It was hoped that a fixed installation used daily would have a better control of the shredding than the fairly light duty mobile shredders. This was not the case in this test.

TPS had an old Svedala-Arbrå Malin (today Svedala-Allis) crusher available. This is a roll mill type of crusher for construction wood and similar coarse and contaminated materials. It has three rollers and a bottom screen to size the material. This machine proved to be excellent as far as the quality of the product was concerned, a bulk density of 70 – 80 kg/m^3 and very even small particles. The capacity was another story. One bale would take between 30 minutes to two hours to process. The supplier did not have any larger size crusher available, and they thought that in a larger mill, because of clearances and tolerances, the product quality would not be sufficiently good anyway, advising against using this type of machine.

A supplier of all kinds of milling equipment received a sample and tried it in an AZ7 knife-mill. Again, a bulk density of less than 20 kg/m^3 resulted, in combination with a capacity as low as 60 kg/h.

As many of the problems occurring seemed to stem from the fact that straw cutting machinery was not sturdy enough to cope with the coarser diameter trash tops and the layered structure of the bale, it was decided to try forestry chipping machinery. At a chip recovery site in the forest, tests were made with a Bruks 803 CT chipper. This is a drum type of chipper, with either knives or a hog rotor and it is powered by a nominal 300 kW diesel engine (**Figure 78**).

In this case, the capacity was not a problem, since a bale could be processed within a matter of minutes. However, the quality of the material was not improved. Tests were also made later with two different types of chipping machinery of slightly different design from another manufacturer, ERJO, as well as with a stationary chipper without any improvement.

Figure 78

Bruks 803 CT chip harvester.

Figure 79

Mengele SH 22.

The Mengele SH 22 exact cutter machine is normally towed after a tractor in the field, and thus feeding is achieved by the movement of the vehicle combination (**Figure 79**). The Mengele cutter is also a knife type straw shredder that was connected to, and powered by, a tractor when tried with the trash. The feeding is by fingers moving the material into a screw feeding from both ends into the centre, where the entrance to the shredder is. The knives were mounted on a rotating disc that cut the fuel and also transfers it into a fan that blows the cut straw out of the machine.

The capacity of the equipment was relatively low and one person was continuously occupied by operating the equipment during the test, mainly by controlling the feeding. The first tractor used had a nominal 60 hp motor, and this was not sufficient to maintain speed when layers of the bale were dropped into the shredder.

Figure 80

Milling equipment FRP-102.

The resulting shredding was therefore very variable, and capacity was far too low. Tests in the pilot plant feed system were not successful. As feeding problems were experienced during the test, cutting the fuel two times in the same equipment was tried, which increased the fuel density to between 35 – 40 kg/m^3. Obviously, the capacity of the shredder/cutting operation was not improved by cutting twice. This became impractical, as capacity was reduced to less than one bale per hour, to be compared to two bales usage per hour in the pilot plant. Instead, a stronger tractor was rented, 110 hp. This tractor alleviated the choking somewhat, and by keeping close control of the feeding, a better material could be produced having a bulk density of 25-35 kg/m^3. When tested in the pilot unit, under cold conditions, this material was considered to be feasible for use; however the capacity was possibly derated to 350-400 kg/h. It was then decided to try this material with bagasse pellets as an additional fuel in the first test, week 0039.

It was also decided to send part of the shredded trash for pelletization, but as forage harvesting was still being made, the pelletization plants producing cattle feed pellets would not be available for another 3 to 4 weeks, such that these pellets would not be available for this first test.

Prior to the second pilot plant test, a mill developed for shredding and crushing of waste materials, e.g. wood residue, plastics, and paper, was found and towed to the site, after a test with a few bales. This mill was then used to further disintegrate the leaves and the stems. The mill, FRP-102, is shown in **Figure 80.**

The bales were fed to the mill one by one with a tractor. The mill consisted of a rotary cylinder equipped with teeth manufactured of antiabrasive steel. These teeth crushed the material against steel anvils. A fuel resulted having a bulk density consistent with the demand of the feed system and also with a smaller particle size than previously obtained. The formation of strings formed by twisting of the long particle fibers disappeared. A disadvantage was that the dust fraction increased considerably resulting in problems in the surroundings.

The dimensions of the mill were approximately 3*3*3 m and the weight was 4 700 kg. The power consumption during cane trash milling was about 45 kW when about 5 bales/hour could be milled which is equal to 1.25 tons/hour of cane trash. This corresponds to a shedding energy consumption of approximately 36 kWh/ton of trash.

13.8. Pilot plant tests on cane trash

Gasifier

The gasifier was operated at temperatures from 800°C and upwards during the test campaigns on trash. The first test was planned to validate the agglomeration predictions from laboratory and bench scale tests, by gradually increasing the temperature. In this case, no agglomeration was seen even at the highest operating temperature.

A makeup feed of dolomite was used in the gasifier bed during some of the tests. The purpose was mainly to counteract agglomeration. It was however proven in the second test, that it was possible to run without adding dolomite in view of ash related problems. The high ash content of the trash (which varied between 10 and 20%) made it possible to only start on olivine sand, which was rapidly exchanged for fuel ash during the course of the test. The high ash content of the fuel made it also necessary to drain frequently from the gasifier bottom, as there was tendency for some of the particles to grow in size with time, and thereby accumulate in the gasifier, however, without forming agglomerates. Feeding dolomite with the purpose of maintaining a high concentration would therefore be wasteful.

The cane trash ash also contained a friable fraction of light and small particles. These tended to accumulate in the gasifier, in particular in the second recirculation loop. The nature of these particles led to that the second cyclone had to be drained to avoid circulatory disturbances, or overflow of this fraction of ash to the tar cracker.

There was also a significant difference in the results when using pelletized and loose cane trash. Using loose trash, the carbon content of the bed was lower, the tar content from the gasifier higher and there was also a difference in gas composition. All these results can be explained by the particle characteristics, the denser and heavier pellets yielding more char particles and a gas with longer residence time in the gasifier, compared to loose material, which undergo a rapid decomposition in the upper part of the gasifier.

When mixing trash and bagasse, there were no dramatic changes. The major effect was to decrease the ash discharge, as less ash entered.

Tar cracker

The tar cracker was mostly operated at approx. 900°C. The operation was in many instances less regular than when operating on bagasse. This was on one hand caused initially by the fuel feeding disturbances in the first test, and later, also because a higher inflow of fly ash from the gasifier than for most other fuels increased the bed inventory.

Gas cooling

The first two tests suffered from leakages in the gas cooler such that no relevant data was collected. For the other test the data have yet not been evaluated, but there were no signs of rapid deterioration of the cooling capacity, that would indicate severe fouling. The higher ash flow required frequent use of the sonic horn.

Particle separation and gas filter

From an operational viewpoint, these parts have worked without any trouble, when in use. In the first two tests the gas cooler exit temperature was too low to use the filter, in the third test the filter start-up heater broke down, preventing the use of the filter. However, in the fourth tests, there were no signs of blockage of the cyclone outlet, nor any tendencies for increased pressure drop across the filter bags.

Scrubber

The water scrubber has the task of removing residual tar and water-soluble gases, i.e. ammonia and hydrochloric acid, from the product gas. In addition, it condenses the main part of the gas moisture content. As the baghouse filter was only available for use during the fourth test, the scrubber was also only used in this test. The data for the scrubber have not been evaluated yet.

13.8.1. Preliminary results and discussion

Analysis of solids

Solid samples were regularly collected from the following parts of the plant:

- Gasifier bottom;
- First gasifier cyclone standpipe;
- Second gasifier cyclone standpipe;
- First tar cracker cyclone standpipe;
- Second tar cracker cyclone standpipe;
- Cold cyclone;
- Baghouse filter.

In these tests, the initial bed of the gasifier was established by injecting olivine sand. Some dolomite was also added later continuously. This is reflected by high initial contents of SiO_2/MgO (olivine) in the bottom ash and the first gasifier cyclone solids. The values successively decreased as the olivine was substituted by SiO_2 from the fuel ash.

The bottom ash has, in addition to a low carbon content, < 1% in all cases, also a low dolomite fraction of < 10%. This reflects the higher discharge of bottom ash necessary when using a trash feed. Some unburnt carbon from the pellets is also simultaneously drained, such that this is a result more related to the use of pellets than the use of bagasse fuels

The circulation streams of the gasifier had more or less the same composition as the bottom ash. This shows that the high ash content evens out the various streams, but also that when operating on trash, the carbon content is much lower in the second cyclone than when operating on e.g. wood. This could be attributed to the fuel structure. A number of ash samples from the tests were examined using light microscopy. Photographs were taken using Polaroid techniques. No evidence of agglomeration was seen, however, a similar growth of silica particles could be seen as in the tests on bagasse.

The solids circulating in the second cyclone loop of the tar cracker consisted of 50 – 70% of calcined dolomite and the remainder was fuel ash. A small fraction of carbon was also present. In spite of the high flyash carry over from the gasifier, it was possible to maintain predominant dolomite bed. However, the drainage of flyash from the gasifier would increase the dolomite concentration further.

The dust collected in the cold cyclone consisted of 10 – 30% carbon. The dust from the bag-house filter consisted of just slightly more carbon. The highest carbon content coincided with the use of trash pellets. The low carbon content is caused by the high ash content of the fuel, i.e. a dilution effect, but also because of the high carbon conversion that result from the use of loose material, compared to pelletized material.

A similar analysis of the flow patterns for the various solids will be made in the final evaluation, and probably result in changes to the ash draining system.

Gas production and composition

In **Table 53** typical gas analyses from the four tests are shown, reflecting the combination of fuels used. The composition of the gas exiting the tar cracker depends on gasifier and tar cracker temperatures.

Table 53

Gas analyses in pilot plant tests.

Item% volume	Pelletized bagasse,1999	Pelletized bagasse,2001	Loose cane trash	Pelletized cane trash	Loose cane trash /pelletized bagasse
H_2	10.4	7.6	6.7	7.1	8.9
N_2	57.1	61.7	62.8	62.3	57.7
CO	10.9	9.7	7.9	8.8	10.8
CH_4	3.5	2.9	3.1	3.0	3.7
CO_2	17.6	17.5	18.9	18.4	18.0
C_2H_4	0.5	0.5	0.8	0.5	0.9
LHV, MJ/Nm^3	4.1	3.4	3.3	3.3	4.2

The differences in LHV between the operation with trash and pelletized bagasse is related to the higher ash content of the former, requiring energy to heat up which is taken from a lesser fraction of combustible material. (The difference between the bagasse tests in 1999 and 2001 is that the 2001 data reflects the initial part of the test, before a proper thermal steady state has been achieved, and also that the trash feed system was installed in between the tests, and introducing more nitrogen inert gas diluting the product gas). Again, it should be stated that the high heating losses of the small pilot plant decreases the heating value of the gas, compared to a full scale plant, or where heat losses are compensated by external heating, as in the bench-scale reactor.

The yields of some other gas components, e.g. aliphatic hydrocarbons, BTX and naphthalene were estimated on the basis of the gas and tar analyses. These are essential inputs to the model calculations.

Minor components and constituents in the gas

Some minor constituents of the gas, that is; gas components present at below 1 000 ppm, were measured at numerous occasions during the tests. The components of interest are ammonia (NH_3), hydrogen cyanide (HCN), hydrogen sulphide (H_2S) and hydrogen chloride (HCl).

Ammonia and hydrogen cyanide emanate from the nitrogen content of the cane trash fuel. Normally, the main part, i.e. 50 – 80%, of the fuel nitrogen is converted to ammonia and a very small portion, parts of percent, to hydrogen cyanide. In the three tests where feeding of trash was sufficiently stable to evaluate the data, the following approximate conversions to ammonia and hydrogen cyanide, and ammonia and hydrogen cyanide contents, respectively, of the gas after the tar cracker are in **Table 54**.

Table 54

Ammonia and cyanide conversion.

Week nº	NH_3 (mg/Nm^3)	Conversion NH_3 (%)	HCN (mg/Nm^3)	Conversion HCN (%)
0047	940-1030	51-78	0-14	<1
0117	1430-1580	80		
0124	1280-1570	Approx. 100	3-18	0.2-1

The slightly higher conversions seen in these tests, compared to the bagasse tests, may be a result of a lower dolomite concentration in the tar cracker bed, as flyash from the trash entered more than for other fuels.

Inorganic and organic sulphur of the fuel is released as hydrogen sulphide in the reducing atmosphere of the gasification system. The calcium part of the calcined dolomite, as well as in the ash, has the ability to retain a part of the sulphur in the solid residues as calcium sulphide, CaS, at low temperatures, i.e. below 800°C. A complete conversion of the fuel sulphur content of the fuel, which is approximately 600 ppm weight, would result in a hydrogen sulphide content of the gas of around 200 mg/Nm^3. The actual measured values during the tests after the tar cracker, after the baghouse filter and after the scrubber are in **Table 55**.

Table 55

H_2S in gas (mg/Nm^3).

Week nº	Gasifier	Bag house filter	Scrubber
0047	70-180	-	-
0117	-	-	-
0124	167	92	70-81

From these measurements it seems that the main part of the fuel sulphur is initially released as H_2S in the gasifier. Again, tar cracker values are probably not relevant because of sampling system interaction. The values measured after the baghouse filter and the scrubber are of the same order as the values measured in the gasifier gas showing that the retention of sulphur in the system is in the order of 30 – 50%. Most of this captured sulphur is found in the flyash.

Table 56

HCl in gas (mg/Nm^3).

Week nº	After tar cracker	After baghouse filter	After scrubber
0047	24	-	-
0117	-	-	-
0124	8-540	19	0-25, 101

The cane trash had a mean chlorine content of 1400 ppm weight and a total conversion to hydrochloric acid, which in the stable chlorine containing substance in a reducing atmosphere becomes 500-600 mg/Nm^3. The measured values are in **Table 56**. Thus, it can be stated that the main part of the fuel chlorine is retained in the solids leaving the process, most probably as CaCl .

13.8.2. Mass and energy balances, carbon conversion

Mass balances have been calculated during stable operating periods in the three latter tests. The balance was made on both measured gas flow and a nitrogen balance calculation of gas flow.

During the first test, the fuel flow had large variations, and it was also suspected that the fuel ash content was varying a lot. Therefore the balances did not match up very well. However, there was an impression that the carbon conversion was higher using loose trash, compared to pellets. The numerous ash analyses done in the third test showed that the ash content of the fuel was very varying. Again the data were pointing towards a higher conversion for loose trash than for the corresponding pellet material. The difference is about 4 units of %.

The same trend is not evidence when mixing trash and pelletized bagasse. The carbon conversion when using bagasse is the same as in the tests of 1998-1999, while the preliminary evaluation of mixed fuel test shows lower results on conversion than for loose trash (**Table 57**). This result will be analyzed further during the evaluation.

As can be seen from the table, the carbon conversion to gas, on a normalized basis, narrows to between 95 and 97% for loose trash, i.e the same magnitude as for bagasse pellets. If the carbon balances are normalized, a probable gas flow can be calculated. As very preliminary mean values, 2.3 Nm^3/kg of fuel on a moisture free basis and 2.6 Nm^3/kg of fuel on a moisture and ash free basis. The pelletized material shows consistently lower carbon conversion. This is slightly lower than for bagasse in the first case, as less combustible fuel is available per kg of fed material, whereas on a maf basis, the production is slightly higher, as somewhat more air is necessary for the reaction to compensate for the higher ash content.

Table 57

Carbon conversion.

Week 0047	Pelletized trash	Loose trash	Loose trash	Loose trash
Carbon in gas/carbon input	80	122	71	100
Carbon balance on measured gas flow	91	130	74	101
Carbon balance using a nitrogen balance	88	134	76	82
Corrected carbon conversion	89-92	88-92	95-97	99-118

Week 0117	Loose trash	Loose trash	Pellet trash	Pellet trash	Pellet trash
Carbon in gas/carbon input, measured gas flow	99	101	104	104	107
Carbon in gas/carbon input, nitrogen balance	92	97	91	93	93
Carbon balance (out/in), measured gas flow	101	105	115	111	115
Carbon balance (out/in), using a nitrogen balance	95	101	103	101	101
Corrected carbon conversion	97	96	89	93	92

Week 0124	Pelletized bagasse	Loose trash /Pelletized bagasse	Loose trash /Pelletized bagasse	Loose trash /Pelletized bagasse
Carbon in gas/carbon input, measured gas flow	107	95	107	105
Carbon in gas/carbon input, nitrogen balance	91	91	95	95
Carbon balance (out/in), measured gas flow	110	102	114	110
Carbon balance (out/in), using a nitrogen balance	95	99	102	101
Corrected carbon conversion	96	93	93	94

Based on the mass balances, energy balances have been made. The quality of an energy balance is reflected by the value of heat loss. This term is calculated as balance and should be in the order of 12 – 13% of the total energy supply for wood fuel. This corresponds to the convective and radiative heat loss of the vessels and piping.

The higher ash content, and sometimes the lower fuel feed rate when operating on loose trash makes the expected value to increase a bit (**Table 58**).

Table 58

Energy balances

Week nº	Heat loss with calculated gas flow	Heat loss with adjusted gas flow
0047 Pelletized trash	23-25	17-19
0047 Loose trash	-1—3	17-19
0047 Loose trash	41-42	24-25
0047 Loose trash	23-37	23-25
0117 Loose trash	11-16	11-12
0117 Loose trash	7-10	10-11
0117 Pelletized trash	7-16	16-17
0117 Pelletized trash	12-19	18-19
0117 Pelletized trash	11-21	20-21
0124 Pelletized bagasse	10-22	18
0124 Pelletized bagasse/ loose trash	10-13	10-12
0124 Pelletized bagasse/ loose trash	1-11	11
0124 Pelletized bagasse/ loose trash	7-15	14-15

Tar cracking

The two varieties of cane trash fuels, i.e. loose and pelletized fuel, gave completely different results regarding tar production in the gasifier and regarding the efficiency of the tar cracker.

An initial production of 1.0 – 3 g/Nm^3 of tar emanated from the use of cane trash pellets from the gasifier. The initial low level in the gasifier from the pelletized cane trash was not reduced further at all in the tar cracker, the result ending up similar to the results for pelletized bagasse in 1998-1999. When using loose cane trash the production was as high as 5 – 9 g/Nm^3 from the gasifier. However, from this high level the tar content of the gas was reduced to 2 – 5 g/Nm^3 with a mean reduction factor of 37 – 50%, when passing the tar cracker. From these results it can be stated that the initial production mechanism in the gasifier is completely different, when using pelletized and loose cane trash. One likely explanation is that the pelletized material will predominantly stay in the bottom section of the gasifier during the devolatilization, such that the escaping tars have a long residence time, in relative terms, in the gasifier, and also a good contact with the bed ash and the dolomite present. The remaining tar from this initial breakdown becomes more refractory, such that the relative conversion of the tar cracker is reduced. When loose material is fed, the material will rapidly undergo pyrolysis, but this will occur within the entire gasifier shaft, such that tars have less time in the gasifier and less contact with other solids present. Therefore, the tar from the gasifier is higher in concentration, but the reduction is also higher in the tar cracker, off-setting this initial high tar content.

Another effect, when using these high ash fuels, is that ash entrained from the gasifier will be building up to a steady state concentration in the tar cracker, thereby decreasing the amount and concentration of dolomite in this vessel. This can also be responsible for a somewhat more reduced tar conversion using trash, compared to using bagasse pellets.

During operation on pelletized bagasse alone, during the fourth test Week 0124, the amount of tar in the gas from the gasifier was 5 – 6 g/Nm^3 of dry gas that was reduced to 1 – 2 g/Nm^3 in the tar cracker unit, the conversion of tar were calculated to 57 and 59%. These values are more or less on the same level as obtained during earlier test campaign with bagasse in 1998-99.

The levels of tar in the gas from co-feeding bagasse/loose cane trash operation were ranging from 8–12 g/Nm^3 after the gasifier and 4–8 g/Nm^3 after the tar cracker and were significantly higher than operation on bagasse alone, but similar to the results from previous test with loose cane trash. The reduction of tar in the tar cracker was during operation on bagasse/loose cane trash between 30 and 50%.

The dolomite feed rate to the tar cracker was during the later part of the test limited by the maximum allowed pressure drop in the tar cracker, which increased considerably due to carry-over of material from the gasifier. Thus, there is potential for an increased reduction in tar content if the operation of the gasifier, and especially the gasifier bed height, could be controlled in a different way when using fuels with this high ash content.

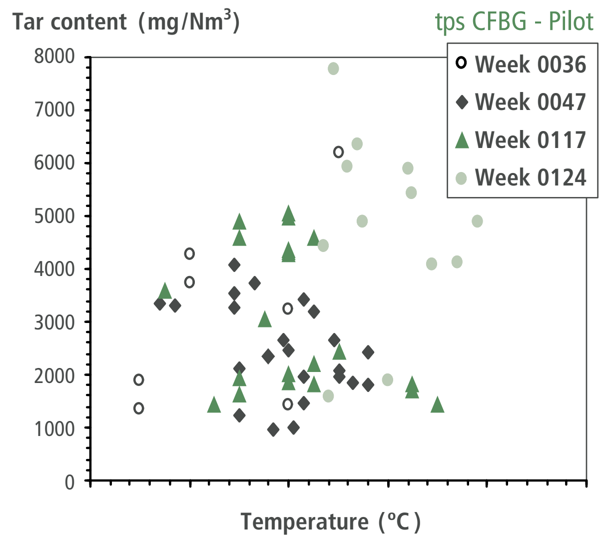
Tar data are collected as a function of temperature in **Figure 81**. The evaluation of all data points in terms of fuel and other operating conditions is yet only partially available. Such more in-depth evaluation will probably reveal more correlation between the operating factors. However, when comparing the data for bagasse and this data, it can be concluded that the trash gives more tar in the gas exiting the tar cracker.

Disregarding the few data points from Week 0036, when operation was unstable, the data form tests with cane trash only, Week 0047 and Week 0117, give quite consistent data. The data for Week 0124, when mixing bagasse and trash tend to be higher. The average for all data is 3.2 g/Nm^3, for tests using trashv alone 2.7 g/Nm^3, compared to 2.0 g/Nm^3 in the case of bagasse. For mixed fuel, the data indicate a mean of 4.8 g/Nm^3.

The preliminary conclusion of these data was that the tar content when operating on cane trash is slightly higher than for bagasse alone. However, the data for the mixed fuel is probably not so related to the fuel as to the other operating conditions influencing the efficiency of the tar cracker in this case, i.e. the ash/dolomite ratio in the bed. There are also other relations that must be considered such as the actual operating conditions, bed inventory, dolomite type, feed rate etc. This will be more closely analysed in the final report of the trash tests.

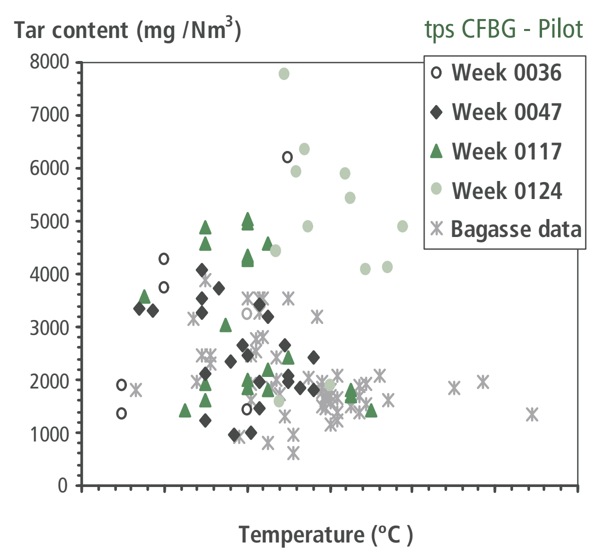
However, when comparing the trash and bagasse test (**Figure 82**), the difference in tar result is mostly eliminated, as the operating temperatures for the bagasse tests were, on the average, higher compared to the trash tests. Therefore, the conclusion may well,

Figure 81



Tar Concentration in the tar cracker off gas vs. temperature. (temperatures are blanked off). Trash test series.

Figure 82



Complete set of tar data for both bagasse and trash test series. (temperatures are blanked off) after the final analysis, be that the tar content will be very similar when using bagasse and cane trash, and the cause of the higher tar resulting for the mixture of these fuels is more related to the other operating conditions of that test.

Furthermore, trash contains more chlorine, which is known to have an inhibiting effect on the dolomite activity for tar conversion. The full evaluation, also involving the trace components in the bed materials, will look at this further. In addition, the final process engineering study may introduce changes to improve the system when using high ash fuels.

In spite of this higher tar content, scrubbing was efficient to decrease the tars in the gas downstream of the scrubber to levels consistent with the operating temperature of the scrubber, as was also the case for bagasse.

After the gas scrubber, which was only used in combination with the higher tar content in Week 0124, incoming tar was further reduced to between 2 – 3.5 g/Nm^3 of dry gas, which is in line with the higher operating temperatures used in this case, than for the previous tests on bagasse. However, obviously the amount of condensed tar to be reinjected in the gasifier increases.

Water condensate

These data remain to be evaluated for the tests with cane trash.

Comparison of test results and modelling parameters

The computer model used for the process integration work requires inputs of empirical nature in order to predict the gas composition and the process performance correctly. These parameters depend on the process conditions, but even more so on the fuel. Thus, for a new fuel, pilot plant tests are necessary to accurately predict the process performance. As the process integration work started prior to the pilot plant tests, default values on the basis of other fuels were used for these parameters. For this preliminary work, no distinction was made between bagasse and trash.

Following the pilot plant tests on bagasse, modelling parameters were established for bagasse. These were, for lack of other data, also used for trash. One objective of these pilot plant tests was to generate such data specifically for trash. This evaluation and its outcome was that most main items are uncorrected. In the case of the gasifier temperature, the tests have shown that trash is less sensitive than bagasse.

The tar cracker temperature used was higher to achieve a conservative value with respect to obtaining sufficient tar removal. It is suggested to retain this higher temperature to maybe more easily accommodate also the use of cane trash, and adjust the tar yields upwards slightly.

For trash, a lower gas heating value is a result of the higher ash content, rather than also an effect of fuel parameters, and the span in gas LHV to be considered in the design can be decreased. Ethylene has also been lowered slightly as a result of the tests. The BTX fraction, on the other hand, has been increased slightly and a figure for HCN yield has been reached. However, in general, the model parameters used up to now fit well with the pilot plant tests.

13.9. Conclusions

The properties of the trash make it suitable as a feed for a gasification process. The physical properties of the fuel in the case of pellets makes it easy to feed and no problems are expected in a full scale feeding system when operating on pellets as long as it is designed to limit the disintegration of the pellets.

Loose bagasse and cane trash can be handled if the design of the handling and feed system are made specifically for these fuels. However, pre-treatment of in particular cane trash is very important to achieve a consistent quality of the material.

As a result of the improvement in the trash fuel quality from improved shredding and also from adjustments of the feed system the availability for the gasification system increased with time to over 90% in the tests.

The chemical reactivity of the organic part of the fuel results in a high carbon conversion to gas, above 95% in the case of loose trash, while for pelletized trash only 90% is achieved. This higher conversion value should also be achievable for loose bagasse material, although this should be verified by testing. The bottom ash, being about 50 – 70% of the total ash entering with the fuel, is low in carbon.

No tendency for agglomerate formation at any of the temperatures tested was seen, either as operating disturbances or when examining the ash.

The tar content for cane trash fuel was similar or only slightly higher than when operating with bagasse alone, at similar tar cracker temperatures. The reasons for any deviations are that the chlorine is higher in the trash, interfering with the function of the dolomite, and also that the high ash content of the trash caused flyash to be entrained to the tar cracker, where it diluted the dolomite concentration in the bed. This is the probable reason for the higher tar content when testing a mixed trash and bagasse feeding. This underlines that the tar conversion is not a fuel property, but is linked to the operation of the tar cracker. The increased tar levels did not cause difficulties in the operation of the scrubber.

The composition and heating value of the gas generated from trash was lower than for a typical test in the pilot plant operating on a dry biomass fuel. The reason is the higher ash content that drains a fraction of the energy content of the fuel to reach the reaction temperatures.

The fuel contains some undesirable components such as nitrogen; yielding ammonia, chlorine; yielding hydrochloric acid and sulphur; yielding hydrogen sulphide to a higher degree than bagasse. The ammonia content is high and requires removal upstream of the gas turbine to reduce NOx emissions to below acceptable limits. The sulphur content is higher than for bagasse, but still lower than the emission limit in Sweden. The hydrochloric acid will react with spent dolomite, and the remaining traces in the gas will be removed in the water scrubber.

Parameters used for modelling have been validated by the tests, and no essential deviations from the corresponding values for bagasse, apart from higher tar yield, were noticed.

Thus, the main objective of the tests, to show that sugar cane trash can be used as a fuel in the gasification process was achieved. Also the other objectives, namely, to find a stable operating regime and validation of the data and parameters used for modelling and scaleup were achieved. Thus, the gasification process, utilizing trash as the fuel, can now be scaledup with reasonable confidence to a size consistent with an LM 2500 gas turbine.

Table 59

Summary of conclusion from pilot plant tests.

» Conclusion of pilot plant tests.

» Pelletized bagasse tests (3 x 1 weeks) **1998-1999**

» Loose trash tests (4 x 1 weeks) **2000-2001**

	Bagasse	**Trash**
• Feeding properties	Excellent	Good
• Availability in tests	Excellent	Fair-good
• Gas heating value, rel. wood	Similar	Slightly lower
• Carbon conversion	> 95%	> 95%
• Tar content in product gas, rel wood	Similar	Similar to slightly higher
• Agglomeration	Above limit temp	None
• Carbon content in bed ash	Low	Low
• Fouling of gas cooler	Not observed	Not observed
• Ammonia content, rel. wood	Similar	Higher
• Mixed trash bagasse fuel op.	Yes	Yes
• Other contaminants	no	Some S, Cl

13.10. Overall conclusion of the pilot plant tests

Table 59 is a summary of the results of the pilot plant tests on the sugar cane fuels bagasse and trash. Both fuels were found to be acceptable for use in the gasification process and data were collected to allow modelling of the process for operation on these fuels at larger scale.

The overall conclusion is that sugar cane fuels, both bagasse and trash can be used in the CFBG process to generate a gas of suitable quality and heating value for a gas turbine.

14. Integration of BIG-GT system with a typical mill

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14.1. Introduction

In the WBP Project (Brazilian Woodchips Project), that was used as reference for this project, the BIG-GT plant concept was an independent thermal power plant, operating in a combined Brayton/Rankine cycle, using woodchips from a dedicated planted eucalyptus forest.

To use the same BIG-GT module, based on the gas turbine GE LM 2500 in a sugar mill it is necessary to carefully evaluate the following points:

- Supply/demand of biomass fuels – bagasse and trash;
- Impacts of the BIG-GT system in the mill operation and vice versa;
- Necessary modifications in the mill and in the BIG-GT module;
- Preprocessing and conditioning of bagasse and trash;
- Auxiliary systems and equipment sizing;
- Estimation of investment cost;
- Estimation of surplus energy generation;
- Estimation of energy cost.

» Objective

To evaluate the possibility of integrating a BIG-GT system with a typical mill and to determine the main parameters necessary for the technical and economic analysis of the total installation to generate surplus power to be fed to the grid.

14.2. Methodology

The BIG-GT – mill integration evaluation process was divided into several interrelated steps, which were:

- Typical mill selection;
- Study of the modifications in the mill necessary for the integration;
- Process engineering modification to adapt the BIG-GT package to operate with sugar cane residues in a sugar mill environment;
- Gasifier feed system testing with loose bagasse and trash;
- Preliminary basic engineering;
- Design and engineering of the fuels conditioning systems;
- Design and engineering of the mill modification;
- Investment costs assessment;
- Energy cost estimate.

Part of the activities planned was developed by CTC and part by TPS; the interrelation between these activities required a close collaboration and active information exchange between CTC and TPS.

14.3. Purpose

The purpose of this work is to define the basic BIG-GT system data and operating conditions, considering both the stand alone and mill integrated solution using sugar cane bagasse and trash as fuel. The data is intended to be used in the economic analyses.

A stand alone BIG-GT unit works as an independent thermal power plant operating in a combined cycle (CC). In this case the BIG-GT receives bagasse surplus from the mill and part of sugar cane trash from the field. This study considered that trash is baled in the field after sugar cane harvesting and transported to the plant. Bagasse and trash are fed to a gasifier, the gas from the gasifier after adequate cleaning is burned in a gas turbine, and the hot flue gas goes to a heat recovery steam generator (HRSG) that produces steam at 60 bar, 500ºC. This steam goes to a condensing steam turbine and the steam condensate goes back to the HRSG (**Figure 83**).

The BIG-GT plant integrated with the mill provides steam to the sugar and ethanol factories. An amount of bagasse from the mill and trash from the field are gasified. The gas after adequate cleaning is burned in a gas turbine, the hot flue gas goes to a heat recovery steam generator that produces steam at 21 bar, 300ºC. This steam goes to the mill where is added to the steam generated by conventional boilers, producing electric / mechanical power and heat to the sugar and ethanol factories. In the off season the steam turbine operates in a condensing mode (**Figure 84**).

One of the main purposes of project BRA/96/G31 is to evaluate the cost and amount of electric power generated by BIG-GT system either integrated with the sugar factory or as a stand alone plant. The BIG-GT/Mill Integration study intends to determine BIG-GT capital costs, erection costs, operating costs, electric power self consumption, net electric power for export, sugar cane bagasse and trash consumption for economic and environmental evaluations.

Figure 83

Simplified diagram, Stand alone BIG-GT plant.

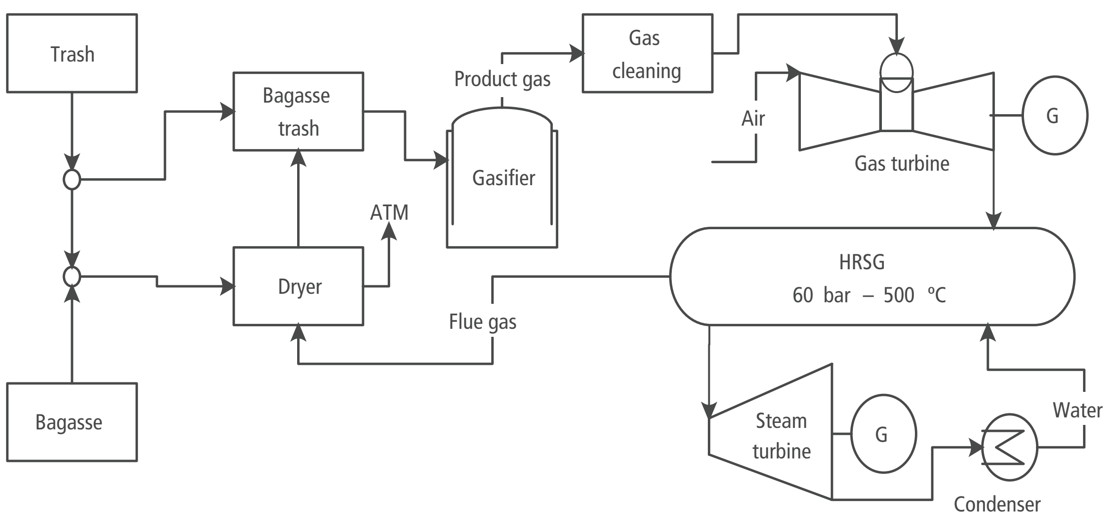
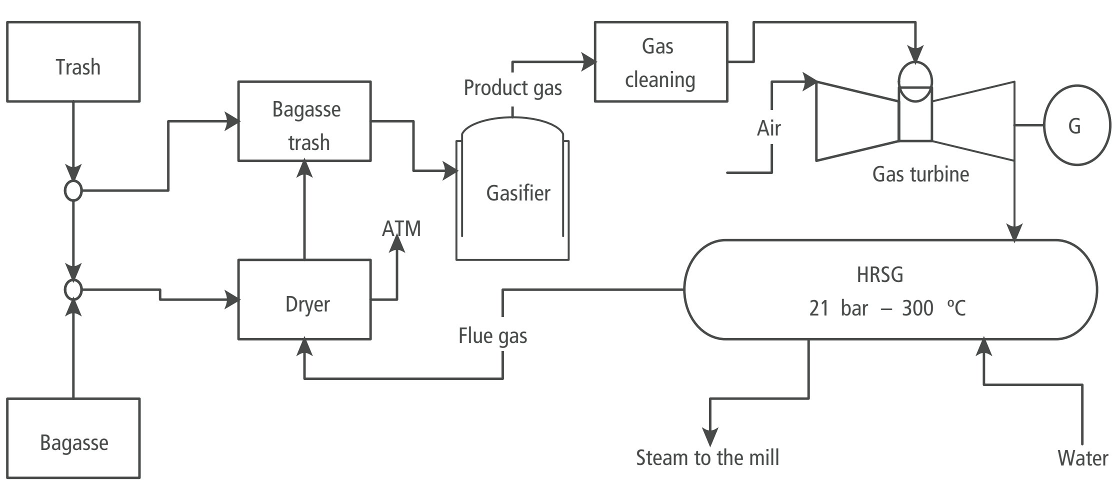


Figure 84

Simplified diagram, Plant integrated with the mill.



14.4. Typical sugar mill

In order to obtain basic data, process parameters and installation design in a more realistic way, the decision was to select a typical mill to be a model for the project.

The choice was based on Copersucar/Eletrobras project and other new data available. The main points considered in the selection process were total sugar cane crushed, crush rate (close to Brazilian average), availability of process and energy data, mill's management willingness to cooperate and experience with unburned sugar cane harvesting.

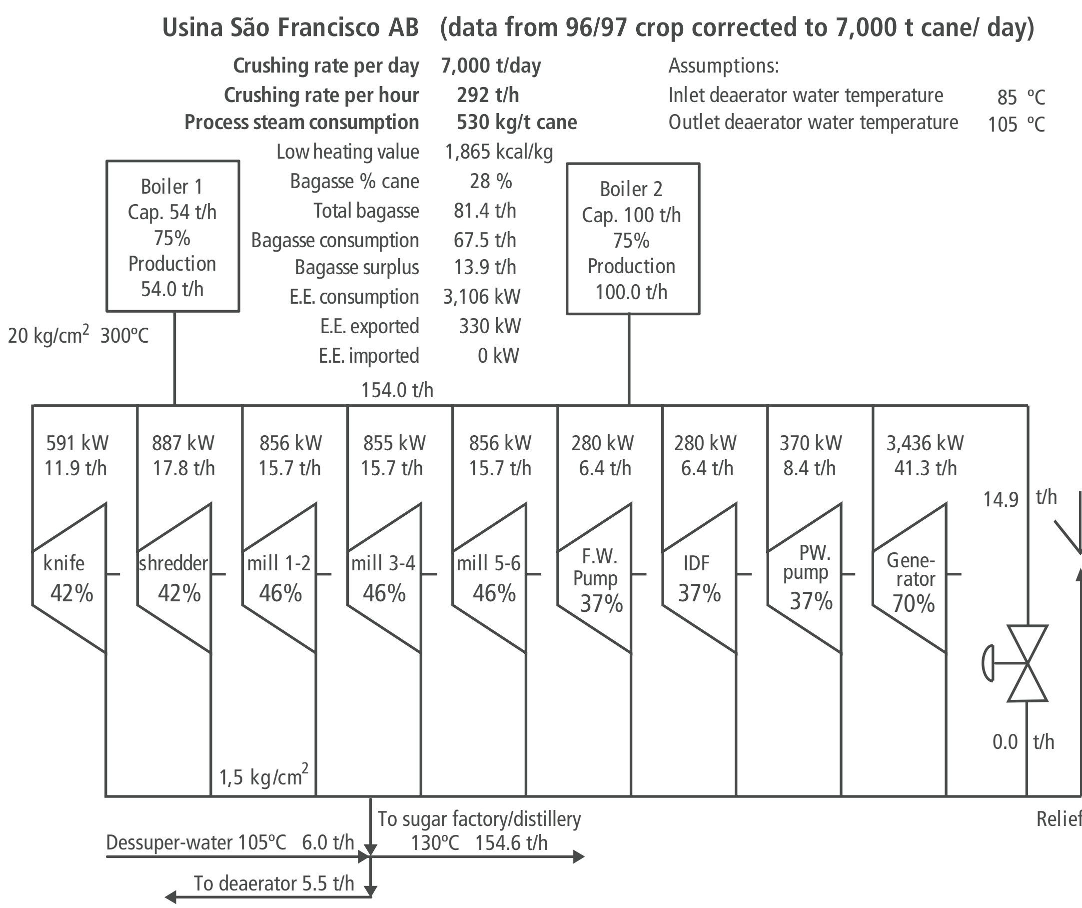
Usina São Francisco S.A. (Barrinha-SP) was the selected mill, with the following technical features:

- Total harvested cane: 1,300,000 t/year
- Crushing rate per day: 7,000 t/day
- Crushing rate per hour: 292 t/h
- Harvesting season: 4,457 h
- Sugar production: 8,000 bag/day (50 kg bag)
- Ethanol production:
  - Anhydrous: 177,000 L/day
  - Hydrated: 177,000 L/day
- Fiber % cane: 13.8%
- Process steam consumption: 530 kg/t cane

The heat balance for the present conditions is shown in **Figure 85**.

Figure 85

Heat balance (present situation).



14.5. Process parameters

Three steam conditions were initially selected for BIG-GT typical mill integration:

- High pressure cogeneration (HP) - Pressure 82 bar and temperature 480ºC;
- Medium pressure cogeneration (MP) - Pressure 22 bar and temperature 300ºC;
- Low pressure cogeneration (LP) – Pressure of 2.5 bar saturated (process steam).

For these three conditions TPS developed studies obtaining bagasse and trash consumption, net electric power and net steam for the mill supplied by BIG-GT module (**Table 60**). For the stand alone option, steam conditions for the heat recovery steam generator were defined as pressure of 60 bar and temperature 500ºC.

Table 60

Basic BIG-GT system parameters.

Operating	Steam pressure (bar)*	Steam temp. (ºC)	Produced steam (t/h)	Bagasse consuption BIG-GT (t/h)**	Gas flow (t/h)*	Gas temp. (ºC)*	Electric power BIG-GT (MW)
Cogeneration HP	82.0	480	56.52	18.36	255.6	221	16.8
Cogeneration MP	22.0	300	72.36	18.36	255.6	144	16.8
Cogeneration LP	2.5	sat	83.16	18.36	255.6	132	16.2
Stand alone	60.0	500	55.08	18.36	255.6	136	33.2

(*) Heat Recovery Steam Generator. (**) Dry basis.HP= high pressure, MP= medium pressure, LP= low pressure and sat= saturated

14.6. Fuel features

Samples of bagasse and trash were sent to TPS in Sweden, where laboratory tests were performed obtaining the fuel basic features, fuel gas composition and ash composition. **Table 61** and **Table 62** show the main values of fuel features.

Table 61

Fuel analysis – Sample sent to TPS.

Fuel	Palletized bagasse
Moisture content (%)	8.7
Volatile matter (%)	82.9
Ash (%)	3.6
HHV (MJ/kg)*	18.75
LHV (MJ/kg)*	17.44
LHV (MJ/kg)**	7.5
Ash fusion temperature (ºC)	1,530

Table 62

Trash (baled/shredded) and bagasse analysis.

Fuel	Baled trash	Loose trash
Moisture content (%)	9.6	7.6
Volatile matter (%)	73.5	57.1
Ash (%)	10.1	29.1
HHV (MJ/kg)*	17.44	14.31
LHV (MJ/kg)*	16.09	13.33
LHV (MJ/kg)**	6.82	-
Ash fusion temperature (ºC)	1,370	1,650

HHV= Higher heating value; LHV= Lower heating value; (*) Dry basis; (**) Moisture content of 50%

14.7. TPS data analysis

The fuel tests and BIG-GT simulations have been used by TPS to define the basic parameters to be used in the project, as:

- Selected gas turbine for BIG-GT = GE LM 2500.
- Moisture content of the bagasse fed to the gasifier must be about 10%, for this a bagasse dryer is needed in the project.
- The sugar cane trash must be mixed with bagasse to feed the gasifier, in order to keep the low heating value of product gas above the minimum limit set by the gas turbine manufacturer.
- Net overall efficiency for stand alone system is about 38%.
- Net overall efficiency for mill integrated system in cogeneration is about 78%.

14.8. Heat balance – Cogeneration studies – BIG-GT mill integration

BIG-GT integration with typical mill studies were started based on TPS basic data. The alternative of cogeneration with low steam pressure was not studied in detail due to the high capital costs involved in changing all existing steam turbines drives to electric/hydraulic motors. Three process steam consumption alternatives have been considered namely 500 kg/ton cane, 340 kg/ ton cane and 280 kg/ ton cane.

Different HRSG steam pressures and temperatures, associated with three process steam consumption levels and two alternative of equipment drives (steam turbines/electric motors), result in several heat balance alternatives. At first only cogeneration operation in the crushing season has been analyzed. Based on these studies results, it has been concluded that this operation mode (season only) was economically unfeasible.

After that new studies have been performed considering season and off season power plant operation with 87% annual availability factor, supplying nearly the same electric power for export in season and off season. In this part of work seven heat balances have been done (**Table 63**), including two modules BIG-GT system study.

Table 63

Summary of alternatives.

Alternative	BIG-GT HRSG pressure (bar)	Temp. (°C)	Steam consumption (kg/ton cane)	Mill boiler pressure (bar)	Drives converted from steam turbines to electric motors*
20T340	22	300	340	22	Auxiliary drives (pumps, etc)
20M280	22	300	280	22	Auxiliary + Shredder / Knifes
81M2802B	82	480	280	-	Auxiliary + Shredder / Knifes
81T340	82	480	340	22	Auxiliary drives (pumps, etc)
81M280	82	480	280	22	Auxiliary + Shredder / Knifes
C81M280	82	480	280	82	Auxiliary + Shredder / Knifes
C81T340	82	480	340	82	Auxiliary drives (pumps, etc)

HRSG= Heat Recovery Steam Generator

(*) In all alternatives the mills are driven by steam turbines.

The basic features, capacity and technical specifications of main equipment required for mill integration were defined as a result of these studies. Costs assessments were done for a preliminary economic analysis. At this time it was concluded that an alternative must be selected for detailed design and investment and operating costs assessment.

The selected alternative for detailed design was 20T340, based on the amount of exported electric power, fuel consumption and changes in sugar mill for process steam consumption reduction. This solution requires less mill changes, thus it is cheaper and it has a smaller impact (**Figure 86**).

14.9. Heat balance – Stand alone BIG-GT

In this alternative it has been considered that all bagasse and trash to the BIG-GT plant must be supplied by the typical sugar mill. To get enough BIG-GT fuel the mill would need to reduce process steam consumption to produce more bagasse surplus. It has been selected a similar alternative to mill integrated mode named 20T340a (**Figure 87**).

14.10. BIG-GT stand alone plant

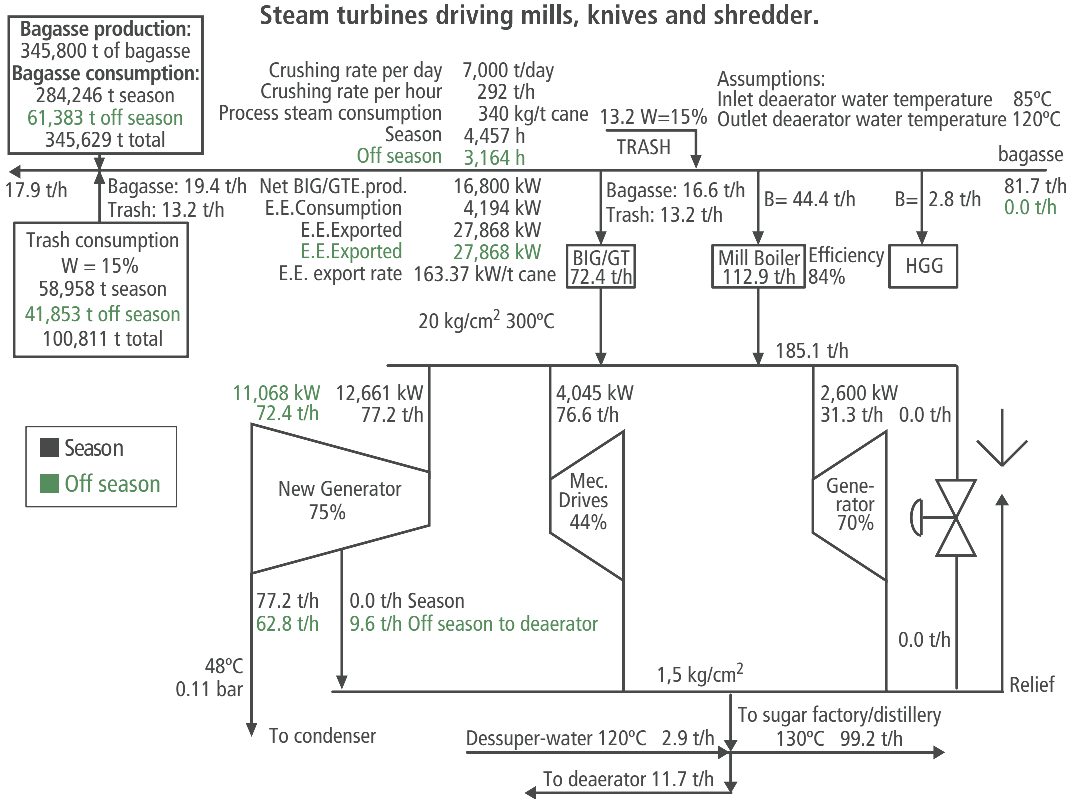
14.10.1. Basic information

The typical mill supplies bagasse (50% moisture) and bailed trash (15% moisture) to the stand alone BIG-GT plant. To increase the bagasse surplus the sugar and ethanol factories will need equipment changes to reduce the

Figure 86

Heat balance - Cogeneration mill integrated BIG-GT (20T340).

BIG/GT mill integration Typical Mill. 7,000 tons of cane/day, 340 kg of steam/t of cane per hour. Steam turbines driving mills, knives and shredder.



process steam consumption. The boilers overall efficiency will be 85%. The BIG-GT stand alone plant needs bagasse dryer system to dry the received bagasse to 10% moisture content.

Figure 87 and **Table 64** show the typical mill data summary. **Table 65** summarizes the fuel consumption (bagasse and trash) for a BIG-GT stand alone plant.

BIG-GT stand alone operation

- Bagasse warehouse (Surplus from sugar mill)
- Bagasse discharge
- Bagasse discharge capacity: 4 trucks/h (80t/h)
- Bagasse transport: 6 days/week and 12 h/day
- Sugar cane baled trash used as supplementary fuel
- Sugar cane trash receiving in season only
- The trash is shredded when received in the plant
- After shredded the trash is stored in a yard
- Storage yard area (bagasse/trash): 21,000 m^2 (maximum height 25m)
- Baled trash discharge with two machines (front end loader)
- Discharging and shredding system area: 840 m^2
- Baled trash transported by trucks
- Number of bales transported per trip: 72 bales
- Number of trips: 38 per day (24 h/day)
- Dry fuel warehouse for 1 day operation: 5,900 m^3

Bagasse and trash data used in the storage / transport design

- Loose bagasse (50% moisture content) : 125 kg/m^3

Table 64

Typical mill basic features – BIG-GT stand alone plant.

Crushing rate	7,000 t/day
Harvesting season	4,457 h
Process steam consumption	340 kg/t cane
Electric power consumption	4,193 kWh/h
Electric power self produced	2,100 kWh/h
Electric power imported from BIG-GT	2,093 kWh/h
Boilers steam production	102 t/h
Bagasse surplus*	37.0 t/h
Bagasse surplus season*	164,900 t/season

(*) Considering 5% loss on total bagasse and bagasse with 50% moisture content.

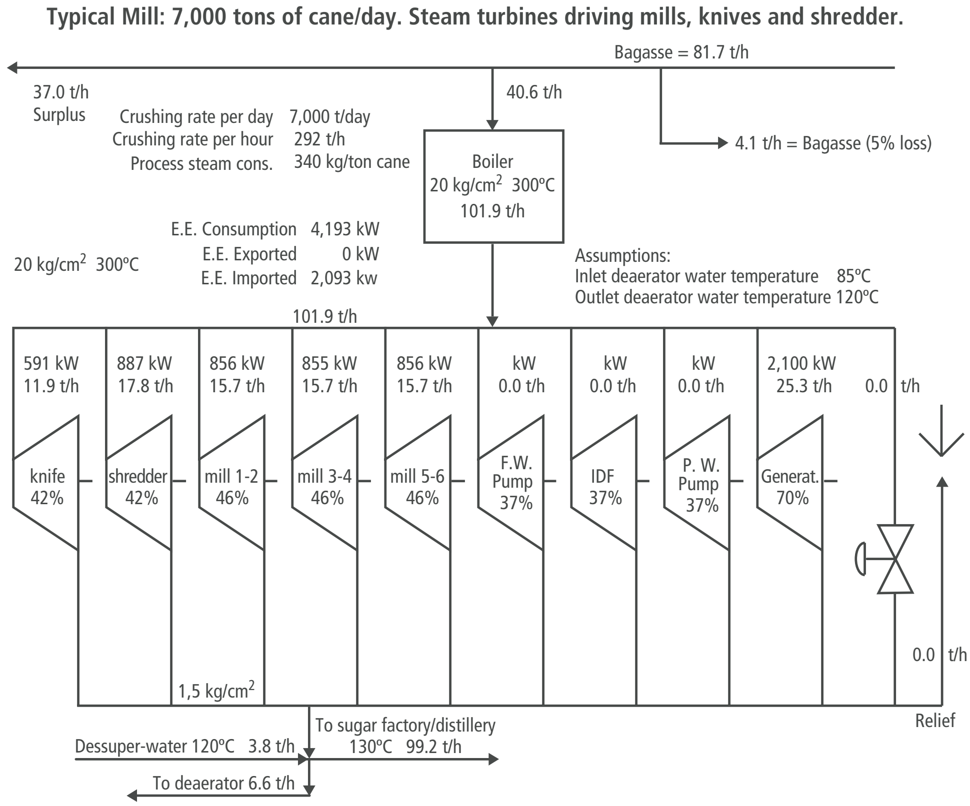
Table 65

Bagasse / trash consumption – BIG-GT stand alone plant.

Fuel		Bagasse	Trash
Moisture content	(%)	50	15
Consumption of bagasse and trash:			
BIG-GT	(t/h)	18.3	12.1
HGG	(t/h)	3.3	0
Total	(t/h)	21.6	12.1
Yearly	(t/year)	164,900	92,108

Figure 87

Heat balance – Typical mill is the bagasse supplier to stand alone BIG-GT Plant (20T340a).



- Bagasse in stack: 300 kg/m^3
- Loose dry bagasse (10% moisture content): 90 kg/m^3
- Dry bagasse (10% moisture content) and shredded trash (15% max moisture content): 90 kg/m^3(*)
- Mix condition: 46% of bagasse and 54% of trash
- Shredded trash (15% moisture content): 35 kg/m^3
- Shredded trash stack stored: 150 kg/m^3(*)

(*) to be confirmed in future tests.

Main equipment list

To obtain the main equipment costs the following manufacturers have been contacted: Codistil – Dedini (boiler, bagasse dryer), CBC (boiler), Caldema (hot gas generator), ABB (steam turbine), Albraz (bagasse/trash feed valve), Termoquip (hot gas generator), Fantecnic and Aeolus (fan).

14.11. BIG-GT plant

The TPS BIG-GT plant main equipment: dry bagasse silos, biomass gasifier, tar cracker, strainer, scrubber, heat recovery steam generator (HRSG 60 bar 500ºC), gas turbine GE LM 2500, steam turbine, steam condenser, pumps, heat exchanger and thermal deaerator (**Figure 88**).

Bagasse/trash handling, preparation and storage

The bagasse/trash handling, preparation and storage system has slat and canvas belt conveyors, discharge stage, handling machines, bagasse and trash dryer (dryer, cyclone, fan, duct and conveyors), trash bale knife and shredder, dry fuel warehouse. The system estimated cost was US$ 3,171,429.00.

Water treatment and water cooling system

Consisting of a water demineralization station for high pressure boiler, storage tank, water cooling towers for the steam turbine and scrubber condensers and pumps. This system estimated cost was US$ 488,824.00.

Electric Installation, instrumentation & control and auxiliary equipment

Consisting of electric 138 kV substation, electric power distribution system, electric motors control system, bagasse/trash handling and storage control/ instrumentation system, ash conveyor and dolomite bin. The estimated cost of this system was US$ 2,511,765.00.

Chemicals

The main products used in the BIG-GT are: dolomite, sulfuric acid, sodium hydroxide and nitrogen. The nitrogen is produced by a rented plant in the site. Other materials are fuel oil, diesel oil for tractors/trucks etc., materials for generated gas purification and effluent treatment. The main Brazilian suppliers contacted were: White Martins, Ultragaz, Petrobras Distribuidora, Brasilminas, Cal Maravilha. The overall yearly estimated cost corresponding to these products was US$ 1,001,932.00/year

Maintenance costs

The maintenance costs for the BIG-GT were estimated by TPS as US$ 1,640,000 per year. For belt conveyors it was adopted the maintenance factor of 3% of the initial capital cost per year. For the bagasse/trash handling shredder machines it was adopted the maintenance factor of 10% of the initial capital cost per year. The total annual maintenance cost was estimated as US$ 173,353.00/ year.

Labor needed

The estimated total workers for the stand alone BIG-GT plant for bagasse/baled trash handling:

- Season 42 workers
- Off season 36 workers

Electric power self consumption and net for export

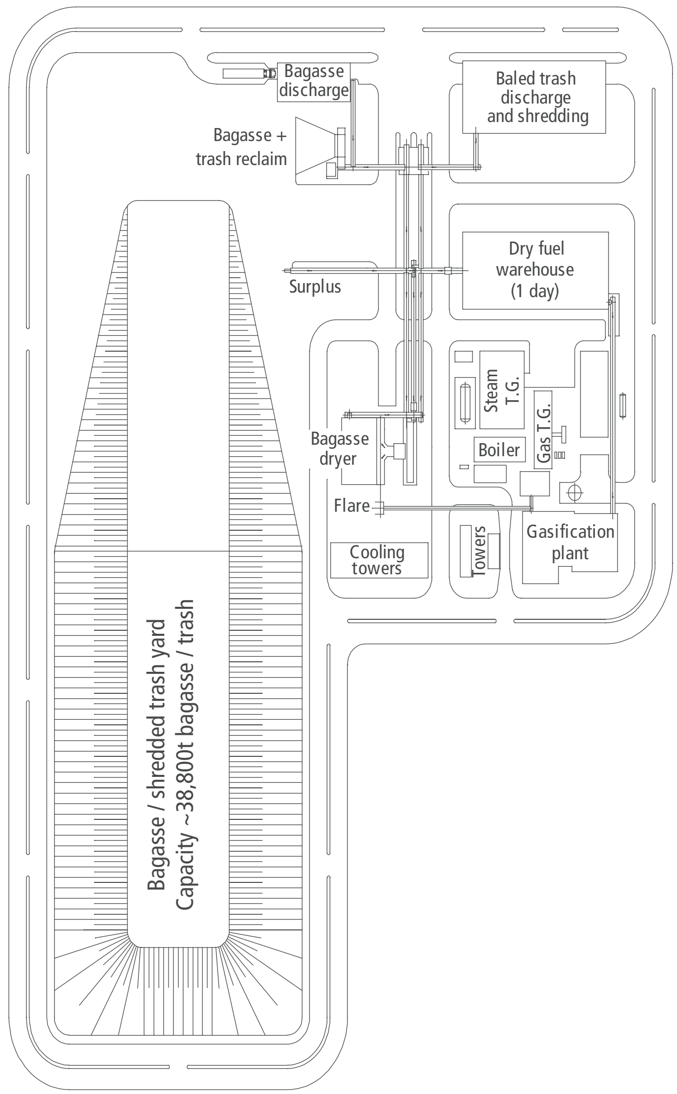
The electric power generation and consumption is summarized in **Table 66**.

14.12. Baled trash receiving system – BIG-GT mill integrated plant

14.12.1. Basic information

The typical mill feeds BIG-GT with bagasse (50% moisture) after the mill tandem. Part of this bagasse goes to a dryer system to feed the gasifier. The bagasse surplus goes to a yard where bagasse and trash are stored. The baled trash is brought to the plant only in the season. After discharged at the mill, it is shredded and sent to the BIG-GT plant. If the trash moisture content is adequate (~10%), the trash goes directly to a covered bagasse/trash warehouse, if not it goes to the dryer or to the yard. In rain time or mill maintenance

Figure 88



Layout BIG-GT stand alone plant.

Table 66

Electric power.

	Season MW	Off season MW
Operating period	4,457	3,164
Net BIG-GT electric power[(a)]	33.2	33.2
Fuel handling equipment[(b)]	2.1	1.6
Sugar mill consumption[(c)]	2.1	0
Net electric power	29.0	31.6

(a) Already considered the following electric power consumptions: compressor, generated gas cleaning system, ash discharge, condensate and feed water pumps. (total of 7,1 MW).

(b) Includes discharge, handling and preparation of bagasse and trash.

(c) Electric power to be supplied to the mill.

the fuel is reclaimed from the yard to be dried and it is sent to the covered warehouse afterwards. In off season the stored fuel is fed to the system.

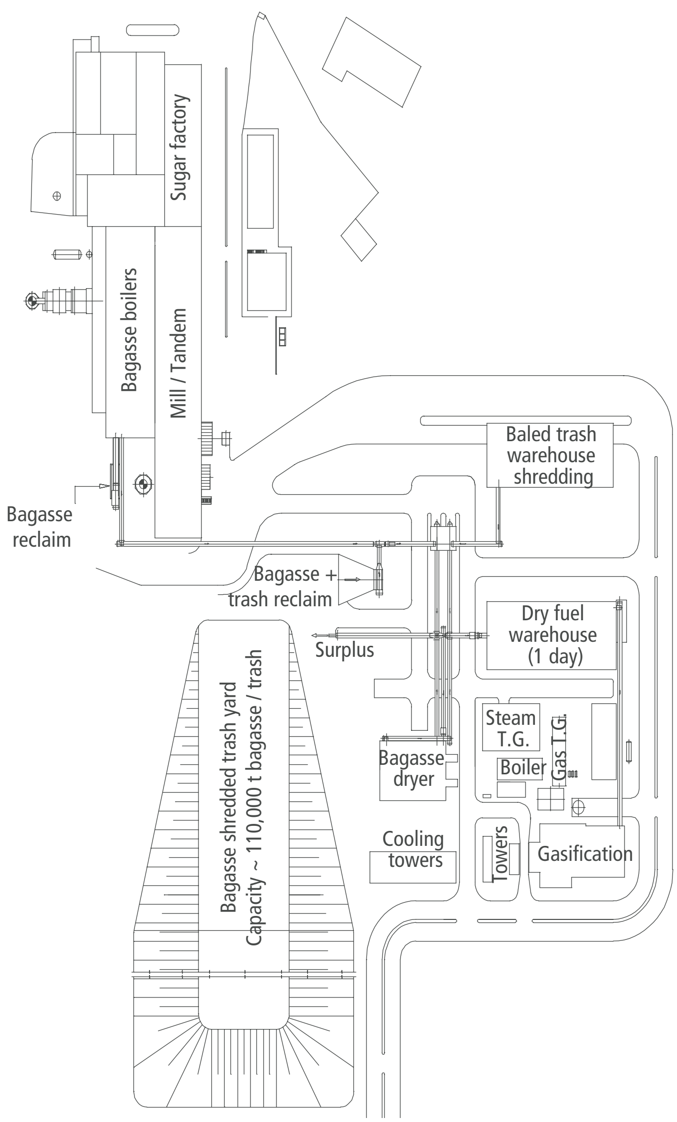
As in the case of the stand alone BIG-GT plant, the mill integrated BIG-GT plant needs also a fuel dryer and a hot gas generator.

Table 67

Bagasse and trash consumptiom - Mill integrated BIG-GT with baled trash (BIG-GT module only)

Fuel	Unity	Bagasse	Trash
Moisture content	%	50	15
Consumption of bagasse and trash			
BIG-GT	t/h	16.6	13.2
HGG	t/h	2.8	0
Total	t/h	19.4	13.2
Yearly	t/year	147,800	100,600

Figure 89



Reference layout - Baled trash alternative

14.12.2. Operating mode – Mill integrated BIG-GT with baled trash

• Bale dimensions: 1.90 x 0.80 x 0.875 m; average weight ~210 kg.
• The baled trash is shredded at the mill and could be fed to the gasifier or sent to the storage yard, depending on process conditions.
• The trash is stored shredded in an open yard.
• The mill receives all the trash during the season.
A covered area of 840 m^2 (20 x 42 m) is used to receive and to shred the bales.
• Baled trash handling: 24 h/day - 6 days/week.
• Amount of bales per trip: 72.
• N° of trips/day: 42.
• Baled trash discharged with two machines.
• The off season yard area for bagasse/trash storage: 42,000 m^2
• Covered warehouse for trash and bagasse (10% moisture) with capacity of 5,900m^3 or one day requirement for BIG-GT operation.
• On season the existing mill turbo generator set works producing 2.1MW.
• On season the existing mill 22 bar boilers work producing 113 t/h.
• The new extraction/condensing mill turbo generator set works on season and off season.

The fuel consumption (bagasse and trash) for the integrated BIG-GT plant is summarized in **Table 67**.

Main equipment list

BIG-GT

The TPS BIG-GT plant main equipment: dry bagasse silos, biomass gasifier, tar cracker, strainer, scrubber, heat recovery steam generator (HRSG, 22 bar 300°C), gas turbine GE LM-2500 (**Figure 89**). The overall cost of this set of equipment has been estimated by TPS as U$ 61,000,000.

Steam turbo generator

Nominal power: 12,600 kW

- Description

• Multi-stage condensing steam turbine, with controlled extraction:
  - Turbo set lubricating oil system
  - Control and safety systems
  - Speed governor
  - Oil tank
  - Steam line valves
• Couplings
• Gear box
• Generator 13.8 kV, 1,800 rpm, 60 Hz:

- Protection panels
- Protection cells
• Steam condenser with vacuum system and accessories
• Cooling tower
• Electro-mechanical interlock
• Building construction
• Erection
• Tests and inspections
• Cost: US$ 3,767,706.00

Bagasse/trash storage and handling

The bagasse/trash storage and handling system consists of canvas belt conveyors, feed table, handling machines, stone and metal separator, bagasse/trash drying system (dryer, cyclone, fans, duct and conveyors), baled trash knife and shredder, dry fuel warehouse. The overall estimated cost was US$ 2,862,606.00

Cooling water system

The system has the water cooling towers, for the scrubber condensers, and water pumps. The estimated cost of this system was US$ 138,824.00. The steam turbine condenser cooling water system was included in turbo set cost.

Electric and control installations and auxiliary equipment

It consists of the 138 kV substation, electric power distribution system, motors startup and control, bagasse/trash handling control, ash conveyors and dolomite bin. The overall estimated cost was US$ 2,555,882.00.

Chemicals

The main products consumed in the BIG-GT plant are: dolomite, sulfuric acid, sodium hydroxide and nitrogen. The nitrogen is produced by a rented plant in the site. Other materials are also used like fuel oil, diesel oil for tractors/trucks etc., materials for generated gas purification and effluent treatment The estimated overall consumables cost was estimated as US$ 999,530.00/year

Maintenance costs

The BIG-GT maintenance cost was estimated by TPS as US$ 1,220,000 per year. For belt conveyors it was adopted the maintenance factor of 3% and for the bagasse/trash handling/shredder machines it was adopted the maintenance factor of 10% of the initial capital cost per year, resulting in an estimated maintenance cost of US$ 185,118.00/year.

Labor needed

The estimated labor requirement for the mill integrated BIG-GT plant, for baled trash alternative, for bagasse/baled trash handling and conventional boiler operation are:

• Season 42 workers
• Off season 33 workers

To operate the BIG-GT system TPS has estimated that 18 workers are needed year round (included on those above).

Electric power self consumption and net for export

The electric power generation and consumption is summarized in **Table 68**.

Table 68

Electric power.

Information	Season MW	Off season MW
Operating period	4,457	3,164
Net BIG-GT electric power(a)(b)	32.0	27.9
Fuel handling equipment(c)	2.1	1.6
Sugar mill consumption(d)	4.2	0
Net electric power	25.7	26.3

(a) BIG-GT + Mill + Steam TG.
(b) Already considered the following electric power consumption: compressor, generated gas cleaning system, ash discharge (total of 7.6 MW).
(c) Includes discharge, handling and preparation of bagasse and trash systems.
(d) Mill power requirement.

14.13. Mill integrated BIG-GT plant – Trash received with sugar cane (partial cleaning)

14.13.1. Basic information

The typical mill provides BIG-GT with bagasse (50% moisture) that exits the mill tandem. Part of this bagasse goes to a dryer prior feeding to the gasifier. The bagasse surplus goes to the yard where bagasse and trash are stored. The mill receives the trash with sugar cane and the trash is separated from sugar cane by a sugar cane dry cleaning station. After the cleaning station the trash goes to a shredder. If the trash moisture content is adequate (~10%), the trash goes directly to the bagasse/trash warehouse; if not it goes to the dryer or to the yard storage. In rainy season or during mill maintenance the fuel is reclaimed from the yard for drying. In off season stored fuel is fed to the system.

In the same way as the stand alone BIG-GT plant, the mill integrated BIG-GT plant needs fuel drying and a hot gas generator.

14.13.2 Operation mode - Mill integrated BIG-GT with loose trash

- The trash is received at the mill with the sugar cane and it is separated by a sugar cane dry cleaning station.
- After separation, the trash is shredded and directly sent to the gasifier system.
- The trash can either be fed to the gasifier or be directed to the storage yard, depending on moisture content and process conditions.
- The plant receives all the trash during the season.
- Open yard area for bagasse/trash storage: 42,000 m^2.
- Covered warehouse for trash and bagasse (10% moisture) capacity is 5,900 m^3 or one day BIG-GT operation.
- On season the existing mill turbo generator set works producing 2.6 MW.
- On season the existing mill 22 bar boilers works producing 113 t/h.
- The new extraction/condensing mill turbo generator set works on season and off season.
- Sugar cane dry cleaning station electric power consumption: 0.7 MW.

The fuel consumption (bagasse and trash) for the integrated BIG-GT plant is summarized in **Table 69**.

Table 69

Bagasse and trash consumption - Mill integrated BIG-GT with loose trash (BIG-GT module only).

Fuel	Unity	Bagasse	Trash
Moisture content	%	50	15
Consumption of bagasse and trash			
BIG-GT	t/h	16.6	13.2
HGG	t/h	2.8	0
Total	t/h	19.4	13.2
Yearly	t/year	147,800	100,800

Main equipment list

Steam turbo generator

Capacity, auxiliary equipment and main features are the same as in the baled trash alternative.

Cost: US$ 3,764,706.00

Bagasse/trash storage and handling

The bagasse/trash storage and handling system consists of belt conveyors, feed table, handling machines, stone separator and electromagnet, bagasse/trash drying system (dryer, cyclone, fans, ducts and conveyors), trash knife and shredder, dry fuel warehouse. The overall cost was estimated as US$ 2,738,488.00.

Cooling water system

The system has the water cooling towers, for the scrubber condensers and water pumps. The cost of this system was estimated as US$ 132,941.00. The steam turbine condenser cooling water system was included in turbo set cost.

Electric and control installations and auxiliary equipment

It consists of the 138 kV substation, electric power distribution system, motors startup and control, bagasse/trash handling control, ash conveyors and dolomite bin. The estimated overall cost was US$ 2,555,882.00.

Chemicals

The main products consumed in the BIG-GT plant are: dolomite, sulfuric acid, sodium hydroxide and nitrogen. The nitrogen is produced by a rented plant in the site. Other materials are also used like fuel oil, diesel oil for tractors/trucks etc., materials for generated gas purification and effluent treatment. The overall consumables cost was estimated as US$ 986,589.00/year.

Maintenance costs

The BIG-GT maintenance costs were estimated by TPS as US$ 1,220,000 per year. For belt conveyors it was adopted the maintenance factor of 3% of the initial capital cost per year. For the bagasse/trash handling/shredder machines it was adopted the maintenance factor of 10% of the initial capital cost per year. The total annual maintenance cost was estimated as US$ 181,588.00/ year.

Labor needed

The estimated labor requirements for the mill integrated BIG-GT plant with sugar cane dry cleaning station alternative trash, for bagasse/baled trash handling and conventional boiler operation are:

- Season 36 workers
- Off season 33 workers

To operate the BIG-GT system TPS has estimated 18 workers are needed year round (included on those above).

Table 70

Electric power.

Information	Unity	Season	Off season
Operating period	h	4,457	3,164
Net BIG-GT electric power(a)	MW	32.0	27.9
Fuel handling equipment(b)	MW	2.8	1.6
Sugar mill consumption(c)	MW	4.2	0
Net electric power	MW	25.0	26.3

(a) Already considered the following electric power consumption: compressor, generated gas cleaning system, ash discharge, total of 7,6 MW + Mill + Steam TG.
(b) Includes discharge, handling and preparation of bagasse/trash and sugar cane dry cleaning systems.
(c) Mill power requirement.

BIG-GT

The TPS BIG-GT plant main equipment are: dry bagasse silos, biomass gasifier, tar cracker, strainer, scrubber, heat recovery steam generator (HRSG, 22 bar 300ºC), gas turbine GE LM-2500. The overall cost of this equipment set was estimated by TPS as US$ 61,000,000.

Electric power self consumption and net for export

The electric power generation and consumption is summarized in **Table 70**.

14.14. Bagasse dryer

14.14.1. Introduction

About 20 years ago, Copersucar Technology Center (CTC) has developed a bagasse dryer of the "flash-dryer" type. The equipment has been changed since its first prototype until the present model. Among others, the most important change was the internal operating pressure, that in the beginning was negative and now it is positive. With this change the explosion risk due to auto-ignition is almost eliminated. The equipment in the present concept was installed in some mills (**Figure 90**) and has shown good performance.

Figure 90

Usina São Martinho, Bagasse dryer and cyclone.

Purpose

The TPS bagasse/trash gasification simulations have shown that the bagasse/trash moisture content must be about 10% to produce gas with heat value adequate for the operation stability of the modified GE LM 2500 gas turbine.

To get this moisture content the BIG-GT system needs a bagasse/trash dryer. Based on CTC know-how, the dryer selected to the BIG-GT module in study is a Copersucar model, sized to be operated receiving HRSG flue gas.

14.14.2. Process

Stand alone BIG-GT

The bagasse is received from the mill in the same condition as it left the mill tandem, with moisture content around 50%. The bagasse/trash handling, preparation and storage system has belt conveyors, discharge station, handling machines, bagasse and trash dryer system (dryer, cyclone, fan, duct and conveyors). Transportation between the mill and BIG-GT plant is done by trucks with special containers with capacity of 90 m^3, about 22 t of bagasse by trip. This system was operating in some mills, with good performance and low operating/maintenance costs.

The trash is received in bales with 1.9 m x 0.8 m x 0.875 m, and weigh around 210 kg. The handling is in a covered place containing discharge and feed table, belt conveyor and a set of knifes (COP-8) and a shredder (COP-5). In this plant the truck discharge is made by a sugar cane loading machine.

All baled trash is received on season and stored to be used all year. The shredded trash is stored together with the bagasse in an open yard. The baled trash has moisture content ~10%, part of it could be directed to the dry fuel warehouse.

During season the dryer is used mostly for drying the bagasse only, in small quantities (20 t/h with 50% moisture). The trash flow, to the dry fuel warehouse is controlled by a moisture sensor assembled in the belt conveyor according to its moisture content. The capacity (5,900 m^3) of the dry fuel warehouse is enough for 24 operating hours.

Mill Integrated BIG-GT plant

After leaving the mill tandem the bagasse goes to the boilers and to the dryer. The bagasse surplus goes to a storage yard.

The trash flow has two alternatives:

a) Baled trash

The baled trash is discharged in the covered warehouse, in the same way as in stand alone plant. Part of shredded trash goes to the dry fuel warehouse and the other part goes with bagasse to the yard.

b) Sugar cane dry cleaning station trash

The trash is shredded near the dry cleaning station and part of shredded trash goes to dry fuel warehouse, if the moisture content is about 10%. If the moisture content is higher, the trash goes together with the bagasse to the storage yard.

14.14.3. Heat balance

The HRSG flue gas does not have enough energy to dry the bagasse/trash in stand alone plant nor in the mill integrated plant.

• Wet bagasse	36.8 t/h
• Initial moisture content	50%
• Final moisture content	10%
• Outlet HRSG gas flow	71.0 kg/s
• HRSG outlet gas temperature	136°C (stand alone plant)
• HRSG outlet gas temperature	144°C (mill integrated plant)
• Dryer outlet gas temperature	100°C

Thus a hot gas generator (HGG) was installed between the HRSG and the dryer to produce supplementary thermal energy for drying the fuel.

The data considered derived from TPS information. It is possible to get enough drying energy HRSG flue gas but in this case the HRSG, steam production will drop; but in this work a hot gas generator was added to avoid changes in the BIG-GT module.

14.14.4. Hot gas generator (HGG) design

The HGG was designed to burn wet bagasse (50% moisture) and its capacity is enough to attend the system even in the worst operating condition, such as feeding the dryer with the HRSG flue gas of stand alone plant (136ºC) for drying 40 t/h of wet bagasse (50% moisture).

Design parameters

• Fuel	bagasse (50% moisture)
• Low Heating Value (LHV)	1,792 kcal/kg
• Heat release rate	1,800,000 kcal/h m^2 (max)

Calculations results

- Bagasse flow (50% moisture) 5.7 t/h
- Furnace volume 23 m^3
- Heat release rate 1,135,000 kcal/h m^2

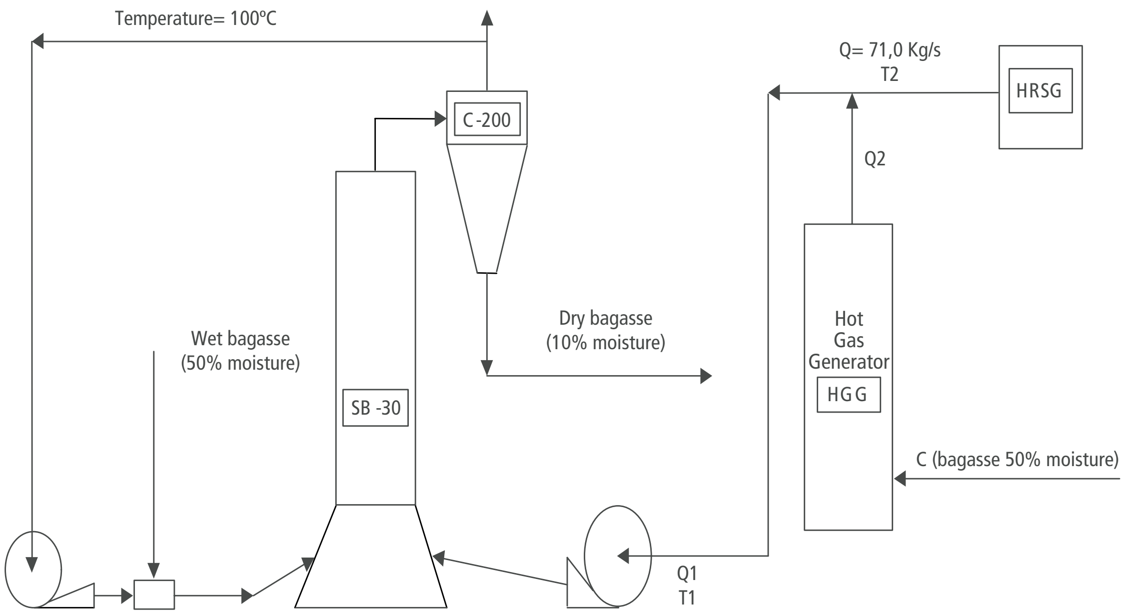
Heat balance and dryer installation flow diagram

BIG-GT basic parameters for the 20T340 option:

- Total bagasse 18.36 t/h (dry basis)
- Required bagasse (10% moisture) 20.4 t/h (wet basis)
- Initial moisture content 50%
- Final moisture content 10%
- HRSG outlet gas flow 255,600 kg/h
- HRSG outlet gas temperature:
  - Stand alone plant 136ºC

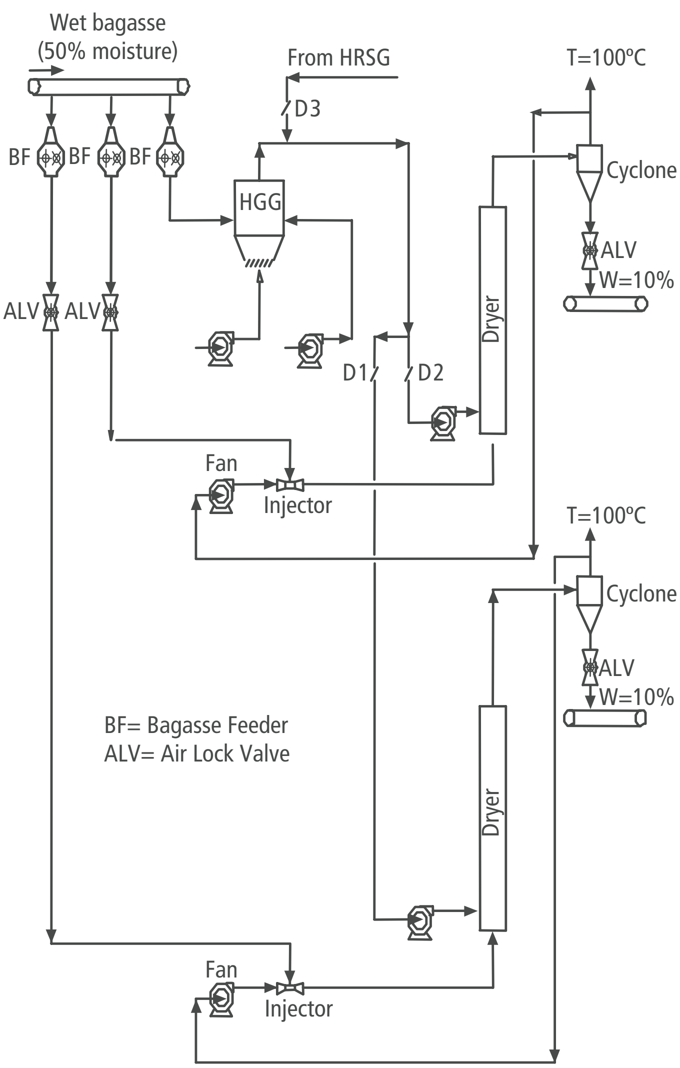
Figure 91

Heat balance



	Wet bagasse t/h	Dry bagasse t/h	C t/h	T1 °C	Q1 Nm³/h	T2 ºC	Q2 Nm³/h
Stand alone plant							
– Season	19.5	10.8	2.1	186	205,053	136	7,679
– Off season	36.8	20.4	5.1	253	216,297	136	18,922
– Design	40.0	22.2	5.7	264	218,396	136	21,022
Mill integrated plant							
– Season	16.6	9.2	1.3	175	202,123	144	4,748
– Off season	36.8	20.4	4.8	254	215,230	144	17,850
– Design	40.0	22.2	5.4	266	217,332	144	19,958

Figure 92



Drying system.

Table 71

Operating data - BIG-GT stand alone and bagasse drying system.

Mill bagasse surplus(a)	t/h	37.0
Harvesting period	h	4,457
Total surplus bagasse(a)	t/year	164,900
BIG total bagasse consumption(a) (c)	t/ year	279,850
BIG consumption(a)	t/h	36.8
Available bagasse for the BIG(a)	t/h	21.6
HGG season consumption(a)	t/h	2.1
HGG off season consumption(a)	t/h	5.1
HGG total consumption(a)	t/year	25,150
Total available bagasse for the BIG(a)	t/year	139,750
Total trash needed(b)	t/year	92,100

(a) 50% moisture content
(b) 15% moisture content
(c) If only bagasse is used

- Mill integrated plant - 22 bar 144°C
- Dryer outlet gas temperature 100°C

Bagasse dryer design parameters

- Wet bagasse 40.0 t/h
- Initial moisture content 50%
- Final moisture content 10%

Based on these parameters two SB-30 Copersucar bagasse dryers were selected, with a drying tower diameter of 2,200 mm.

Figure 91 shows the simplified diagram of the bagasse dryer installation using HRSG flue gas, season and off season operation.

14.14.5. P & I diagram

The P&I diagram shows the main equipment, fuel flow and utilities consumption, for different plants. The **Figure 92** shows the drying system.

14.14.6. Bagasse dryer and HGG operating conditions

Stand alone BIG-GT

The typical mill factory process will be modified to increase bagasse surplus; the main changes are basically:

- Steam process consumption reduction to 340 kg/ton of cane;
- Auxiliary steam turbine drives (pumps, fans, etc.) must be replaced by electric motors drives;
- Make improvements in the conventional 22 bar boilers to reach 85% efficiency.

Under these conditions the typical mill bagasse surplus will be 37 t/h net (5% loss already included). **Table 71** presents the main data on bagasse and trash availability and consumption.

Mill integrated BIG-GT plant (**Table 72**)

14.14.7. Auxiliary equipment specifications

After selecting the dryer and HGG size/quantity, the auxiliary equipment technical specifications were prepared (IDF, bagasse injection fan, bagasse feed valve, injector "T", HGG primary and secondary fans).

Ductwork design

To simplify ductwork design and cost assessment, the duct design was standardized considering an average of the three operating modes, changing only parts between the HRSG/HGG and HGG/gas induced draft fan.

Site and gas data

- Altitude 550 m above sea level
- Atmospheric pressure 712 mm Hg
- Flue gas specific weight 1.295 kg/Nm^3 (HRSG outlet)

14.14.8. Drying system cost

The estimated drying system installation cost was US$ 599,959.00 including two bagasse dryers and cyclones, bagasse feed valves, steel structure, induced draft fans, HGG, fans and ducts. This value had already been included in the total values listed in item: Bagasse/trash storage and handling.

Operating labor

To operate the dryer, HGG and its conveyors one worker/shift is enough. The construction of an operating room with all controls and monitoring equipment is recommended.

Maintenance cost

The maintenance cost was estimated for each drying system equipment varying between 3% and 15% per year. The estimated total annual cost was US$ 40,412.00. This value has already been included in item: Maintenance costs.

Table 72

Operating data – Drying system – Mill integrated BIG-GT plant.

BIG total bagasse consumption[(a) (c)]	t/ year	279,850
BIG consumption[(a)]	t/h	16.6
HGG season consumption[(a)]	t/h	1.3
HGG off season consumption[(a)]	t/h	4.8
HGG total consumption[(a)]	t/ year	21,340
Total available bagasse for the BIG[(a)]	t/ year	126,508
Total trash needed[(b)]	t/ year	100,590

(a) 50% moisture content
(b) 15% moisture content
(c) If only bagasse is used

14.14.9. Instrumentation & control

The I&C estimated cost was based on baled trash alternative, and it is almost the same (only with small changes) for the others alternatives.

Control system

The bagasse/trash drying and handling system automation main purpose is safety and standard, operation ensuring fuel quality.

All used instrumentation is based on digital technology.

Closed TV circuit monitoring

The bagasse/trash drying and handling system strategic points like discharge section, yard, warehouse, fuel reclaiming, fuel feeders, etc. will be monitored by a closed circuit TV.

Cost assessment

The estimated total cost of this monitoring and control system was US$ 305,588.00 including: field and auxiliary instrumentation, control and supervision system hardware and software, design, installation and tests. This value has already been included in item: Electric and control installations and auxiliary equipment.

14.14.10. Electric diagrams

The electric safety system philosophy considered electric energy sources ground system (generators, transformers of public grid), reactive and active electric energy flow controls according to electric utilities rules.

Electric power generation

The net exported power for each alternative is:

- Stand alone BIG-GT plant — 29.0 MW season and 31.6 MW off season
- Mill integrated BIG-GT (baled trash) — 25.7 MW season and 26.3 MW off season
- Mill integrated BIG-GT (loose trash) — 25.0 MW season and 26.3 MW off season

Electric substation

The utility grid connection will be made by a substation with two 20 MVA transformers (138 KV/13.8 KV).

Electric power distribution

The electric power distribution system consists of a substation/transformer with the following capacities: 1 MVA for gasifier section; 1.5 MVA for BIG-GT section; 225 KVA for auxiliary equipment section; and 1.5 MVA for fuel handling and drying sections.

Table 73

Summary

Information		Stand alone	Mill integrated baled trash	Mill integrated loose trash
BIG-GT system BIG-GT	US$	82,000,000	61,000,000	61,000,000
Other capital costs	US$	6,172,018	9,322,018[a]	9,192,018[a]
Maintenance cost	US$/year	173,353	185,118	181,588
Consumables cost	US$/year	1,001,932	999,530	987,000
Labor force (season/off season)		26/23	24/21	22/21
Bagasse consumption, 50% moisture	t/year	164,900	147,500	147,500
Trash consumption, 15% moisture	t/year	92,108	100,600	100,600
Electric power exported	GWh/year	229.2	197.7	194.6

(a) 12.6 MW steam turbo generator included

Ground system

The ground system selected for all electric sources was neutral ground with low impedance resistor, to reduce the fault ground current and at the same time activating the protection relays.

Cost assessment

The total cost of the electric power system and its control and protection was estimated as US$ 2,058,824. This value had already been included in item: Electric and control installations and auxiliary equipment.

14.14.11. Summary

An integrated work between CTC and TPS was done to define basic parameters to design two operating modes of BIG-GT in sugar industry.

The first alternative was named stand alone plant, and in this case the BIG-GT operates independent from the mill, receiving bagasse and trash from the mill, and producing electric power. The BIG-GT does not supply steam to the mill process. The HRSG generated steam drives a condensing steam turbo generator in a conventional combined cycle (BIG-CC).

The second alternative was named "mill integrated BIG-GT plant". The BIG-GT is installed in the sugar mill area, receiving fuel (bagasse/trash) and condensed steam, supplying steam and electric power to the mill. Two trash recovery alternatives have been studied. In the first alternative the trash is baled in the field and transported to the mill where it is shredded to be used as fuel. In the second alternative the trash is transported with sugar cane to the mill where it is separated in a sugar cane dry cleaning station. After separation, the trash is shredded to be used as fuel (**Table 73**).

The "other capital cost" does not include sugar cane dry cleaning system, process equipment improvement, field to mill transportation and related labor expenses, maintenance, etc. These values will be considered in the feasibility studies.

15. Steam economy in the sugar mills

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15.1. Introduction

Brazilian Sugar Mills, similar to mills throughout the world, have process steam consumption in the neighborhood of 500 kg of steam per metric ton of cane processed. In this condition, nearly all bagasse produced is consumed, generating steam at 22 bar/300ºC. This steam amount is sufficient to produce all the electric and mechanical power, with back pressure turbines, required to run the plant. So, fuel availability, power and thermal energy requirement will be balanced.

Beet sugar factories and corn ethanol distilleries are much more efficient in energy use than sugar cane mills because they use fossil fuel that has to be purchased. It is known that the present steam consumption of the average sugar cane mill can be considerably reduced just by using the technology available in beet sugar factories and corn ethanol distilleries.

To be able to integrate the typical sugar/ethanol plant to a BIG-GT system it is mandatory to reduce the process steam consumption to levels compatible to gas turbine/waste heat boiler technology.

In this project, process steam reduction to levels around 340 and 280 kg/ton of cane has been evaluated and the required investment has been estimated, using the project "Typical Mill" as a reference.

15.2. Operating conditions

This typical mill has the following operating conditions:

• Daily milling	7,000 t
• Milling rate	292 t/h
• Pol % cane	14.1%
• Fiber % cane	13.8%
• Sugar production	400 t/day
• Alcohol production	353,000 L/day
• Process steam conditions	2.5 bar saturated
• Steam consumption	500 kg steam/t cane

15.3 Steam utilization

Steam is used ("Typical mill") as follows:

• Evaporation	Five effects with extraction
• Juice heating	Vapor from 1st effect
• Vacuum pan	Vapor from 1st effect
• Distillery	Process steam
• Sugar centrifuges	Steam 6.0 bar
• Syrup concentration	55 – 60ºBrix
• Process steam losses	10 kg/t cane

For the first step of steam economy (340 kg steam/t cane) the following basic modifications have been established:

- Vapor bleeding from 1st, 2nd and 3rd effects for juice heating;
- Regenerative heat exchangers for juice x vinasse, juice x juice and juice x condensate;
- Mechanical stirrers for vacuum pans;
- 2nd stage vapor bleeding for vacuum pans;
- Use of Flegstil technology and molecular sieves in the alcohol distillery;
- Syrup concentration: 70ºBrix.

The total investment has been estimated to be US$ 3.4 million and the process steam consumption for an ethanol production of 50% hydrated and 50% anhydrous ethanol is 341 kg steam/t cane.

In the second step of steam economy (280 kg steam/t cane) the additional following modifications are required:

Vapor bleeding from the 1st to the 4th effect for juice heating;
Add one more set of juice heaters;
Vapor bleeding from the 5th effect for the vacuum pans.
The total investment in this case has been estimated to be US$ 5.0 million and the process steam consumption for an ethanol production of 50% hydrated and 50% anhydrous ethanol is 287 kg steam/t cane.

The total investment corresponds to the addition of the following equipment, and to the needed fittings, piping, etc.

Step 1 (340 kg steam/t cane)

- Heat exchangers:
  - 5 shell and tube, 1 plate
  - 1 x 1200 m^2 evaporator
- Set of 4 way valves for evaporators
- Condensate flash recovery system
- 6 x mechanical stirrers for vacuum pans
- Conversion of distillation columns to a more efficient Dedini's distillation process called Flegstil
- Molecular sieves
- Instrumentation and controls

Step 2 (280 kg steam/t cane)

- Heat exchangers:
  - 4 shell and tube, 2 plate
  - 2 x 3000 m^2 evaporator
  - 2 x 2700 m^2 evaporator falling film type
- Condensate flash recovery system
- 6 x mechanical stirrers for vacuum pans
- Conversion of distillation columns to a more efficient Dedini's distillation process called Flegstil
- Molecular sieves
- Instrumentation and controls

16. Process and preliminary basic engineering, integrating gasifier/gas cleaning with gas turbine, fuel pre-treatment and feed system testing

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16.1. Introduction

As part of the Global Environment Facility (GEF) Bagasse Project, the integration of the BIG-GT plant with the sugar mill has been studied. The objective of the process integration study was to give to Copersucar Technology Center (CTC) data for the gasification plant for use in their sugar mill energy balance studies, and to have a coordinated optimization effort. The initial work was done in 1998 and after evaluation by CTC, new model calculations were evaluated in 1999.

The BIG-GT process design has been made on the basis of available data on the bagasse and cane trash fuels, and the results of the pilot plant tests carried out on bagasse and trash. The capacity of the unit was from the start of the project defined to generate sufficient gas to fire a GE LM 2500 PH gas turbine. This choice was made already in the contract negotiation phase. The reason for this selection was that to allow this Bagasse Gasification Project, an extension of the WB/GEF project, having a limited budget, to utilize data generated within the eucalyptus project as far as was possible. For this project, GE had developed the gas turbine for firing low heating value fuel gas from a wood fuelled gasification plant.

The gasification system is based on an airblown CFB (circulating fluidized bed), followed by dolomite catalytic tar cracking prior to gas cooling, filtering and scrubbing. The gas prepared and cleaned in this way is then compressed and fired in a GE LM 2500 PH gas turbine. The gas turbine exhaust gas is cooled in an HRSG with a small amount of supplementary firing, in which steam is generated, and, together with steam from the gas cooling section, superheated before use in the mill or steam turbine.

The choice of the LM 2500 gas turbine does not imply that it is the only gas turbine available for firing LHV (low heating value) gas as there are other machines available for both smaller and larger capacities, nor that this capacity level is suitable for sugar mills in general, as there is a variation of sugar milling capacity, fuel availability, level of integration wanted, etc. in sugar mills. It should rather be seen as an example, based on good information, of the potential of BIG-GT.

16.2. Process integration

16.2.1 Drying of the fuel

The need for fuel drying was evaluated in 1998. The moisture content of the fuel entering the gasifier strongly affects the heating value of the produced gas, as energy is required for the vaporization of the moisture. On cooling the gas, by the condensation that takes place in the scrubber, the moisture content of the fuel gas is decreased, which increases the heating value of the gas. The moisture content of the gas leaving the scrubber is set by the exit temperature of the gas, which has been assumed to be 35°C in the case of a plant in Brazil using an open cooling circuit.

General Electric has performed tests with the LM 2500 gas turbine and found that stable combustion could be maintained with a fuel gas with a heating value as low as 3.9 MJ/Nm^3, in particular if the fuel contains a few % of hydrogen. A higher heating value; 5.9 MJ/Nm^3 is considered to be without limitations, even if hydrogen is not present.

In the case of bagasse the upper level, 5.9 MJ/Nm^3, is reached at moisture content of 13% while 3.9 MJ/Nm^3 is reached at fuel moisture content of 40%.

From the analysis made on the baled sugar cane trash in 1998, at 10% ash content and assuming 10% moisture, it can be stated that the gas generated has a lower heating value than gas generated from bagasse, approximately 5 MJ/Nm^3 compared to 6 MJ/Nm^3 in the case of bagasse. As a result, only limited amounts of sugar cane trash could be mixed with the bagasse, if the fuel has high ash content or other characteristic (apart from moisture content which can be controlled) that result in a low heating value of the gas.

Drying is necessary if we assume that the moisture content of the fuel used is above 20%, as received. Drying to 10% is recommended, this gives a reasonably good heating value for the bagasse fuel and allows for some margin for uncertainties and variations in the bagasse fuel as well as for changes caused by results from e.g. pilot plant tests and also for some mixing of cane trash. Thus, in the work reported below on the initial estimates for the process integration made in 1998, it was assumed that bagasse fed to the gasifier had been dried to 10%.

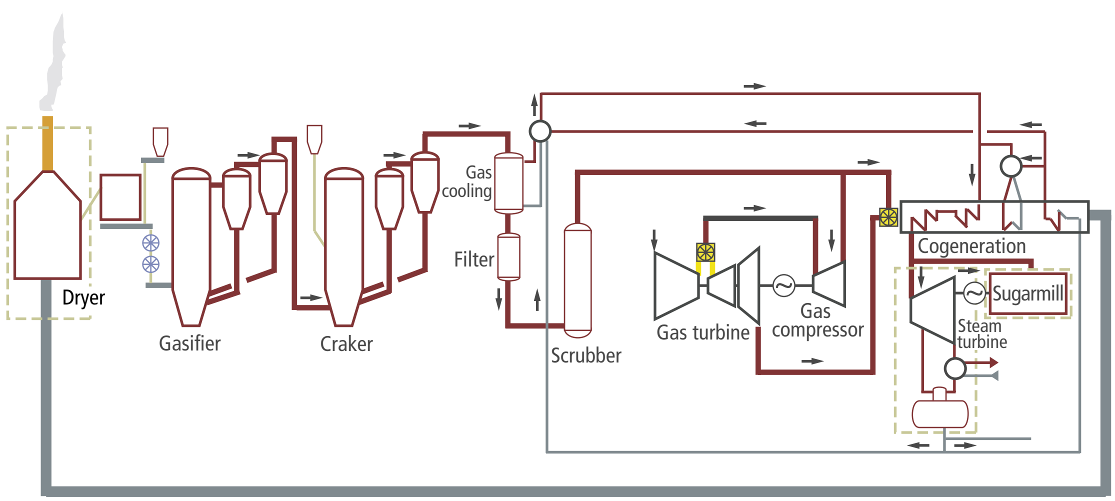
The review made in 1999 indicated that for bagasse, the moisture content during the season and also offseason was consistently 50%. For the trash, it was however concluded that the moisture content during the harvest season was 15%, whilst by rewatering it was increased to about 50% during the offseason. The impact of this will be further discussed in a later section as this means that during the season operation on trash without drying is feasible. The ash content in the trash expected after the review, 6%, however gives a higher heating value in the gas approaching that of bagasse, and hence does not from this aspect, give limitations in the fraction of trash used. In these calculations trash can be used up to 100% of the fuel entering the gasifier. The impact of the revision of the input data to the model that was done on the basis of pilot plant data was insignificant.

16.3 Gasification process description

Figure 93 shows the BIG-GT system with the process options used in the different cases studied in this initial process integration assessment. In the independent operation case, TPS produced preliminary mass and energy balance data for the whole process shown, with and without, the flue gas fuel dryer integrated. In the cogeneration mode, TPS produced preliminary mass and energy balance data for the gasification process including the fuel gas cleaning, fuel gas cooling, fuel gas compression, gas turbine and flue gas cooling for steam generation, with and without the flue gas fuel dryer being integrated. The fuel dryer system can therefore either be a flue gas dryer as shown in Figure 93 or independent operation not integrated with the BIG-GT plant. The latter case was studied by CTC. The steam produced can either be fed to a steam turbine system with condensate and feedwater equipment integrated in the BIG-GT process, which is the case in the independent operation case, or it can be sent to the sugar mill, which is the case in the cogeneration mode. The parts in Figure 93 that are not part of the dryer box or the steam system box is referred to as the BIG-GT system which is described in short in the next section.

Figure 93

BIG-GT System with process options.



The dried fuel is fed to the atmospheric CFB gasifier by a feeding system specially designed to handle lowbulk density fuels, such as bagasse, cane trash and other agrofuels. The fuel is gasified in an airblown CFB gasifier at slightly above atmospheric pressure and about 850°C. Bottom ash is continuously withdrawn from the gasifier. The raw low heating value fuel gas generated is catalytically cleaned from tar by hot gas cleaning in a second CFB unit, the tar cracker, wherein the catalytic influence of the bed material effectively breaks down the tar to light hydrocarbons. Dolomite is used as catalyst bed material in the tar cracker, which is operated at slightly higher temperature than the gasifier. Thus, it is possible to cool down the fuel gas without suffering problems with tar condensation. The hot fuel gas is cooled stepwise to lower temperature to enable removal of dust, nitrogen containing compounds, chlorides, alkalis, etc. in the second-stage gas cleaning. The energy recovered by the gas cooling preheats BFW and generates saturated steam. A baghouse filter working at about 180°C efficiently removes the flyash dust, where also the chloride in the gas is absorbed on the dolomite. A wet scrubber in which a solution of ammonium bicarbonate circulates cools the gas and causes most of the water vapor to condense. At the same time it absorbs remaining contaminants from the gas, primarily ammonia.

The condensate is cleaned from ammonia by a desorption-absorption process, whereby an ammonium bisulphate solution is produced. The remaining condensate is cleaned by a biological treatment integrated with the sugar mill. The cleaned fuel gas is pressurized in a gas compressor prior to entering the gas turbine combustion chamber. Heat to the steam system is provided both by the flue gas from the gas turbine in the HRSG (heat recovery steam generator) and by the cooling of the fuel gas. Some of the fuel gas is used for supplementary firing in the HRSG. A small amount of the fuel gas is fired in the HRSG as supplementary firing. The HRSG preheats BFW (boiler feed water) and produces superheated steam. In the cogeneration option, this steam is delivered to the sugar mill steam system, which returns BFW to the BIG-GT unit.

In the standalone option, steam turbine, condenser and BFW system are included in the BIG-GT plant; the fuel gas is also used in an integrated fuel dryer.

Within the TPS battery limit are the following process units: fuel and bed material feeding, gasification and tar cracking, gas cooling, gas filtering, gas scrubbing, gas compression, gas turbine, HRSG and process air compression. Outside the TPS battery limit are fuel reception, treatment and drying, steam turbine, etc.

Not shown in **Figure 93** are the utilities needed. Inert gas supply and flare are within the TPS battery limit. The remaining utilities include cooling water, BFW system, effluent water treatment and instrument air supply. The process and utility units that are outside the TPS battery limit are part of the sugar mill plant.

16.4. Process integration, Input data and assumptions

The initial BIG-GT plant mass and energy balances are presented for a GE LM 2500 gas turbine using both bagasse and trash. A minimum capacity of a bagasse fuelled BIG-GT plant is approximately 10 kg/s of bagasse fuel with 50% moisture, using a LM 2500 gas turbine. At this point the gas turbine is fully loaded, and more fuel will be used to generate gas for supplementary firing of the HRSG.

The LM 2500 gas turbine is estimated using the simulation model developed by TPS in the eucalyptus project. According to this model there is a need for an air bleed from the gas turbine when operating on bagasse. This air bleed is used for process air in combination with the air from the process air compressor (needed for start-up and balance of air during normal operation).

In independent operation a steam condition of 60 bar/500°C was chosen. When a dryer is integrated, a steam driven regenerative feed water heater is needed.

In the cogeneration cases, the feedwater was assumed to be 120°C on entering the BIG-GT system. Three cases of steam conditions were specified prior to the start of the work; high pressure: 80 bar/480°C, medium pressure: 22 bar/300 °C and low-pressure: steam 2.5 bar/saturated, respectively. In the low pressure steam case no feedwater preheating and no steam superheating is included. In the medium pressure case with integrated dryer, feedwater preheating is only performed in the fuel gas cooling, since the heat remaining in the flue gas after the HRSG boiler is needed for fuel drying.

The model fuel used in all cases in this first activity of the project, made in 1998, was 100% bagasse, dried to 10% moisture. An example of a case using 100% cane trash, having high ash content, was also calculated.

16.5. Plant capacity and sizing

Table 74 summarizes the results for all cases under consideration in the initial integration study in 1998. In the cases with an integrated dryer the fuel has 50% moisture on entering the plant and is dried to 10% moisture. In the cases without an integrated dryer the fuel is assumed to be dried outside the plant as a separate operation

Table 74

Results for independent and cogeneration operation.

Operation	Fuel	Fuel gas dryer	Steam pressure bar	Steam temp. °C	Fuel flow kg/s dry	Fuel energy MW	Net elect output(a) MW
Independent operation	Bagasse	X	60	500	5.1	76.5	30,8
Independent operation	Bagasse		60	500	5.1	87,6	33.2
Independent operation	Cane trash	X	60	500	5.7	77.8	29.1
Cogeneration high pressure steam	Bagasse	X	82	480	5.1	76.5	16.1
Cogeneration high pressure steam	Bagasse		82	480	5.1	87.6	16.8
Medium pressure steam	Bagasse	X	22	300	5.1	76.5	16.2
Medium pressure steam	Bagasse		22	300	5.1	87.6	16.8
Cogeneration low pressure steam	Bagasse	X	2.5	Sat.	5.1	76.5	16.2
Cogeneration low pressure steam	Bagasse		2.5	Sat.	5.1	87.6	16.8

Operation	Net elect. efficiency %	Steam produced kg/s	Steam production efficiency(b) %	Total efficiency (c) %	Power to heat ratio	Flue gas flow kg/s	Flue gas temp. °C
Independent operation	40.2					75.6	70
Independent operation	37.9					71.0	136
Independent operation	37.4					76.3	72
Cogeneration high pressure steam	21.0	15.5	57.3	78.3	0.37	75.6	71
Cogeneration high pressure steam	19.2	15.7	50.8	70.0	0.38	71.0	221
Medium pressure steam	21.2	17.4	57.1	78.3	0.37	75.5	70
Medium pressure steam	19.2	20.1	57.5	76.7	0.33	71.0	144
Cogeneration low pressure steam	21.2	19.6	58.3	77.5	0.38	75.5	71
Cogeneration low pressure steam	19.2	23.1	57.9	77.1	0.33	71.0	132

(a) The net electric output includes the internal electric consumption for gas compressor, flue gas dryer, fuel, mineral and ash feeding, baghouse filters, scrubber system, gas turbine, steam turbine, process air compressor, bfw and condensate pumps and effluent water treatment. In the cogeneration cases only the gas turbine electric output is counted, not possible electric generation in steam turbines in the sugar mill. The steam turbine and condensate pumps are not included in the internal consumption in the cogeneration cases.

(b) Steam production efficiency = energy input to the steam/fuel energy

(c) Total efficiency = net el. Efficiency + steam production efficiency

and enters the plant with 10% moisture. The first three cases are for independent operation; bagasse with and without integrated dryer and sugar cane trash with integrated dryer. Net electric output and net electric efficiency is given as well as the flowrate of flue gas and its temperature to the stack.

In independent operation, for one BIG-GT module, a net electric output of more than 30 MWe and a net electric efficiency of 40% can be achieved. In co-generation mode, i.e. inside a sugar mill, two cases, using three steam pressure alternatives, were studied, namely integrated drying or external drying. The net electric output of one BIG-GT module is 16 MWe with a total efficiency of 78% and a power to heat ratio of 0.37-0.38 if a fuel dryer is integrated in the BIG-GT plant using HRSG exhaust flue gas. If the drying is performed outside the BIG-GT unit, the power to heat ratio decreases to 0.33, as more heat is recovered in the HRSG. The integration of the dryer in this case must be evaluated on the sugar mill level, as the integration with of the dryer in the BIG-GT unit shifts fuel usage from an external dryer to the mill boiler to meet the overall steam demand.

These initial data were evaluated for a typical mill, starting at a steam consumption of 500 kg/ton cane, and having savings potential to 340 and 280 kg/ton cane, respectively. Also, investing in a new high-pressure boiler was considered. The 500 kg/ton cane case was not suited for a BIG-GT installation, as fuel availability could not meet both an unaltered steam demand in combination with more power production.

However, using one BIG-GT module, the specific net power of 160-170 kWh/ton cane was not affected to any high degree when decreasing the steam consumption below 340 kg/ton cane or when using a new boiler, such that the added investment cost did not give any added value. CTC also concluded that the potential long-term maximum net electric production, 290 kWh/ton cane, was achieved, within fuel availability, using two BIG-GT modules (or a bigger gas turbine) combined with the lowest steam consumption, generating both power and all sugar mill steam demand without any other boiler. Tentative concepts to allow year-round operation considering the available bagasse and trash fuels on the basis of fuel prorating were also proposed to TPS for further evaluation.

16.6. Updating of the process integration cases

On the basis of the above study, CTC wanted to have two cases studied further, one BIG-GT module with a mill specific steam consumption of 340 kg/ton cane, and two BIG-GT modules with a mill specific steam consumption of 280 kg/ton cane, respectively. These case studies, being the last activity in the process integration task, included an evaluation regarding the dryer integration for the first case involving one BIG-GT module, and regarding the trash and bagasse usage during the season and off-season for both cases.

Questions remained regarding the impact of fuel drying system and fuel composition/fuel blending on the power and steam production. Also an evaluation of the alternatives of one BIG-GT module in parallel with the sugar mill boilers for the total steam generation at 20 bar pressure, and steam consumption 340 kg/ton of cane, 20T340, and of two BIG-GT modules providing the total sugar mill steam generation at 81 bar, and steam consumption 280 kg/ton of cane, 81M2802B, respectively to generate process design data for these two cases, both for season and offseason operation. These two cases can be said to represent the configuration of a probable demonstration project, 20T340, and the configuration long term to maximize the power production potential, 81M2802B, respectively. The mixing of bagasse and trash varies during season; the moisture content in the trash fuel will also differ depending on the season. Both alternatives are evaluated and compared with different fuel composition and moisture content:

All the following calculations with trash as fuel were done with an ash content of 6%. The parameters used in the mass balance models were also updated with the latest data from the pilot plant test program.

The fuel flow to the BIG-GT system in the different alternatives was set to fully load the gas turbine with a margin for variations in the gas flow. When a blend of bagasse and cane trash is used, all the available cane trash is consumed and the bagasse fuel flow is adjusted to fully load the gas turbine. **Table 75** shows a summary of the results from the calculations.

The conclusion of the first part is that dryer integration has very little impact on the total sugar mill fuel consumption or steam production, the small difference pointing towards the use of an external dryer. Therefore, and even more

Table 75

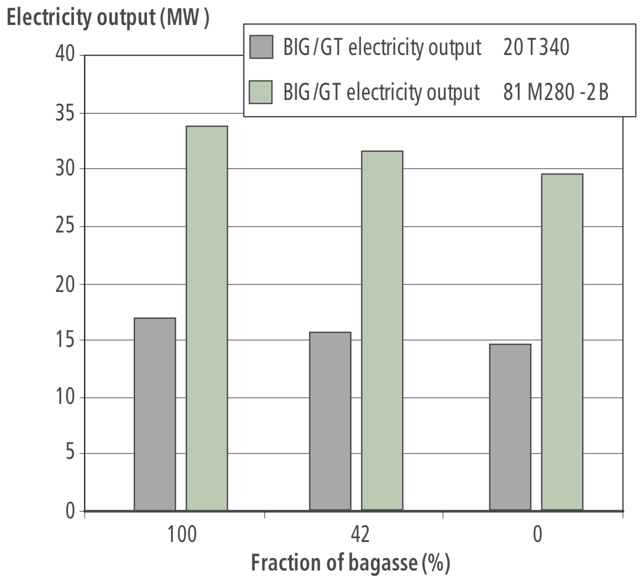
Summary of results from final design calculations.

Case	Fuel/moisture content to BIG-GT unit	Dryer in BIG-GT	Steam condition Bar/°C	Fuel flow bag./trash kg/s dry	Fuel energy LHV MW	Net. el. Output MW	Net electric efficiency %	Steam produced kg/s
Task 1								
Indep. oper.	cane trash/50%	yes	60/500	0/5.40	77.7	29.1	37.4	-
Indep. oper.	cane trash/15%	no	60/500	0/5.55	91.0	31.0	34.0	-
Task 2								
20T340 (A)	bagasse/50%	yes	22/300	5.1/0	76.5	16.2	21.2	17.4
20T340 (B)	bagasse/10%	no (HGG)	22/300	5.1/0	87.6	16.7	19.1	20.1
Task 3								
20T340 (A)	bagasse/10%	no (HGG)	22/300	5.1/0	87.6	16.7	19.1	20.1
20T340 (B)	trash/15%	no	22/300	0/5.55	91.0	14.8	16.3	21.2
20T340 (C)	bag./tra./10/15%	no (HGG)	22/300	2.23/3.12	89.5	15.7	17.5	20.7
20T340 (D)	bag./tra./10/10%	no (HGG)	22/300	2.15/3.12	88.6	15.9	18.0	20.4
81M280-2B (A)	bagasse/10%	no (HGG)	82/480	5.1/0	87.6	16.7	19.1	15.7
81M280-2B (B)	trash/15%	no	82/480	0/5.55	91.0	14.7	16.1	16.3
81M280-2B (C)	bag./tra./10/15%	no (HGG)	82/480	2.85/2.44	88.9	15.8	17.8	15.9
81M280-2B (D)	bag./tra./10/10%	no (HGG)	82/480	2.77/2.44	88.0	16.0	18.2	15.6

Note 1: HGG = Fuel is dried in an external hot gas generator dryer from 50% to 10% moisture.

Note 2: Case 81M280-2B (A)-(D) is designed with two BIG-GT units. Output data are given for one BIG-GT unit.

Figure 94



Electricity output vs. fuel blend.

on the basis of practical reasons, notably the CTC experience of these dryers and the fuel, TPS recommended that the dryer not to be integrated in the BIG-GT module, but rather as a separate unit within the sugar mill.

Secondly, the feasibility of the CTC proposal for the two system configurations, using mixtures of bagasse and trash for year-round operation (100% bagasse, 50% moisture (season and offseason), 100% trash, 15% moisture (season), fuel blend, season (bagasse 50% moisture and trash 15%), fuel blend, offseason (bagasse 50% and trash 50%)), has also been verified by detailed calculation for the cases of one and two BIG-GT modules. **Figure 94** shows the electric output when varying the fraction of trash in the fuel fed to the gasification plant.

The case of one BIG-GT module integrated with a sugar mill of 340 kg/ton cane steam consumption, and a separate dryer will be the basis for the Basic Engineering Activity. The case of two BIG-GT modules shows the long-term potential of the BIG-GT system in the sugar mill.

16.7. Preliminary basic engineering

16.7.1. Introduction

The objective of the Preliminary Basic Engineering study was the preliminary design of an integrated cogeneration power plant, based on the TPS ACFBG process, at the Usina São Francisco, a sugar mill at Sertãozinho, São Paulo, Brazil. Boundary conditions imposed by the integration of the process plant into the specific settings of the sugar/ethanol industry selected for this study were set by CTC.

To gain advantages from the BIG-GT system integration, changes to the sugar mill steam users are foreseen to reduce the mill's specific steam consumption from 500 to 340 kg/ton cane processed to permit the installation of a back pressure/condensing steam turbine in the mill that generates electric energy from the excess steam during the season, and which would also be utilized in condensing mode for the steam produced in the BIG-GT system during the offseason. The mill will also include an integrated bagasse/trash preparation facility, consisting of a trash bale shredder and/or a trash dry cleaning station followed by a flash drying unit for drying of the bagasse and the shredded trash, prior to its delivery to the BIG-GT unit.

The battery limits for TPS's area of responsibility (B.L.) was from the delivery of the dried fuel to the gasification plant; and includes the gasification plant, gas compressor, gas turbine up to the HRSG exhaust and the associated steam system's connection to the mill system. Electric and control systems are included in the battery limit as far as they constitute an integral part of the gasification plant, but for electric power, the battery limit is the terminal on the incoming and outgoing lines into the switchyard. The main equipment in the BIG-GT plant is shown in the simple process flow diagram in Figure 93.

Steam, boiler feed water (BFW), and other products/consumables and utilities will be delivered/ taken at the battery limits at conditions specified by CTC. Bagasse and trash unloading, handling, storage and transfer to the dryer are handled by CTC, as well as the plant steam system and steam turbines.

Gasification unit performance, i.e. mass and energy balances, as well as gas composition and gas turbine performance have been calculated by TPS based on information provided by GE. Details on the equipment used in the process have been derived from TPS's inhouse design and cost data, and in other cases, the result of preliminary quotations given by a number of vendors on the basis of TPS's specifications.

The plant concept is based on the following philosophy and criteria:

- The present work represents state of the art of bagasse gasification in terms of performance when integrated in a sugar mill with a minimum of changes to the mill. The design reported should therefore be seen as an example of the first bagasse/cane trash fuelled BIG-GT demonstration project, which can be realised within a short time frame. This limits the net specific power per ton of cane processed.

- The sugar mill, even if integrated with the BIG-GT unit, should be able to operate independently, when the BIG-GT unit is not operating or operating at lower than normal capacity.
- Changes to the sugar mill should be minimal and balanced from the point of view of the trade off between cost and additional power consumption. This led to the decision to retain the typical sugar mill steam conditions of 22 bar and 300°C for the BIG-GT unit, as solely increasing the steam pressure whilst not making extensive modifications in the sugar mill did not improve the yield of electricity.
- Whenever possible, the BIG-GT system is integrated with the sugar mill to have the benefit of the supply of BFW, cooling water, etc. without additional investments in the BIG-GT unit from system duplication.
- As the sugar milling is only in operation during the harvesting season of approx. six months, the BIG-GT unit and part of the mill steam system can be operated independently of the sugar process to permit the maximum utilization of the cane fuels and the annual electric production. The plant is designed to use bagasse or cane trash in a nominal 42/58% blend, but the design has been made flexible to also allow for the use of each fuel alone up to 100% feeding the gas turbine, and also to cope with variations in the fuel quality.
- As the overall impact in terms of power output was negligible when integrating drying with the BIG-GT unit, it was decided to use a semi integrated approach to utilize the sugar industry's experience by integrating the fuel preparation with the sugar mill. However, the hot gas generator (HGG) uses same fuel for the drying. This is taken into account of the overall performance of the plant.
- The gasification system is based on an airblown CFB, followed by dolomite catalytic tar cracking prior to gas cooling, filtering and scrubbing. The gas prepared and cleaned in this way is then compressed and fired in the gas turbine.
- The gas turbine used in the BIG-GT plant is the GE LM 2500 PH machine producing nominally 24 MW electrical. The gas turbine exhaust gas is cooled in an HRSG with a small amount of supplementary firing, in which steam is generated, and, together with steam from the gas cooling section, superheated before use in the mill or steam turbine. The HRSG operates with lower steam pressure, 22 bar, than normally used in power plants of this type, say 40 to 80 bar.
- The plant is optimized for operation at approximately base load, defined as the maximum gas throughput to the gas turbine. The design was not made to cope with gas compressor and GT outages by designing the HRSG for fresh air firing.

During nominal plant operation, the capacity of the BIG-GT unit at the site of Usina São Francisco is 24 MW gross, and an estimated net electrical output of 16 MW. In addition, steam, 75 ton/h, is exported to the sugar mill. It is estimated that the steam can generate another 12 MW electrical i.e. during the offseason, the exact number being provided by CTC. The usage of dried fuel is 90 MW thermal in total. The efficiency of electrical and steam export is 76%, in this configuration. Annual usage of fuels on a dry basis is approx 59,000 and 84,000 ton of bagasse and trash, respectively. Production of steam is 550 000 ton and the BIG-GT plant alone exports 116 GWh.

16.7.2. Process design

As a result of process integration studies, see below, the process design calls for the use of a mixture of cane trash and bagasse, where the cane trash humidity varies between season and offseason.

As it is impractical to expect a fixed ratio of the two fuels, without variations, and since in practice the cane trash properties themselves are likely to vary, it was decided to design the unit for operation on any mixture from 100% bagasse to 100% cane trash, such that the gas turbine is utilized to its maximum capacity. As the gas properties and air consumption, as well as the gas turbine operating conditions, vary as a result, the design allows for such variations. In particular, this influences the process air system due to a large amount of air bleeding from the gas turbine when operating on trash, and the fuel feed system volumetric throughput. The high throughput of material, and the wish to maintain a high reliability, called for the use of two feed lines, each of 100% capacity. Each line consists of one hopper, hopper discharge into two lines of gas seals and feed screws to cope with the volumetric quantity of material.

The HRSG, for the integrated case, operates with lower steam pressure, 22 bar, than normally used in power plants of this type. In the case of a standalone unit, the pressure would be higher, say 40 to 80 bar. There are no provisions for fresh air firing of the HRSG in the proposed design. The supplementary firing in the HRSG used in the proposed design has been kept to a minimum for controlling the gas turbine, a flow that will fluctuate as part of normal operation due to variations in the fuel properties and gasification system operating conditions.

As mentioned above, the process air usage varies with the fuel mixing ratio and the amount of air bleeding required to maintain the gas turbine at the optimum operating conditions. The bleed air is recovered to generate additional process air. Thus, there are several operating modes of the process air system, to maximise the process efficiency. During startup, the process air compressors are both in use. When gasification conditions are reached, but prior to gas turbine operation, one compressor is used. As bleed air becomes available from the gas turbine, and depending on fuel mixture and operating conditions, the recovery of the bleed air will produce 50 to 100% of the process air requirements.

The gas cooling is integrated with the HRSG such that, in the case of integrated operation, gas cooling is used to preheat and evaporate some of the BFW, followed by superheating in the HRSG.

Table 76

Fuel and operating conditions.

Case 1	
	Nominal case
	Normal operating case during season
	42% bagasse, 58% cane trash (dry basis)
	Moisture contents: bagasse 10%, cane trash 15%
Case 2	
	Normal operating case during off season
	41% bagasse, 59% cane trash (dry basis)
	Moisture contents: bagasse 10%, cane trash 10%
Case 3	
	100% bagasse
	Moisture content: 10%
Case 4	
	100% cane trash
	Moisture content: 15%

16.7.3. Plant capacity, feedstock and operating cases

The nominal operating case during the milling season uses a fuel blend of 42% bagasse and 58% trash, dry basis. The bagasse has a moisture content of 50% before it is dried to 10%. The trash has a moisture content of 15% and no drying is done. The normal operating case during off season is 41% bagasse and 59% trash, dry basis. The bagasse moisture content and drying is the same as during the milling season, but the trash moisture content is 50% before it is dried to 10%. As extreme cases, 100% bagasse dried to 10% moisture content and 100% trash at 15% moisture content, were evaluated. A summary of the operating cases with the conditions of the fuels as they are fed to the gasifier are found in **Table 76**.

Mass and energy balances, plant performance for all operating cases and fuel feedstock and other materials consumed as well as products, waste streams, byproducts and internal media are specified in more detail in later sections.

16.7.4. Mass and energy balance

Overall material balance

At 100% load with nominal fuel blend conditions the plant consumes approximately 9 tons/h of bagasse (at 10% moisture) and approximately 13 tons/h of cane trash (at 15% moisture) to produce 47 000 Nm^3/h of cleaned wet gas having an LHV of 5.1 MJ/Nm^3. From the gas produced, which is fired mainly in the gas turbine, but also as supplementary firing, a flow of 198 000 Nm^3/h flue gas is generated at above 500°C. On cooling the flue gas in the HRSG, 75 ton/h of steam at 22 bar and 300°C is generated. Downstream of the HRSG, the gas is routed to the dryer within the sugar mill, where the gas is mixed with hot product gas from the combustion of bagasse fuel.

The plant performance for the nominal case and other operating cases and production and consumption figures are given in a later section.

Overall energy balance

The fuel input of 90 MW at 100% load and nominal fuel blend during season (operating case 1) gives a fuel gas with a thermal energy flow of 66 MW. Most of the gas is fired in the gas turbine producing 24 MWe at the gas turbogenerator. Some fuel gas is also burnt in the HRSG, together with 0.4 MW of oil used in the pilot flame of this burner. This produces a flue gas at 572°C that is cooled to 133°C, while producing 75 tons/h of steam at 22 bar and 300°C that is directed to the sugar mill.

The internal consumption in the BIG-GT unit for the nominal case is 8 MW, of which more than 90% is used by the gas compressor. Power consumption of the feed water system and utilities outside the TPS battery limit is not included in this figure. 16 MW is delivered from the BIG-GT plant to the grid. This gives a net electric efficiency of 18% (LHV) on the total fuel usage for the BIG-GT plant alone.

The steam is added to the steam produced in the mill's steam system. Part of the total steam is used to drive some equipment by directly coupled backpressure steam turbines. The rest is expanded in a extraction/ condensing steam turbogenerator to produce electricity. During the offseason only the steam turbogenerator is used and then in full condensing mode with only limited extraction. The steam from the BIG-GT plant is estimated to produce 12 MWe if expanded in the steam turbine. Thus, the total gross production of electricity that can be attributed to the BIG-GT plant is estimated at 36 MWe. Net electric efficiency becomes 33% (LHV) on the basis of predried fuels.

The plant performance for the nominal case and other operating cases are given in a later section.

16.7.5. Plant performance

The estimate of the plant's fuel consumption, net steam and power output for four operating conditions are summarized in **Table 77** and **Table 78**.

The amount of fuel required under full load conditions varies depending on fuel blend and seasonal variations of the fuel moisture content. The table below summarizes fuel flow and moisture content for the four cases considered in the mass and energy balance calculations. The fuel conditions before drying are also specified even though fuel drying is outside TPS's battery limits. However, the drying, and its fuel consumption in the HGG (hot gas generator), has a positive impact on the overall efficiency.

Table 77

Fuel consumption.

Fuel blend / Operating case	Nominal fuel blend (season) 1		Nominal fuel blend (off season) 2		100% bagasse 3		100% sugar cane trash 4	
Fuel flow to HGG+ Dryer	t/h (AR)	% moisture	t/h (AR)	% moisture	t/h (AR)	% moisture	t/h (AR)	% moisture
Bagasse	16.1+1.3[(b)]	50	15.5+4.8[(b)]	50	36.7+4.8[(b)]	50	-	-
Trash	-	-	22.5	50	-	-	-	-
Fuel flow to BIG-GT plant	t/h (AR)	% moisture	t/h (AR)	% moisture	t/h (AR)	% moisture	t/h (AR)	% moisture
Bagasse	8.9[(a)]	10	8.6[(a)]	10	20.4[(a)]	10	-	-
Trash	13.2	15	12.5[(a)]	10	-	-	23.5	15
Energy to installation LHV on AR basis	HGG+ BIG-GT MW	BIG-GT MW	HGG + BIG-GT MW	BIG-GT MW	HGG+ BIG-GT MW	BIG-GT MW	HGG + BIG-GT MW	BIG-GT MW
Bagasse	35	38	41	37	84	87	-	-
Trash	51	51	45	52	-	-	91	91
Total Fuel	86	89	86	89	84	87	91	91

(a) Fuel to BIG-GT plant from the dryer, after drying.
(b) Fuel to dryer.
AR = as received

Definitions of efficiencies

1) Net electric efficiency of BIG-GT or Total Plant, cogeneration mode:
Net el. output BIG-GT (excl. ST) divided by Total fuel input i.e. bagasse, trash, oil to the relevant plant
2) Net electric efficiency of BIG-GT or Total Plant, condensing mode:
Net el. output BIG-GT (incl. ST) divided by Total fuel input i.e. bagasse, trash, oil to the relevant plant
3) Steam production efficiency of BIG-GT or Total Plant:
Thermal steam production for BIG-GT divided by Total fuel input i.e. bagasse, trash, oil
4) Total net co-generation efficiency of BIG-GT or Total Plant:
Net electric efficiency + Steam production efficiency

Efficiency for electric production is 16-19% for co-geneneration operation and 30-33%, based on condensing operation, if the fuel received at the BIG-GT plant is used as a basis. If the drying installation is also included, the

Table 78

Power and steam production.

Fuel blend Operating case	Unity	Nominal fuel blend (season) 1	Nominal fuel blend (off season) 2	100% bagasse 3	100% sugar cane trash 4
		Production			
GT generator output	MWe	24	24	23.8	24.1
Medium pressure steam at 22 bar	ton/h	74.7	73.6	72.7	76.5
Medium pressure steam at 22 bar	MW(a)	52.1	51.3	50.7	53.3
Estimated ST generator output from BIG-GT steam production	MWe	12.9	12.1	11.9	12.5
In plant loads	MW(b)	8.3	8.0	7.1	9.3
Net plant electric output, incl. ST	MWe	28.6	28.0	28.6	27.3
Net plant electric output, excl. ST	MWe	15.7	15.9	16.7	14.8
		Fuels usage, BIG-GT Plant			
Fuel LHV,					
Bagasse	MW	38	37	87	0
Cane trash	MW	51	52	0	91
Fuel oil	MW	0.4	0.4	0.4	0.4
Total fuel input	MW	89.4	89.4	87.4	91.4
		Fuels usage, total plant			
Fuel LHV,					
Bagasse	MW	35	41	84	0
Cane trash	MW	51	45	0	91
Fuel oil	MW	0.4	0.4	0.4	0.4
Total fuel input	MW	86.4	86.4	84.4	91.4
		Efficiencies for BIG-GT plant			
Net electric efficiency of BIG-GT, co-generation mode, exclusive ST	%	18	18	19	16
Net electric efficiency of BIG-GT condensing mode, inclusive ST	%	32	31	33	30
Steam production efficiency of BIG-GT	%	58	57	58	58
Total net co-generation efficiency of BIG-GT	%	76	75	77	74
		Efficiencies for total plant			
Net electric efficiency of BIG-GT, co-generation mode, exclusive ST	%	18	18	20	16
Net electric efficiency of BIG-GT, condensing mode, inclusive ST	%	33	32	34	30
Steam production efficiency of BIG-GT,	%	60	59	60	58
Total net co-generation efficiency of BIG-GT	%	78	77	80	74

(a) The thermal steam production is defined as enthalpy of steam exported minus enthalpy of feed water received from sugar mill. (b) Excluding ilumination and building services.
MWe = MW electric ST = Steam turbine; GT= Gas turbine.

moist fuel having lower LHV then after drying, the efficiencies increase by a few percent. The relatively low steam pressures and superheats used in the mill, limits the overall power production efficiency to 34% for 100% bagasse operation, for the condensing mode.

Total efficiency, also including the steam delivered to the mill ranges from 74-77% on the basis of the fuel to the BIG-GT, and increases up to almost 80% when the drying is included.

16.7.6. Investment and operating cost

Investment cost

The investment cost for the BIG-GT cogeneration plant has been estimated with a target accuracy of ± 30%. The estimate is presented in **Table 79**. The cost estimate covers the process units and utilities within the TPS battery limit and all indirect costs connected with them. However, the BIG-GT cogeneration plant has most central facilities and administration in conjunction with the sugar mill and they have not been included. The total plant cost in **Table 79** covers the total investment cost of the BIG-GT plant being built on the sugar mill site.

The input for the process unit costs are based on budgetary quotations received for the bagasse project, or for other similar projects. In some cases, TPS has made their own estimates. If quotations for other projects have been used, the costs have been recalculated to apply to this project.

The sources for this information were mostly vendors in Europe, such that the price reflects the equipment costs in an area associated with the Euro rather than the US dollar, in which currency the cost is presented. No adjustments were made to make the estimate more specific for Brazilian conditions.

The total plant cost for the BIGGT plant within the TPS battery limit was estimated in the middle of year 2000 to be US$ 62.7 million.

It should be noted that this price is that for a first of a kind plant. Future plants are assumed to have considerably lower investment cost and higher efficiency, according to the normal "learning curve" theory. Also, plant scaleup would reduce the specific cost on the grounds of economy of scale. The cost and efficiency of the gas turbine is of great importance for the economy of the plant.

Secondly, given the current exchange rate situation in Brazil relative USA and Europe, a preferential sourcing of equipment and services with Brazilian suppliers, as evidenced from other projects in the sugar industry sector, most likely would result in a drastically lower investment cost (25% or more difference).

16.7.7. Operating cost

The estimate of operating costs are based on operation both in the milling season and off season, utilising both the mill bagasse and cane trash brought and prepared at the mill. Bagasse and trash is supplied at B.L. dried and shredded.

No fuel cost for bagasse is included, since it is a residual product from the sugar mill process. To balance, no credit is given for the steam exported to the sugar mill. The cost for trash is the cost to bring it from the fields to the plant.

Maintenance cost is set at 2% of the total investment cost. The organization of the personnel is based on substantial interaction with mill personnel for laboratory, maintenance, I&E and administrative services. This cost is 1.2 million U$ per year.

The credit for electricity export is not included in the breakdown, as this is taken into account at mill level by CTC. No capital charges have been included in the annual costs.

The operating costs (in million US$) become:

- Maintenance 1.2
- Trash 1.0
- Personell 0.3
- Materials, aux. fuels etc. 0.4
- Total annual O&M cost, incl. fuels 2.9

Table 79

BIG-GT TPS B.L. Cost summary.

Item	(US$1000)
Process units, spare parts,	38 400
Total direct cost process units	38 400
Bulk materials, civil, I&EC	10 600
Total construction cost	49 000
General engineering, indirect costs, commissioning	8 400
Total construction cost including engineering	57 400
Contingency, 10%	5 300
Total BIG-GT plant cost	62 700

17. Energy costs

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17.1. Introduction

Large quantities of trash resulting from the cane harvesting operations can be either left on the ground, creating a blanket that protects the soil, or taken to the mill for utilization as fuel. Thus, the possibility of using this trash along with the bagasse to generate power with the BIG-GT technology has been visualized.

Several studies and field tests have been carried out to determine the best agronomic routes to recover the trash, transport it to the mill and to prepare it to be used as gasifier fuel. After the analyses of the alternative routes, a baseline was adopted considering a typical mill that mechanically harvests the cane without burning, with the harvester chopping and cleaning the cane simultaneously, leaving the trash on the ground.

Three alternatives have been considered evaluating the transition from the baseline situation to routes that include the trash recovery operation; they are:

Alternative 1: the harvesting operation is executed in the same manner as in the baseline condition and the trash left in the field is baled, transported to the mill and shredded to fineness similar to bagasse.

Alternative 2: the cane harvesters are operated with the cleaning fans turned off; the trash is transported to the mill with the cane and the trash/cane separation process takes place in the cane dry cleaning station installed in the mill.

Alternative 3: the cane harvesters cleaning system has the secondary cleaning fan off and the primary fan set at a convenient rpm; therefore only partial cleaning of the cane is obtained during the harvesting operation leaving a thinner blanket on the ground; the trash transported with the cane is separated by the cane dry cleaning station at the mill.

This report presents the main collected data, technical parameters and assumptions that have been used to develop the economic analysis of power generation with a BIG-GT system integrated with the typical mill, using as fuels sugar cane residues resulting from cane harvesting – trash and from cane processing to sugar and alcohol – bagasse. An economic analysis has been performed for an independent BIG-GT system operating with the cane residues from the mill, but the preliminary results indicated that this alternative is worse, from the economic point of view, than the integrated BIG-GT/mill situation. Therefore, these results are not included in this report.

17.2. Technical parameters of the typical mill

A – Agricultural parameters

Technical parameters of the agricultural area of a typical mill used in this analysis have already been presented. **Table 80** shows the parameters that can affect the total cane to be milled and, consequently, the surplus bagasse

Table 80

Agricultural parameters (wb= wet basis and db= dry basis).

Item		Baseline	Alternative 1	Alternative 2	Alternative 3
Material delivered to the mill	t	1,301,290	1,301,290	1,511,275	1,445,744
Bagasse produced (wb)	t	416,037	416,037	438,591	411,104
Bagasse surplus (wb)	t	115,230	115,230	134,649	112,501
Surplus/produced bagasse rate	%	27.7	27.7	30.7	27.4
Trash available in the field (db)	t	180,697	180,697	180,697	180,697
Recovered trash (db)	t	114,902	114,902	119,531	89,554
Recovered/available trash ratio	%	63.6	63.6	66.1	49.6
Trash cost at the mill (db)	**US$/t**	**-**	**18.49**	**31.12**	**13.70**

and recovered trash (baled or loose), depending on the agronomic route considered. This analysis considered that total sugar cane in the field is the same for all alternatives – 1,290,695 tons (that corresponds to 1,300,000 tons of cane and extraneous material in the burned cane harvesting alternative).

The term "surplus bagasse" means the excess bagasse that would result from the normal mill operation without the BIG-GT plant; in the baseline condition it is assumed that this amount of bagasse is sold at a price of US$5.00/ton. Therefore in alternatives 1, 2 and 3 the difference of total surplus bagasse with respect to the baseline is considered as benefit (if positive) or a cost (if negative) in the total trash cost.

B – Industrial parameters

As in the case of the previous item, some parameters listed below have already been described in this report, but they are repeated here to make clear how the other data related to the cane processing or power generation are obtained.

The assumptions for technical parameters related to the typical mill operation in the baseline conditions are:

- Mill extraction efficiency 96.24%
- Pol % bagasse 1.89%
- Bagasse moisture content 48.67%
- Total bagasse consumption 231 kg/t cane, wet basis
- Process steam consumption 530 kg/t cane

Using the agricultural parameters and assumptions above, power production under the present situation in the typical mill (without BIG-GT) can be determined for the three alternatives (**Table 81**).

The term "effective hours" used in Table 81 and in other parts of this chapter means effective full load hours of BIG-GT system operation.

Table 81

Power production in the typical mill (bagasse weight as wet basis).

Item		Baseline	Alternative 1	Alternative 2	Alternative 3
Milled material	t	1,301,290	1,301,290	1,314,855	1,291,761
Effective season hours	h	4,817	4,817	5,007	4,768
Effective off season hours	h	2,804	2,804	2,614	2,854
Bagasse produced	t	416,037	416,037	438,591	411,104
Bagasse production rate	t/h	86.37	86.37	87.60	86.23
Bagasse consumption rate	t/h	62.45	62.45	60.70	62.63
Surplus bagasse rate	t/h	23.92	23.92	26.89	23.60
Surplus bagasse	t	115,230	115,230	134,649	112,501
Electric power consumption	kW	3,106	3,106	3,106	3,106
Electric power exported	kW	330	330	330	330
Total energy exported	**MW/year**	**1,590**	**1,590**	**1,652**	**1,573**

C – Economic / financial parameters

- Bagasse sale price, without taxes US$ 5.00/t, wet basis (48.67%)
- Capital attractive rate 12% per year
- Cash flow period 15 years

17.3. Technical parameters of the future typical mill

The future typical mill is the actual typical mill with all modifications designed to reduce steam consumption to optimize integration with the BIG-GT package.

With the preliminary data provided by TPS for the BIG-GT system the integration of this system with the typical mill started to be analyzed. Several alternatives have been evaluated and alternative 20T340 has been chosen

Table 82

Bagasse consumption (wet basis) in the typical mill in future conditions.

Item		Baseline	Altern. 1	Altern. 2	Altern. 3
Bagasse consumption	t/h	62.45	44.40	44.40	44.40
Bagasse economy[(a)]	t/h	-	18.05	16.30	18.23

[(a)] Bagasse economy due to steam consumption reduction from 530 to 340 kg/t cane.

for detailed engineering and design development. The bagasse consumption for the three alternatives of trash recovery routes are in **Table 82**.

To reduce process steam consumption in the typical mill considered in this analysis (530 kg/t cane to 340 kg/t cane), with a corresponding reduction in bagasse consumption, some investments have been made (**Table 83**) and, consequently, the surplus bagasse is used for power generation.

Table 83

Investments to reduce the steam consumption.

Item		Quantity	Unit cost (US$ 1,000)	Total cost (US$ 1,000)
1.	**Utilities**	-	-	**106.1**
	400 kW electric motors	3	35.37	106.1
2.	**Process**	-	-	**1,996.2**
	Carbon steel juice heater (160 m^2)	3	21.18	63.5
	Carbon steel heater for clarified juice (250 m^2)	2	31.76	63.5
	Regenerative heat exchanger for vinasse x juice	1	56.47	56.5
	Piping and fittings 2nd and 3rd effect vapor bleeding	1	35.29	35.3
	Carbon steel tubes last effect 1200m^2 evaporator	1	84.71	84.7
	Condenser flash steam recovery system	4	3.18	12.7
	Mechanical stirers, with drives, for vacuum pans	1	211.76	211.8
	Modification of distillation columns for Flegstil	1	56.47	56.5
	Molecular sieves for 400 m^3/day	1	1,411.76	1,411.8
3.	**Erection and instrumentation**	-	-	**1,298.7**
	Steel structures for heaters and evaporators	1	299.44	299.4
	Erection Labor and other modifications	1	399.24	399.2
	Instrumentation for the sugar and alcohol factories	1	600.00	600.0
4.	**Total**	**-**	**-**	**3,401.0**

17.4. Power generation plant

Trash and bagasse (residues of cane harvesting and cane processing for sugar and alcohol) consumption, investments in power generation and costs of production are modified, depending on the power generation alternative. This economic analysis considered the power generation integrated with the typical mill. Analysis for the independent BIG-GT system has been performed and the results indicated that this alternative is worse than the BIG-GT system integrated with the mill. Therefore, they are not included in this report.

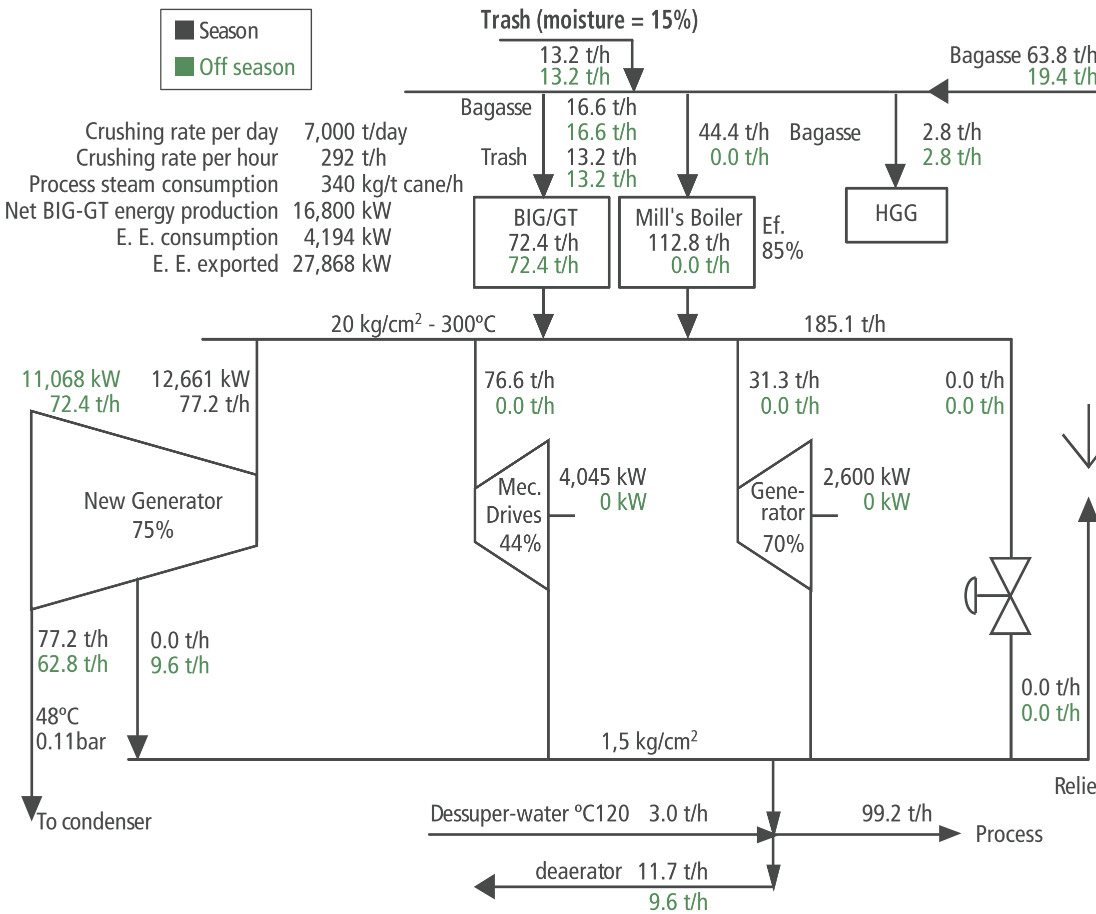
A simplified flow diagram for the BIG-GT plant integrated with the mill is shown in **Figure 95**; the mass and energy balances for the three alternatives are also indicated.

Table 84 shows parameters of the bagasse consumption in the mill, BIG-GT system and hot gas generator (HGG). These data have been provided by TPS or calculated by Copersucar.

Based on the data above, availability of additional bagasse for consumption and the surplus trash for the three alternatives have been calculated in reference to the baseline condition. The total surplus trash and bagasse have been made available for sale, outside the plant, at a price equivalent to bagasse on an energy basis (bagasse at 50% moisture content for US$5.00/t). This is summarized in **Table 85** comparing with the baseline conditions.

Figure 95

BIG-GT plant integrated with the mill.



Implementation of the power plant will provide energy surplus for export (**Table 86**). These values have been determined by Copersucar based on BIG-GT information provided by TPS and in house information.

The investments that are required for the implementation of the power generating plant integrated with the typical mill are detailed in **Table 87**.

Technical parameters and unit cost of fuels and chemicals used in the power generation plant integrated with a typical mill are defined in **Table 88**.

This way, the annual cost of the fuels and chemicals can be calculated for the three alternatives. The results are shown in **Table 89** for the power plant integrated with the typical mill.

Annual maintenance costs have been estimated considering they are a certain percentage for each group of investment required (**Table 90**).

Labor requirements to operate the power generating systems, integrated with the typical mill, refer to the requirement per shift and the operation will require three shifts. Both season and off season data are presented (**Table 91**).

The wages adopted for each worker, in each activity, considering 220 hours per month as reference, are presented in **Table 92**.

Therefore, the annual expenditure with operating labor, including a 75% addition for social security and other taxes on the wages, can be calculated as shown in **Table 93**.

Table 84

Bagasse (50% moisture, wet basis) and trash (15% moisture, wet basis) production/consumption and waste streams (t/year).

Item	Baseline	Alternative 1	Alternative 2	Alternative 3
1. Bagasse				
Bagasse produced	416,037	416,037	438,591	411,104
Surplus bagasse without BIG-GT	115,230	115,230	134,649	112,501
Bagasse available for consumption	300,807	300,807	303,942	298,603
Bagasse – season (t/h effective)	62.45	63.80	63.80	63.80
- Mill	62.45	44.40	44.40	44.40
- BIG-GT	-	16.60	16.60	16.60
- HGG[(a)]	-	2.80	2.80	2.80
Total	300,807	307,317	319,447	304,171
Bagasse – off season (t/h effective)	-	19.40	19.40	19.40
- BIG-GT	-	16.60	16.60	16.60
- HGG	-	2.80	2.80	2.80
Total	-	54,404	50,715	55,360
Total bagasse consumption	300,807	361,721	370,162	359,531
Additional bagasse consumption, referred to the baseline	-	60,914	66,220	60,928
Additional wastes (ash from additional bagasse)[(b)]	-	3,046	3,311	3,046
Surplus bagasse (after BIG-GT)	115,230	54,316	68,429	51,573
2. Trash				
Trash – season (t/h effective)	-	13.20	13.20	13.20
- BIG-GT (t/h effective)	-	13.20	13.20	13.20
- HGG (t/h effective)	-	-	-	-
Total	-	63,583	66,092	62,932
Trash – off season (t/h effective)	-	13.20	13.20	13.20
- BIG-GT (t/h effective)	-	13.20	13.20	13.20
- HGG (t/h effective)	-	-	-	-
Total	-	37,017	34,507	37,668
Trash consumption (wb)	-	100,600	100,600	100,600
Additional wastes (ash from trash)[(b)]	-	5,030	5,030	5,030
Recovered trash	-	135,179	140,625	105,357
Surplus trash	-	34,579	40,025	4,757
Surplus trash, referred to the baseline	-	58,784	68,043	8,087

(a) HGG – Hot Gas Generator for the bagasse/trash dryer

(b) 5% on the additional bagasse and trash consumption; cost of disposal of this additional ash is added to the operating costs.

Table 85

Additional bagasse consumption and surplus trash for sale (t/year, wet basis).

Item	Baseline	Alternative 1	Alternative 2	Alternative 3
Surplus bagasse without BIG-GT[(a)]	115,230	115,230	134,649	112,501
Surplus bagasse with BIG-GT[(b)]	115,230	54,316	68,429	51,573
Bagasse consumption for power generation[(b)]	-	60,914	66,220	60,928
Surplus trash with BIG-GT[(c)]	-	34,579	40,025	4,757
Surplus trash with BIG-GT[(d)]	-	58,784	68,043	8,087
Trash sale income (US$1,000/year)	-	293.9	340.2	40.4

(a) Conditions prior to power plant installation (baseline)

(b) Conditions after the power plant installation; considered in the cost of energy generated

(c) Wet basis, 15% moisture content

(d) Wet basis, 50% moisture content

Table 86

Generated, consumed and exported power (kW).

Item	Baseline	Alternative 1	Alternative 2	Alternative 3
Electric power - season				
- Generated	3,436	31,994	31,994	31,994
- Consumed by power plant	-	2,100	2,100	2,100
- Consumed by mill	3,106	4,194	4,194	4,194
- Exported	330	25,700	25,700	25,700
Electric power – off-season				
- Generated-		27,900	27,900	27,900
- Consumed by power plant	-	1,600	1,600	1,600
- Exported-		26,300	26,300	26,300
Operating hours – season[(a)]	4,817	4,817	5,007	4,768
Operating hours – off-season[(a)]	-	2,804	2,614	2,854
Annual total exported energy (MWh)	1,469	197,547	197,433	197,577

(a) Differences in operating hours among the baseline and alternatives are due to different amounts of fiber being milled (sugar cane plus vegetal impurities).

Table 87

Investments in the power generating plant (US$ 1,000).

Item	Alternative 1	Alternative 2	Alternative 3
BIG-GT package (gasifier, gas turbine, HSG)	61,000.0	61,000.0	61,000.0
Steam turbine generator (12,600 kW)	3,764.7	3,764.7	3,764.7
Belt conveyors	1,067.6	1,258.8	1,258.8
Bagasse/trash reclaiming system	267.6	267.6	267.6
- Rocks separator	70.6	70.6	70.6
- Feeding table	52.9	52.9	52.9
- Belt conveyors	26.5	26.5	26.5
- Tractor	117.6	117.6	117.6
Trash receiving and processing system[(a)]	29.7	-158.2	-158.2
Bagasse/trash drying system	570.5	570.5	570.5
- Trash/bagasse dryer	377.7	377.7	377.7
- HGG and auxiliary systems	192.8	192.8	192.8
Dried fuel warehouse	322.6	322.6	322.6
- Warehouse	205.9	205.9	205.9
- Overhead crane	47.1	47.1	47.1
- Fuel feeder	58.8	58.8	58.8
- Electromagnet	10.9	10.9	10.9
Water cooling systems	138.8	138.8	138.8
Instrumentation, controls and auxiliary systems	2,555.9	2,555.9	2,555.9
- Electric system (includes substation)	2,058.8	2,058.8	2,058.8
- Instrumentation and controls	305.9	305.9	305.9
- Dolomite silo	17.6	17.6	17.6
- Ash conveyors	26.5	26.5	26.5
- Other (pumps, piping, fittings)	147.1	147.1	147,1
Total	**69,717.6**	**69,720.8**	**69,720.8**

(a) The negative values are due to the fact that these values have already been considered in the trash processing costs.

Table 88

Fuels and chemicals technical parameters and unit cost.

Item	Unit	Technical parameters (unit/kWh)			Unit cost
		Alternative 1	Alternative 2	Alternative 3	(US$/Unit)
Bagasse (wb, 50% moisture)	t	262.16	284.05	262.45	5.00
Trash (wb, 15% moisture)	t	432.96	431.52	433.34	(a)
Demineralized water	m^3	59.04	58.84	59.09	0.18
Chemicals for BIG-GT	(b)	788.87	788.87	788.87	1,176.47
Diesel oil (for equipment)	L	590.40	588.43	590.92	0.37
Lube oil	m^3	0.02	0.02	0.02	1,073.53
Waste transportation	km	69.51	71.56	69.58	0.50

(a) Depends on the alternative route

(b) Different units; technical parameter adjusted to give correct total cost

Table 89

Annual costs of fuels and chemicals (US$ 1,000).

Item	Alternative 1	Alternative 2	Alternative 3
Bagasse	304.6	331.1	304.6
Trash	1,581.4	2,661.1	1,171.6
Subtotal 1 (bagasse and trash)	1,886.0	2,992.2	1,476.3
Demineralized water	2.5	2.5	2.5
Chemicals for BIG-GT	928.1	928.1	928.1
Diesel oil (for equipment)	51.2	51.2	51.2
Lube oil	4.3	4.3	4.3
Waste transportation	8.1	8.3	8.1
Subtotal 2 (chemicals and other items)	994.2	994.4	994.2
Total annual (subtotal 1 + 2)	**2,880.2**	**3,986.6**	**2,470.5**

Table 90

Annual maintenance costs (US$ 1,000).

Item	% of investment	Alternative 1	Alternative 2	Alternative 3
BIG-GT	1	610.0	610.0	610.0
Steam turbine	1	37.6	37.6	37.6
Conveyors	3	32.0	37.8	37.8
Bagasse/trash reclaim system	10	26.8	26.8	26.8
Trash processing systems	10	3.0	-15.8	-15.8
Dryer and auxiliary equipment	7	39.9	39.9	39.9
Dried fuel warehouse	1	3.2	3.2	3.2
Cooling system	3	4.2	4.2	4.2
Electrical equip., instrument. and controls	3	76.7	76.7	76.7
Annual total		**833.4**	**820.4**	**820.4**

Table 91

Labor requirements (worker/shift).

Item	Alternative 1		Alternative 2		Alternative 3	
	Season	Off season	Season	Off season	Season	Off season
BIG-GT plant manager	0.33	0.33	0.33	0.33	0.33	0.33
BIG-GT plant superviser	1	1	1	1	1	1
BIG-GT plant operators	4.67	4.67	4.67	4.67	4.67	4.67
Trash reception	2	-	-	-	-	-
Trash processing	1	-	1	-	1	-
Conveyors monitoring	1	1	1	1	1	1
Fuel reclaiming	2	2	2	2	2	2
Time off replacement (7/1)	2	2	2	2	2	2
Total	**14**	**11**	**12**	**11**	**12**	**11**

Table 92

Wages for workers in each activity.

Activity	Base wage (US$/h)
BIG-GT plant manager	10.70
BIG-GT plant superviser	4.01
BIG-GT plant operators	2.14
Bagasse reception	2.14
Trash reception	2.14
Trash processing	2.14
Bagasse Drying – HGG	2.14
Conveyors monitoring	2.14
Fuel reclaiming	2.14
Time off replacement	2.14

Table 93

Annual labor costs (US$).

Item	Alter-native 1	Alter-native 2	Alter-native 3
BIG-GT plant manager	30,918	30,918	30,918
BIG-GT plant superviser	35,134	35,134	35,134
BIG-GT plant operators	87,506	87,506	87,506
Trash reception	11,843	-	-
Trash processing	11,843	11,843	11,843
Conveyors monitoring	18,738	18,738	18,738
Fuel reclaiming	37,476	37,476	37,476
Time off replacement	37,476	37,476	37,476
Subtotal	270,934	259,091	259,091
Social security and other costs	203,200	194,318	194,318
Annual total	**474,134**	**453,409**	**453,409**

Table 94

Estimated working capital.

Item	Unit	Average period days	Parameters unit/day	Unit cost US$/unit	Value US$1,000
1. Requirements					**(1)**
Materials storage					534.51
- Bagasse	t	90	166.9	5.00	75.10
- Trash	t	90	275.6	15.72	389.94
- Chemicals	MWh	30	541.2	4.28	69.47
Customers	MWh	30	541.2	(1)	(1)
2. Resources					**(1)**
- Suppliers	MWh	30	541.2	12.40	201.27
- Taxes	MWh	25	541.2	(1)	(1)
3. Total working capital					**(1)**

(1) These values are dependent on the final energy cost and therefore will be determined later.

17.5. Working capital requirement

The initial investment estimated for the working capital was calculated with the parameters already determined. It was detailed only for one of the three alternatives (Alternative 3 – partial cleaning), as an example of the procedure used (**Table 94**). The assumptions considered were:

a) Brazilian sale taxes: 14.65% (12% ICMS, 2% Cofins and 0.65% PIS).
b) Average period to pay taxes: 25 days.
c) Average period for customer payment: 30 days.
d) Average period to pay suppliers: 30 days.
e) Bagasse/trash average storage period is 90 days and for chemicals and other consumables is 30 days.
f) The sale price of energy has been calculated in the end of this analysis.

Table 95

Investment, own capital and financing (US$ 1,000).

Item	Alternative 1	Alternative 2	Alternative 3
Process investment	3,401.0	3,401.0	3,401.0
Power generation plant investment	69,717.6	69,720.8	69,720.8
Total Investment	73,118.6	73,121.9	73,121.9
Own capital (30%)	21,935.6	21,936.6	21,936.6
Financing (70%)	51,183.0	51,185.3	51,185.3

17.6. Financing

Financing conditions considered possible to obtain the necessary resources to support investment for the power generation plant are detailed in the sequence of this analysis. In this way, 70% of the investment cost has been considered to be financed (**Table 95**).

The interest rate considered for financing is 6% per year plus variation of the US$. The interest is paid monthly, including the grace period (two years) and the amortization is paid biannually (**Table 96**).This is very similar to BNDES (National Bank for Economic and Social Development) special conditions for power generating plants financing, considering the inflation in Brazilian currency (R$) and currency exchange rate.

Table 96

Financing - Total value, amortization and interest (US$ 1,000).

Year		Alternative 1	Alternative 2	Alternative 3
	Financing value	51,183.0	51,185.3	51,185.3
0	Amortization	-	-	-
	Interest	1,536.0	1,536.1	1,536.1
1	Amortization	-	-	-
	Interest	3,072.0	3,072.1	3,072.1
2	Amortization	-	-	-
	Interest	3,072.0	3,072.1	3,072.1
3	Amortization	12,795.8	12,796.4	12,796.4
	Interest	2,688.0	2,68.1	2,688.1
4	Amortization	12,795.8	12,796.3.	12,796.3
	Interest	1,920.0	1,920.1	1,920.1
5	Amortization	12,795.7	12,796.3	12,796.3
	Interest	1,152.0	1,152.1	1,152.1
6	Amortization	12,795.7	12,796.3	12,796.3
	Interest	384.0	384.0	384.0

17.7. Income tax

Income tax charged to the net profit of energy sales has been considered as 35%.

17.8. Economic concept

Based on the data detailed in previous tables, electric energy cost using BIG-GT technology can be determined for each alternative. Therefore, in this analysis the economic concept below has been considered:

"The electric energy cost determined in this analysis, is the value obtained when the Net Present Value (NPV) from cash flow of project is null, for a period of 15 years and 12% per year as minimum atractivity interest rate".

The detailed cash flow for alternative 3 is presented in **Table 97** as an example of the procedure used in determining the energy cost. It is important to point out that this cash flow presents only the incremental values with respect to the baseline ones. For instance, the item "electric energy sales" is 1469 MWh/year in the baseline situation while in Alternative 3 it raises to 197 577 MWh/year; so, the incremental value for "electric energy sales" is 196,108 MWh/year. All other incremental costs and incomes are calculated in a similar way.

Table 97

Cash flow - alternative 3 (US$ 1,000).

Item	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7/14	Year 15
1. Inputs	51,185	16,127	16,127	16,127	16,127	16,127	16,127	16,127	23,439
Electric energy sales		15,786	15,786	15,786	15,786	15,786	15,786	15,786	15,786
Surplus bagasse/trash sales		40	40	40	40	40	40	40	40
Residual value of investment									7,312
Financing	51,185								
2. Output	74,658	14,923	13,052	25,464	24,696	23,928	23,16	9,979	8,105
Bagasse/trash costs		2,992	2,992	2,992	2,992	2,992	2,992	2,992	2,992
Chemicals		836	836	836	836	836	836	836	836
Labor		453	453	453	453	453	453	453	453
Maintenance		820	820	820	820	820	820	820	820
Investment costs	73,122								
Working capital		1,874							-1,874
Financing amortization				12,796	12,796	12,796	12,796		
Expense interest	1,536	3,072	3,072	2,688	1,924	1,152	384		
Depreciation		4,875	4,875	4,875	4,875	4,875	4,875	4,875	4,875
3. Profit before taxes	-23,473	3,078	3,075	3,459	4,227	4,995	5,763	6,147	6,147
4. Income tax		1,077	1,076	1,211	1,479	1,748	2,017	2,151	2,151
5. Net profit	-23,473	2,001	1,999	2,248	2,748	3,247	3,746	3,996	3,996
6. Cash flow	-23,473	5,001	6,873	-5,673	-5,174	-4,675	-4,176	8,870	18,056

17.9. Minimum energy sale prices

With the cash flows calculated as shown in Table 97 and the economic concept presented before it was possible to calculate the minimum energy sale prices (**Table 98**). The minimum energy sale price corresponds to zero Net Present Value (NPV) from the three alternative cash flows.

It is known that the sale prices in Table 98 can be reduced; the factors that can contribute to the reduction of these values are:

a) Reduction of the trash cost in the agronomic routes analyzed;
b) Reduction of the total investment cost in the BIG-GT plant;
c) Increase financing period for both the amortization and grace period;
d) Reduction of income tax on net profit.

The participation of each item in the determination of the energy minimum sale price can be visualized in **Table 99**.

17.10. Sensitivity analysis

Analysis of the data in Table 99, clearly shows that the item with the largest participation in the minimum energy sale price is the investment in the BIG-GT plant (50%), which value of US$ 61 millions (83.4% of total investment cost) was provided by TPS. Therefore, a sensitivity analysis changing the investment in the BIG-GT plant was made (**Table 100**).

Table 98

Minimum energy sale prices (US$/MWh, without taxes).

Financing	Alternative 1	Alternative 2	Alternative 3
Yes	75.04	80.56	73.99
No	89.88	95.40	88.62

Table 99

Detailing of minimum energy sale prices (%).

Item	Alter-native 1	Alter-native 2	Alter-native 3
Bagasse/trash	12.8	19.0	10.2
Chemicals	5.7	5.3	5.8
Labor	3.2	2.9	3.1
Maintenance	5.7	5.2	5.7
Investment[(1)]	51.5	48.0	52.2
Working capital	1.1	1.2	1.1
Expense interest	10.7	10.0	10.8
Income tax	11.3	10.6	11.4
Trash sales	-2.0	-2.2	-0.3
Total	**100.0**	**100.0**	**100.0**

(1) Includes own capital and financing, except the interest expenses.

Table 100

Sensitivity analysis of the investment cost in the BIG-GT plant.

Minimum electricity sale price (US$/MWh)				
BIG-GT	Investment US$/kW	Alternative 1	Alternative 2	Alternative 3
61.0	2,031[(a)]	75.04	80.56	73.99
56.3	1,900	71.22	76.73	70.17
52.7	1,800	68.30	73.81	67.26
49.1	1,700	65.39	70.90	64.34
45.5	1,600	62.47	67.98	61.43
41.9	1,500	59.56	65.06	58.51
38.3	1,400	56.64	62.15	55.60
34.7	1,300	53.73	59.23	52.68
31.1	1,200	50.81	56.31	49.77
27.5	1,100	46.85	53.39	47.90
23.9	1,000	44.98	50.48	43.94

(a) Total investment in the power generating plant is US$ 73.12 millions and the corresponding installed capacity is 36 MW. This figure includes the investment costs in the BIG-GT plant, auxiliary systems and in process steam reduction in the mill (Table 54). The maintenance costs are also adjusted.

Note: The investment cost in the mill and auxiliary systems are assumed constant as they refer to fully mature technologies.

Analysis of data shows that each reduction in the investment cost of the BIG-GT plant of US$100/kW installed causes a decrease in the energy minimum sale prices around US$ 2.90/MWh.

The analysis of the results shows that when the specific investment costs reaches the US$1000/kW installed levels the minimum electricity sales price drops to around US$ 44/MWh for the best alternative. Further improvements in BIG-GT plant efficiencies, trash recovery and other operating costs mill will certainly bring this energy sales price to the US$ 40/MWh area which is the value that the Brazilian Power utilities claim to be the minimum price to make natural gas fired plants economically viable.

The conventional cogeneration facilities specific investment cost (high pressure bagasse fired boilers/condensing – extraction turbine), for whole year operation, is around US$ 1,500/kW installed (plants in Mauritius, Reunion and Guadalupe, operating with bagasse during the season and with coal in the off-season); this figures compares well with the higher costs of the analyzed BIG-GT option which is an emergent technology (US$ 2,500-2,000/kW installed).

Work development in collaboration with the Center for Energy and Environment Studies of the Princeton University suggests that BIG-GT technology can be expected to reach the US$ 1,400/kW installed mark when the commercial maturity is achieved (Larson, E.D. et alli, "A review of biomass integrated – gasifier/ gas turbine combined cycle technology and its application in sugar cane industries, with an analysis for Cuba", Energy for Sustainable Development, Vol. V, no 1, March 2001).

It is important to point out that recent projects for conventional cogeneration facilities in sugar/ethanol mills in the state of São Paulo have indicated total investment costs below US$ 500/kW installed (US$ 420-480/kW range), utilizing high pressure boilers and backpressure turbines for operation only during the season. It is estimated that this type of plant (30 MW range) for year round operation using condensing – extraction turbine, with cooling water system based on cooling towers would cost no more than US$ 700/ kW installed, with all equipment built in Brazil. Therefore, it is reasonable to expect that, if the BIG-GT plant is built in Brazil (except for the gas turbine), it could have a total investment cost in the order of US$ 1,000/ kW installed (considering that the gas turbine for low calorific value gas has reached commercial maturity) in the medium term (N-th plant) and between US$ 1,500 – 1,800/kW installed for the first plant.

This type of reasoning encourages one to believe that the BIG-GT technology integrated with Brazilian sugar/ ethanol mills can become competitive against natural gas fired combine cycle thermal power plants, if it is given the opportunity to reach the technical and commercial maturity by building a certain number of plants (6 to 8 units) to progress in the learning curve as explained in the referenced paper (Larson, 2001).

18. Impacts on the atmosphere

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18.1. Introduction

The production of sugar and ethanol from sugar cane, a highly energy intensive process, has a peculiarity that makes the activity nearly CO_2 neutral – the fuel required to supply the energy (thermal and electro-mechanical) demand of the cane processing industry comes in the cane, as fiber, that becomes bagasse after juice extraction. In reality, the energy balance could go well beyond the self-sufficiency since each ton of cane stalks bears around 145 kg of sugar and 140 kg of fiber and it has another 140 kg of associated fibers in the leaves and tops. The sugars are recovered and the stalks provide the fuel for the industrial plant while the trash is totally lost today – either burned or left on the ground to decompose. Stopping burning cane before the harvesting will improve the local environmental conditions but will bring no global benefits since the trash left on the ground to decompose will release the carbon, in the form of CO_2, back to the atmosphere.

The aim of this work is to estimate the global impacts of recovering this trash, even if in a partial fashion, and use it as fuel in advanced power generating systems, displacing fossil fuels in this process. The objective was to evaluate changes in green house gases (GHG) and particulates emissions due to the large scale adoption of unburned cane harvesting practice with trash recovery and the use of bagasse and trash in BIG-GT systems to generate surplus power in the Brazilian sugar/ethanol mills.

The GHG considered, after a preliminary analysis, were CO_2, methane, NO_x and N_2O.

18.2. Procedure

18.2.1. Baseline and future situation in the mills

The impacts quantified here were not restricted to cane fields; all changes required for the introduction of BIG-GT systems were quantified in the form of differences in fossil fuels and chemical uses, equipment required, volume of biomass fuel available and avoided emissions due to the displacement of fossil fuels in power generation.

Although reasonably accurate figures for the main parameters were obtained in field tests and in simulations considering the typical mill as reference, some adjustments and simplification have been made to extend the estimate to all mills in the country (more than 330 units).

They are reflected in the summaries of "situation today" and "future mill situation", as follows.

18.2.2. Mill situation today

• Burned cane harvesting	100% (actually it is less than 90%)
• Trash in cane (dry matter)	0.140 t/TC*, not used[(a)]
• Surplus bagasse (average)	8%
• Electric power production (average)	11.7kWh/TC (self sufficiency)
• Mechanical power production (average)	20 hph/TC (self sufficiency)
• Boiler efficiency (average)	78.7%[(b)]
• Process steam consumption (average)	500 kg/TC
• Surplus power supplied to the grid	0

* TC= tons of cane

(a) All trash that is burned or decayed will have the carbon released as CO_2; the trash taken along with the stalks to the mill will be converted to bagasse. Trash burned in the field also releases CH_4, NO_x and N_2O.

(b) Average for 147 bagasse fired boilers with different types of burning system and heat recovery equipment (1997).

18.2.3. Future mill situation

Unburned cane harvesting: Area equivalent to 100% in São Paulo State and 50% in the rest of Brazil.

This is a "very long term" situation, but it is used to estimate a "limit" for technology implementation. Another assumption, is that all the trash recovered is used (with the corresponding bagasse) in mills with fully implemented BIG-GT systems; and for the areas still burning sugar cane (50% of the area outside São Paulo State) the co-generation systems are conventional (no BIG-GT systems), represented by the "mill situation today" parameters.

Then, for the processing of 315 million tons of cane per year (190 million in São Paulo), 250 million tons of cane per year will be processed with fully implemented BIG-GT systems, and 65 million by the conventional way.

For the mills with BIG-GT systems the parameters are based on previous study reported as the case "pure BIG-GT" - for Brazil (Larson, E; Williams, R.; Leal, M.R.L; "A review of biomass integrated gasifier/ gas turbine combined cycle technology and its application in sugar cane industries, with an analysis for Cuba, "Energy for Sustainable Development", Vol. V., no 1, March 2001).

• Cane crushing per day	7000 t cane
• Milling period	214 days/year
• Total cane per year	1.3 million tons
• Capacity factor	87%
• Power generation	All year

Two BIG-GT modules, each one with modified GE LM 2500 gas turbine

• Available trash (dry matter) prior to harvesting	0.140 t/TC
• Recovered trash (dry matter)	
- Baling route	0.09 t/TC (used in pure BIG-GT: 0.10)
- Partial cleaning route	0.07 t/TC
• Electric and mechanical power consumption in the industry in season (supplied by bagasse/trash)	29 kWh/TC
• Process steam consumption (supplied by bagasse/trash)	280 kg/TC
• Surplus power supplied to the grid (193 season; 185 off-season)	378 GWh 291 kWh/TC

Note: TC= tons of cane

18.3. Impacts due to substitutions of fossil fuels by sugar cane biomass in power generation

The baseline for power generation in Brazil is still a matter of debate due to the uncertainties that haunt the power sector: price of natural gas, exchange rate of R$/US$, regulation of Law No10.438 (that reserves 1100 MW for biomass derived power, in the short term) and others.

Considering that:

- Hydropower will continue to be the major source of electric energy;
- Thermal power generation will be stimulated to provide a greater safety margin against power shortage in drier years, making up around 20% of total power generation;
- Natural gas will be the main fuel for the thermal power plants;
- Renewable energy will receive legal and other incentives, such as Law No 10.438, to gain a significant market share;
- Both gas fired and biomass fired power plants can be built near consumption centers (distributed power) and in small to medium sizes, economically.

It will be assumed that bagasse and trash fueled generation will be an important portion of the thermal generation needed; and it will be substituting for (actually, avoiding further increase of) natural gas thermal-power generation.

Then the surplus power generated with bagasse and trash will participate in the CO_2 – equivalent emission balance in the following ways:

1) Increasing CO_2 emission due to fossil fuel additional uses (direct and indirect) in agriculture and industry, for the recovery/utilization of the biomass.
2) Decreasing N_2O and methane emissions from burning trash in the fields (corresponding to the fraction of unburned trash).
3) Decreasing (avoiding) CO_2 emissions from natural gas power stations, due to the production of surplus electricity.

A summary is presented in **Table 101**.

Table 101

(CO_2 equivalent) Emissions for future situation (100% BIG-GT) compared to "mill situation today".

	Today	Future (100% BIG-GT)	Difference	Additional kg CO_2/TC
1. Fossil fuel utilization in agriculture	48,208 kcal/TC[a]	54,434 kcal/TC[a]	6,226 kcal/TC	+1.9[b]
2. Fossil fuel utilization in industry – conventional systems	10,790 kcal/TC[c]	10,790 kcal/TC[c]	-	-
3. Additional fossil fuel utilization in industry:BIG-GT installations	-	4,120 kcal/TC[d]	4,120 kcal/TC	+1.3
4. Additional emissions associated with supplies to BIG-GT plants	-	[e]	+3.3kg CO_2/TC	+3.3
5. Other GHG emission in trash burning in field[f]				
Methane (kg/TC)	0.35		0.35	-7.35[g]
N_2O (kg/TC)	0.015	-	0.015	-4.65
6. Surplus electric energy produced with the BIG-GT systems	-	291 kWh/TC	291kWh/TC	- 146[h]
Total				**-151.5**

Note: TC= tons of cane

(a) See Table 102;

(b) Fossil fuel (Diesel oil): 0.305 kg CO2/Mcal (life cycle);

(c) Table 103;

(d) Table 104;

(e)See : "Use of energy";

(f) See Table 106; IPCC parameters;

(g)Taking into account the (GWP)100, in both cases;

(h)Electric power: compared to emissions of combined cycle – natural gas, "future": 502 g CO (equiv.) / kWh.

18.3.1. Estimates of avoided emissions of GHG (in CO_2 – equiv.)

The hypothesis of 250 million tons of cane per year processed entirely without trash burning in field and with maximum use of advanced BIG-GT technology ("pure BIG-GT") will then lead to:

250×10^6 TC x (0.151) t CO_2 (equiv.)/TC = 37.7×10^6 t CO_2 (equiv.)

Even if only half of the cane area was processed in this way, with full BIG-GT technology, the savings in emissions would be ~24×10^6 t CO_2 (equiv.)/year.

18.3.2. Emission of particulates

The difference in particulate emission will be the reduction of 3.05 kg particulate/TC in areas where BIG-GT technology is implanted, with no burning of trash in field. For the first hypothesis (250 millions t cane/year with the new technology) this will result in:

250×10^6 TC x (3.05 kg particulate/TC) = 760,000 t particulate.

18.4. Use of energy

Use of energy in the production of cane, sugar and ethanol and green house gas emissions: Present situation (2002) and future situations (Cogeneration with BIG-GT).

18.4.1. Introduction

This work is a summary of a detailed study done by Copersucar Technology Center (CTC) for a life cycle analysis of the sugar cane industry including both agricultural and factory operations.

The real data obtained from selected mills were adapted based on CTC experience to reflect the average present and future conditions, such as the assumed baseline (without use of BIG-GT technology) and the challenging alternative that considers the introduction of BIG-GT technology in the mills cogeneration system.

Table 102

Energy consumption in cane production and processing.

Level	Item	Energy consumption (kcal/TC) Scen. 1[a]	Scen. 2[b]	Ref.[c]	Fut.[d]
1	**Fuels**				
	Agricultural operation	9,097	9,097	14,039	15,705
	Transportation	10,261	8,720	8,720	8,743
	Subtotal	19,358	17,817	22,759	24,448
2	**Fertilizers**	**15,890**	**15,152**	**12,785**	**15,152**
	Lime	1,706	1,706	1,706	1,706
	Herbicides	2,690	2,690	1,345	2,690
	Insecticides	190	190	190	190
	Seeds	1,404	1,336	1,399	1,585
	Subtotal	21,880	21,074	17,425	21,323
3	**Equipment**	**6,970**	**6,970**	**7,856**	**8,663**
	Subtotal	6,970	6,970	7,856	8,663
	Total	**48,208**	**45,861**	**48,040**	**54,434**

(a) Scenario 1: present situation (100% burned cane, hand harvested) – average mill conditions.
(b) Scenario 2: present situation (100% burned cane, hand harvested) – best practice.
(c) Reference situation: 100% mechanically harvested unburned cane without trash recovery.
(d) Future situation: 100% mechanically harvested unburned cane with trash recovery.

18.4.2. Objective

To quantify the use of fossil fuels in the sugar cane agro industry and the energy generation from de sugar cane biomass, aiming the assessment of GHG net production in the system.

18.4.3. Methodology

Three levels of energy consumption were considered, reflecting different degrees of details in energy analysis, to facilitate the comparison with other studies.

Level 1 – Only the direct fuel and external electricity uses are considered.
Level 2 – The energy used in the production of chemicals, lubricants, lime, etc. is added.
Level 3 – The energy required for the production and maintenance of equipments and buildings is also considered.

Three situations are considered in the life cycle analysis:

Present situation: 100% of hand cut, burned cane (in reality is less than 90%), 8% surplus bagasse and no energy sold to the grid. Two scenarios are considered: one reflecting the average mill conditions (Scenario 1) and the other assuming the "best practice" values (Scenario 2).

Reference situation: 100% mechanically harvested unburned cane with trash left in the field (no trash recovery).

Future situation: 100% mechanically harvested unburned cane with trash recovery by baling.

The summary of the energy balance for these three situations is presented in **Table 102** for the agricultural sector (planting, harvesting, fertilizing, transportation, etc.).

The energy consumption in cane processing in the industry is presented in **Table 103**, for the three levels considered. The differences in processing the cane in the three alternatives mentioned above are negligible and will not be considered in this study.

It is important to point out that there is a surplus of bagasse, that will be considered in the global analysis, corresponding to 41,900 kcal/TC (Scenario 1) or 78,600 kcal/TC (Scenario 2).

Table 103

Energy consumption in the production of sugar and ethanol from sugar cane – Present situation.

Level	Item	Scenario 1 (kcal/TC)	Scenario 2 (kcal/TC)
1	Electric energy	0	0
2	Chemicals and lubricants	1,520	1,520
3	Buildings	2,580	1,930
	Heavy equipment	3,130	2,350
	Light equipment	3,560	2,670
	Total	**10,790**	**8,470**

The energy consumption shown in Table 103 considered the following data:

- Pol cane 14.2%
- Anhydrous ethanol production:
  Scenario 1 85.4 L/TC
  Scenario 2 87.5 L/TC
- Electric generation/consumption 11.76 kWh/TC
- Mechanical energy generation/consumption 20 hph/TC
- Surplus bagasse:
  Scenario 1 8%
  Scenario 2 15%

The implementation, in the future, of power generation systems of BIG-GT technology will imply in the addition of several equipment (gasifier, gas and steam turbines, condenser, cooling water system, compressors, substation, heat recovery steam generator, auxiliary systems), and associated buildings that will require energy use for their fabrication, erection and maintenance as well as in their operation. The energy consumptions for these additional equipments in a typical mill are listed in **Table 104**.

The main chemicals used by the BIG-GT unit (one module) and auxiliary systems are sulfuric acid (800 t/year), sodium hydroxide (350 t/year), dolomite (4,500 t/year), lubricants (4 t/year), iron chloride (5 t/year) and activated charcoal (4 t/year). The energy consumed in the fabrication and transport of these products, in the quantities listed above, is very small and has been neglected in the energy balance. For GHG emissions only dolomite deserves to be included in the balance and it is estimated to be 477 kg CO_2/t dolomite, which results in 3.3 kg CO_2/t cane for the two BIG-GT modules considered.

Table 104

Energy consumption in the additional systems with the BIG-GT cogeneration alternative.

Level Item	Energy consumption (kcal/TC)[(a) (b)]
Buildings	480
Heavy equipment	2,500
Light equipment	1,140
Total	**4,120**

(a) Level 1 energy consumption is not included here because it has already been taken into account in the calculation of the net surplus energy production.

(b) Level 2 energy consumption has been calculated and considered negligible (the GHG emissions are considered in the emissions balance).

Table 105

Comparison of gas emissions from agricultural residues burning in US EPA Report AP-42 and measured in Wind Tunnel Tests (UCD).

Gas	Average wind tunnel tests* (g/kg dry matter)	US EPA AP-42 (g/kg dry matter)
CO	25.48	30 - 41
NO	0.66	-
Nox	1.40	-
SO_2	0.62	-
THC (as methane)	2.25	2.6 - 8
Methane	0.41	0.6 - 2
NMHC (as methane)	1.84	2 - 6
CO_2	10.46	-

*Jenkins, B.M. - "Atmospheric pollutant emission factor from open burning of sugar cane by wind tunnel simulation – Final Report". University of California, Davis, 1994.

18.5. Emissions of methane and other green house gases: Impact of future situation

18.5.1. Introduction

The impacts of the adoption of the new technology considered in the future situation (unburned cane mechanically harvested with trash recovery) in the emissions of methane, NOx, CO or N2O (CO_2 emissions are estimated based on the energy balances presented in the previous sections). The particulate emission changes are also evaluated due to their importance to the local pollution levels.

18.5.2. GHG Emission in the agricultural area: Future situation

It is in the agricultural area that the differences are really significant, between the present and future situations, especially due to the phase out of cane burning before harvest. The use of BIG-GT systems may result in changes in CO and NOx emissions in relation to the existing bagasse fired boilers but the impacts are considered to be small. In the same fashion, the methanization of a small fraction of the trash left in the field is also assumed to be negligible compared to the other effects.

Table 106

GHG emissions reduction.

	Gas			
	Methane	CO	NOx	N_2O
	T burned trash/TC (Future – Present)			
	-0.125	-0.125	-0.125	-0.125
	Emission factor (kg gas/t burned trash)			
IPCC	2.83	59.5	4.37	0.12
Wind tunnel	0.41	25.48	1.40	
	Impact on emissions (kg gas/TC)			
IPCC	-0.35	-7.44	-0.55	-0.015
Wind tunnel	-0.05	-3.19	-0.18	

TC= tons of cane

The N_2O emissions from the soil were calculated but the changes between the present and future situations are not important enough to be considered in the GHG balance differences.

The present situation, considering 100% of the cane harvested burned that corresponds to the burning of 0.125t of residues (dry basis)/TC (90% of total trash), is compared with the future situation where no residue burning will take place in cane fields.

Two sets of data were considered in the emission estimation: US EPA data and wind tunnel tests performed by the University of California at Davis (**Table 105**).

In **Table 106** the wind tunnel values are compared with those suggested by IPCC (1996).

To convert the above values to CO_2 equivalent emissions the IPCC (1995) indices are used:

- Methane (GWP) (100 years) = 21
- N_2O (GWP) (100 years) = 310

18.6. Particle emissions

18.6.1. Objective

To evaluate the changes in particulate emissions to the atmosphere due to introduction of mechanical harvesting of unburned cane and the use of the sugar cane biomass (bagasse and trash) in BIG-GT systems, reducing bagasse burning in steam boilers.

18.6.2. Methodology

Present and future situations are compared with respect to particulate emission in the energy generation system and in the field, in the harvesting process.

Table 107

Results of particulate emissions from trash burning in wind tunnel and US EPA AP-2 emissions factors (dry basis).

Particulate matter	Wind tunnel (g/kg)	US EPA AP-42 (g/kg)
PM (total)	5.6	2.5 - 3.5
PM 10	5.4	-
PM 2.5	5.0	-
MMAD (mm)	0.2	Submicron

Table 108

Particulate emissions from bagasse fired boilers.

Furnace type	Emissions (mg/Nm^3)
Dumping grate without secondary air	5 000
Dumping grate with secondary air	4 000
Pit furnace	6 000
Chimney scrubber	600
External scrubber (Copersucar type)	140

18.6.3. Present situation

The environmental regulations limiting particulate emissions from bagasse fired boilers vary from one country to another; in Brazil they also vary from one state to the other. The mills are located in rural areas and are not, normally, subjected to pressure from the environmental regulations enforcement.

Today practically all bagasse produced in cane milling is used in boilers to generate steam in the mills and in other industries (surplus bagasse).

Also, it is considered that all cane is burned before harvest, with the corresponding gases and particulate emissions.

For mills operating with conventional cogeneration systems it was considered that in the future it will be required the use of chimney scrubbers that will bring the particulate emissions to the 600 mg/Nm^3 level.

18.6.4. Basis for the present situation and future situation

The best estimates for trash burning emissions were based in two studies:

- US EPA report AP-42
- Emissions from trash burning in wind tunnel at the University of California at Davis

The data are shown in **Table 107**.

The wind tunnel values exceeded those of EPA AP-2; in this study it will be used PM (total) = 5.6 g/kg, that is more recent and specific for trash.

For bagasse/trash fired boilers emissions, a survey in 174 boilers at Copersucar mills has been used to estimate the present situation. **Table 108** shows average particulate emissions values for each furnace technology used.

The weighted average (capacity) of the 174 boilers surveyed is 4.57 kg PM/t steam or 2.35 kg PM/TC.

Present situation: 100% burned cane harvesting

Using the datum from **Table 107** for PM (total), with 0.125 t trash /TC (dry basis) it will result in 0.70 kg PM/TC and the bagasse burning in boilers emits 2.35 kg PM/TC or a total of 3.05 kg PM/TC.

Future situation: 100% unburned cane harvesting

The unburned cane fields and BIG-GT systems would have negligible particulate emissions.

Summary of particulate emissions:

• Present situation 3.05 kg PM/TC
• Future situation Zero
(100% unburned cane, BIG-GT cogeneration)

19. Impacts on soil

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19.1. Soil conservation - Nutrient recycling - Agricultural and industrial residues

19.1.1. Introduction

Today, more than 80% of sugar cane fields in the country are burned before harvesting. Due to environmental laws, several mills started harvesting unburned cane in some areas and we can foresee, in the future, the majority of areas will be harvested unburned, leaving large amounts of residue in the field.

The use of BIG-GT systems to generate energy at the mill will demand large amounts of biomass. Besides bagasse, the use of harvesting residues will be a must, with partial or total removal of trash from the field.

Leaving trash in the field has several benefits and problems. Since we will be moving to a future situation of leaving trash in the field or removing it after harvesting, it will be important to know the gains and losses of this trash removal operation regarding to soil impacts.

19.1.2. Soil conservation

In areas where harvesting residues are burned or buried during soil preparation, the unprotected soil will be exposed to the impact of the raindrops which is the first and most important stage in the water erosion process.

This process leads to 'interril erosion' (meaning both movements by rain splash and transport of raindrop-detached soil by thin surface flow), 'rill erosion' and 'gully erosion'. In 'interril erosion' soil losses are almost imperceptible, while rill and gully erosion detach soil layers with organic and mineral resources, carrying the most biologically active soil, that can lead to great yield losses. The water that washes the soil surface is not stored and, therefore, will not be available for the crop during the dry season, causing more crop yield reduction in this area.

Figure 96

Sugar cane lines "crossing".

The conservationist system normally practiced in sugar cane crops uses mechanical protection to reduce water erosion by means of earthworks, generally called terraces, properly positioned in the area. Since there is no parallelism between these terraces, and they are used as guides for furrowing during plantation, sugar cane lines will cross in some points inside the field (**Figure 96**). This causes a lot of machine maneuvering during field operations, since they have to follow the sugar cane lines. Even though they are efficient in erosion control, terraces are detrimental to machine performance.

Studies show that the best and most effective way of avoiding water erosion in arable land is to prevent its beginning, using control measures to avoid raindrop impact on bare soil.

A conservationist system was developed gathering soil preparation and vegetation cover to suit sugar cane mechanical harvesting operations, reducing the cost and improving the quality of the operation when compared to the conventional system. A set of techniques are recommended to keep the soil covered with organic matter (mulch) protecting it from weather agents, especially during crop renovation and planting.

The adoption of land preparation systems where a minimum of mechanized operations is performed with efficacy and at the right time can reduce erosion risks. Furthermore, it allows elimination of terraces up to a given slope, allowing improvement on planning of planting lines, increasing productivity and reducing production costs due to reduction in the number and intensity of field operations during land preparation period. The conservationist system can reduce in about 30% the soil tillage operation in unburned sugar cane areas when compared to the conventional soil preparation using harrow and subsoiler.

Using this system, terraces and other mechanical protection were eliminated, keeping good water erosion control in areas with up to 6% slope (**Figure 97**). This allows better planning of fields with reduction of internal roads, increasing the sugar cane planted area.

19.2. Nutrient recycling

In sugar cane areas harvested without burning, the soil is covered with residues (trash), composed of dry leaves, green leaves, tops and wasted stalks. The mineral components of this material are basically recognized as nitrogen, phosphorus, potassium, calcium, magnesium and sulfur.

Chemical analysis and quantification have been performed in the trash that remained on the soil after harvesting of four sugar cane varieties, SP80-185, SP79-2233, SP79-1011 and RB785148 (**Table 109**). The percentage of each nutrient is an average of the different varieties and the amount per hectare was determined using the average residue per hectare (**Table 110**).

These nutrients are made available to the crop by the action of soil microorganisms, through a process called mineralization. Trash mineralization is dependent on environment factors such as temperature, water and oxygen availability, and also on the chemical composition, especially the carbon/nitrogen ratio (C/N), lignin, cellulose, hemicellulose and polyphenols content.

Crop residues that present nitrogen (N) content up to 18 g/kg and C/N ratio higher than 20, have low mineralization ratio. Since sugar cane trash has an average of 4.6 to 6.5 g/kg of nitrogen and C/N ratio greater than 60, it presents low net mineralization of the nitrogen during one year interval.

Field experiments were carried out to analyze the mineralization ratio of the residue left in the field. In one of them the trash was analyzed after harvesting, and then analyzed again one year later; another experiment used the technique of traced nitrogen (15N), marking the trash left on the soil and the urea applied in the experiment.

Figure 97

600 m length downhill straight sugar cane lines.

Table 109

Average quantities of trash (dry leaves, green leaves and tops) left in the field after unburned chopped cane harvesting, of four different varieties (18 months plant cane).

Mill (variety)	Dry leaves	Green leaves	Tops	Total
	--------------- t dry matter/ha			----------------------
S. Martinho (SP80-185)	14.0	1.3	0.3	15.6
S. Francisco (SP79-1011)	11.4	1.9	0.3	13.6
Santa Luiza (SP79-2233)	13.6	1.2	0.2	15.0
Da Pedra (RB785148)	8.2	1.7	0.5	10.4
Average	**11.8**	**1.6**	**0.3**	**13.7**

Table 110

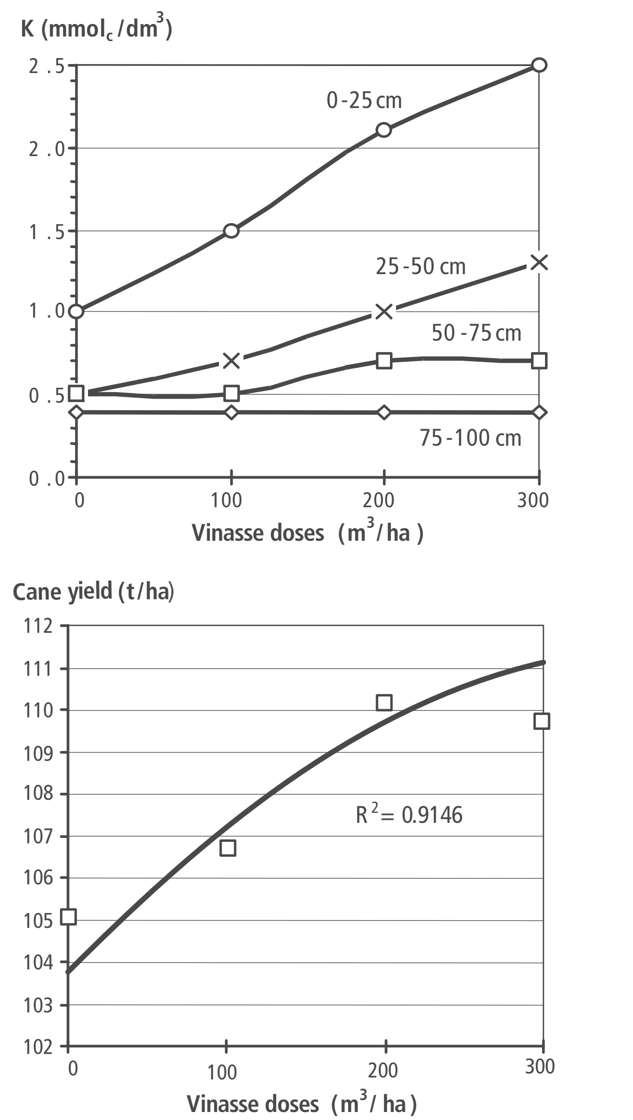
Nutrient concentration of sugar cane trash - Average of four varieties.

Material / Nutrients	N	P	K	Ca	Mg	S
			% of dry matter			
Dry leaves	0.32	0.02	0.34	0.42	0.19	0.11
Green leaves	0.99	0.11	1.69	0.31	0.17	0.11
Tops	0.49	0.09	3.00	0.17	0.15	0.12
			kg/ha			
Dry leaves	37.7	2.4	40.1	49.5	22.4	13.0
Green leaves	15.4	1.7	26.4	4.8	2.6	1.7
Tops	1.6	0.3	9.6	0.6	0.5	0.4
Total	**54.7**	**4.4**	**76.1**	**54.9**	**25.5**	**15.1**

Figure 98

Vinasse application on the experiment area.

Figure 99



Variation in soil potassium content as a function of vinasse dose at different soil depths, and the effect on sugar cane yield.

The results showed low decomposition of sugar cane trash from one year to another. After one year the trash left in the field presented mass reduction of around 20%, mostly due to decarboxylization of the cellular contents and of the hemicellulose. Nitrogen mineralization rate was 18% and the liberation of the nutrients in the trash was greater for potassium, 85%. The plant extracted only 8% of the mineralized nitrogen.

With addition of organic matter to the soil, microorganisms' action might determine the mineralization of the nitrogen or the immobilization of this nutrient, which is held in the microbial biomass. Both processes take place at the same time, and the amount of nitrogen in the material under decomposition is what will greatly determine which one will prevail. It has been verified that crop residues (trash) left in the field, with the C/N ratio greater than 20, cause immobilization of the nitrogen, being detrimental to sugar cane development, specially in the stage of stalk formation and growth, since at this phase the crop requires high amounts of nitrogen. An acceleration of the mineralization is expected with the addition of nitrogen to the trash.

19.3. Agricultural and factory residues

Among several agricultural and industrial residues, the two major ones are vinasse and filter cake.

Vinasse is a residue of ethanol production and it is produced at an average ratio of 13 liters for each liter of alcohol. Its chemical composition varies according to sugar cane variety and several other factory process factors, but potassium (K_2O) is the most significant element. Sugar cane field irrigation with vinasse is a widespread practice in Brazil. Many studies have already been carried out regarding this practice, and it is common sense that it is technically and economically a viable operation.

The experiments carried out (**Figure 98**) show the variation of soil potassium content as a function of vinasse dose at different soil depths, and the effect on sugar cane yield (**Figure 99**).

Vinasse application on experimental areas with trash and without trash on the soil did not show significant differences in soil potassium content, neither in cane yield.

Filter cake is a residue from sugar and ethanol production, and it is produced at an average of 35 kg per ton of milled cane. It is usually returned to the field and applied in furrows during planting operation, or spread in the field. Chemical composition of filter cake presents high organic matter content and several nutrients such as nitrogen (average carbon to nitrogen ratio of 37), calcium and especially phosphorus (P_2O_5). Several studies indicate gains in sugar cane production with this practice, especially applying composted filter cake (carbon to nitrogen ratio less than 17) in the planting furrows.

During the project, an experiment was set up with the application of filter cake and fertilizer in the furrow before planting of variety SP80-1842, to determine the effect of filter cake on sugar cane yield.

The results indicate an increase in yield of approximately 10%, due to filter cake addition (**Table 111**). The amount of phosphorous was reduced in the fertilizer recommendation table according to the amount of filter cake applied. The values for pol % cane and pol per hectare were also increased. It is important to point out that these benefits can be obtained either in areas with trash left on the soil, or in areas without trash.

Table 111

Sugar cane yield (t/ha), pol cane and tons of pol per hectare (TPH) for the different treatments.

Treatment	Filter cake t dry matter/ha	Mineral fertilization kg of N-P_2O_5-K_2O/ha	Cane yield t/ha	Pol cane	TPH
T1	0	30-120-140[(a)]	91	14,4	13,1
T2	7	30-80-140	101	15,0	15,2
T3	14	30-40-140	96	15,0	14,5
T4	21	30-00-140	101	15,1	15,3

(a) Recommended mineral fertilization.

19.4. Soil physical properties

19.4.1. Introduction

The intensification on the use of mechanized field operations, such as soil preparation, planting, harvesting and transportation of sugar cane, has changed the soil physical properties. Characteristics such as soil density, structure, porosity, infiltration and water storage have undergone significant changes. Quantification of these changes has been little studied.

In sugar cane fields harvested unburned, water infiltration occurs basically in the rows of cane, while in the inter-row water infiltration is quite low. Cheong, L. R. N. et al. (Soil compaction due to mechanized harvesting and loading. In: ISSCT, 33, New Delhi, Índia, 1999. p.43-50), studying soil changes, concluded that there is no difference in soil water infiltration in areas harvested fully mechanized or partially mechanized. In both cases water infiltration is six times lower than in areas harvested by hand and with no transport traffic. Primavesi, A. & Primavesi, A.M. (Factors responsible for low yields of sugar cane in old cultivated terra roxa estruturada soils in eastern Brazil. Soil Science Soc. of America, 28, 1964.p.579-580) found out, comparing two similar fields, that the reduction in soil water infiltration through several years lead to sugar cane yield reduction. Gawander, J. S. et al. (Long term study of changes in the properties of a fijian oxisol following sugar cane cultivation. ISSCT, 33, New Delhi, Índia, 1999. p.61-69) concluded that changes in soil physical properties due to different field management are directly related to the amount of organic matter incorporated to the soil.

19.4.2. Objective

To study changes in soil physical properties, through soil water infiltration, in the row and inter-row of sugar cane fields harvested burned and without burning.

19.4.3. Methodology

Tests were set up at Usina São Martinho in soil Red Latosol clay texture dystrophic - LR-2 with variety SP80-185 in the city of Pradópolis, State of São Paulo. The experiment was carried out after the 3rd cut (2nd ratoon), in five plots, in areas harvested burned and without burning in all three cuts.

Harvesting of the experiment was performed with a chopped cane harvester equipped with tracks and the cane was transported in an instrumented truck equipped for cane weighing. The truck is fitted with high flotation tires.

The double rings method was employed for water soil infiltration determination, using the bigger ring of 500 mm diameter and the smaller of 350 mm, with five repetitions in the row of cane and five repetitions in the inter-row for each plot. After setting the rings and filling them up with water to a 30 mm height, water consumption readings were carried out after 15, 30, 60, 120,180, 240, 300 and 360 minutes.

Table 112

Water infiltration rate in the row of sugar cane plots harvested burned.

Time	Infiltration rate (mm/h)			Accumulated infiltration (mm)		
(min)	Av.	Min.	Max.	Av.	Min.	Max.
15	179	93	325	45	23	81
30	157	74	314	84	42	160
60	147	68	296	157	76	308
120	138	62	280	295	138	588
180	126	84	218	421	222	806
240	113	81	185	534	304	991
300	105	81	163	639	384	1154
360	103	78	160	742	463	1314

Av. = average; Min. = minimum; Max. = maximum

Table 113

Water infiltration rate in the inter-row of sugar cane plots harvested burned.

Time	Infiltration rate (mm/h)			Accumulated infiltration (mm)		
(min)	Av.	Min.	Max.	Av.	Min.	Max.
15	286	79	552	71	20	138
30	233	62	475	130	35	257
60	196	57	354	228	64	434
120	175	52	311	402	115	745
180	166	51	292	569	166	1037
240	150	48	287	718	214	1324
300	136	47	250	854	262	1575
360	131	47	236	985	309	1811

Av. = average; Min. = minimum; Max. = maximum

19.4.4. Results and comments

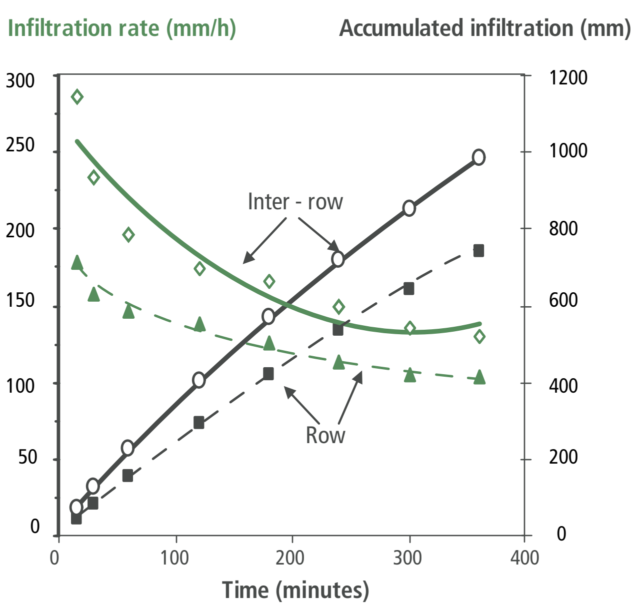
Burned sugar cane

Results indicate that the infiltration rate of the soil is enough to absorb the rainwater. Water infiltration in the row of cane, stabilized after six hours, varied from 78 mm/h to 160 mm/h, with an average of 103 mm/h (**Table 112**). The accumulated infiltration rate in six hours varied between 463 mm and 1314 mm, with an average of 742 mm.

The infiltration rate in the inter-row of the burned cane plots, stabilized after 6 hours of the test, varied from 47 mm/h to 236 mm/h, with an average of 131 mm/h, and the accumulated infiltration in six hours of test, varied from 309 mm to 1811 mm, with an average of 985 mm (**Table 113**).

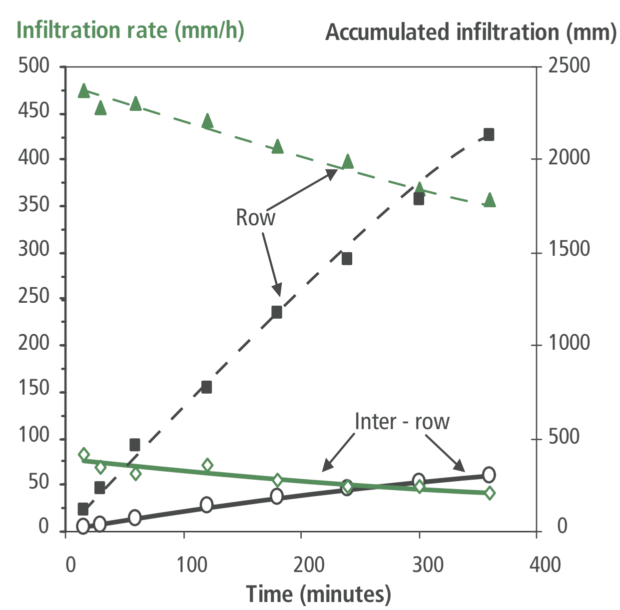
The figures of water infiltration in the inter-row, higher than those in the row are due to the cultivation done in the inter-row of the burned cane plots (**Figure 100**). This cultivation, a normal procedure in sugar cane fields, should

Figure 100



Average water infiltration rate in the row and inter-row for sugar cane field harvested burned.

Figure 101



Average water infiltration rate in the row and inter-row of cane field harvested without burning.

Table 114

Water infiltration rate in the inter-row of the sugar cane plots harvested unburned.

Time (min)	Infiltration rate (mm/h) Av.	Min.	Max.	Accumulated infiltration (mm) Av.	Min.	Max.
15	84	28	144	21	7	36
30	68	17	140	38	11	70
60	63	14	134	68	18	134
120	72	34	113	135	59	226
180	56	26	102	186	86	306
240	48	16	91	225	101	364
300	49	21	82	264	138	407
360	41	18	74	296	158	444

Av. = average; Min. = minimum; Max. = maximum

Table 115

Water infiltration rate in the row of sugar cane plots harvested unburned.

Time (min)	Infiltration rate (mm/h) Av.	Min.	Max.	Accumulated infiltration (mm) Av.	Min.	Max.
15	474	272	1341	119	68	202
30	456	235	1262	233	127	391
60	461	192	1176	463	223	731
120	443	182	1171	768	405	1397
180	415	173	1157	1176	578	2002
240	400	156	1130	1464	734	2623
300	369	145	1140	1790	879	3234
360	356	142	1094	2126	1021	3818

Av. = average; Min. = minimum; Max. = maximum

not have been done for this experiment. To make the comparison of results between burned and unburned cane in the inter-row possible, a new experiment should be performed.

Unburned sugar cane

The water infiltration determination, in the plots harvested unburned, presented large variations between the row and inter-row of the cane field (**Figure 101**). In the inter-row the figures are quite low, varying from 18 mm/h to 74 mm/h, with the average of 41 mm/h stabilized after 6 hours (**Table 114**). The accumulated infiltration in 6 hours of test varied from 158 mm to 444 mm, with an average of 296 mm.

In the row of cane the infiltration rate is high with figures varying from 142 mm/h to 1094 mm/h, with the average of 356 mm/h stabilized after 6 hours (**Table 115**). The accumulated infiltration in six hours test ranged from 1021 mm to 3818 mm, average of 2126 mm.

19.4.5. Conclusion

Even in this short period of the crop under the unburned harvesting system (three crops only) the results of the water infiltration rate showed an impressive positive result.

The reduction of the infiltration rate in the inter-row, compared to the row of sugar cane is caused by the intense traffic during the harvesting and transport of the sugar cane.

Changes in soil physical properties, caused by the mechanized harvesting and transport of sugar cane, reduce water infiltration in the soil, in the row and inter-row of cane. This will imply in a probable reduction in sugar cane yield since the lower water infiltration will likely reduce soil water storage.

The adoption of the unburned harvesting practice, with the trash partially or totally left in the field, can mitigate the effect of mechanization, increasing the water infiltration rates when compared to burned areas.

20. Impacts on terrestrial – biological environment

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20.1. Introduction

Sugar cane is attacked by a large number of insect species that depending on the time of the year and the region can cause serious economic damages; at the same time sugar cane culture can shelter a great number of arthropods and microorganisms that can play an important role on biological control of insects pests or assist in decomposition of organic substances in the soil. Alterations in the environment, as a function of the adopted sugar cane harvesting system will influence development of populations of pests and their natural enemies. The different systems currently used are: mechanized harvest of unburned sugar cane, mechanized harvest of burned sugar cane and manual harvest of burned sugar cane. Thus, it becomes necessary to evaluate populations and damages caused by pests in areas with changes in the harvesting system by comparing entomology parameters.

On the other hand, alterations that occur in the areas where the sugar cane is harvested without burning must also be evaluated, to verify the interference on populations of pests and the necessity of increment in insecticides use to control the main pests of this culture.

Pests present in sugar cane plantations are important due to damage caused to stalks, tillers, leaves, root system, and stalk base, from the establishment of the crop until its renewal, with larger infestations occurring, in general, in older cane.

Infestation by sugar cane borer, *Diatraea saccharalis*, presents variable results independent of the harvesting method. In some cases, large intensity indices were observed in unburned sugar cane areas while in other areas left unburned this did not happen.

The coleopteran insect *Migdolus fryanus* is not directly affected by the harvesting method, since the larvae inhabits the deepest ground layers.

There are five species of leaf-eating caterpillars that attack sugar cane, which in most cases do not require the adoption of control methods. In areas of unburned sugar cane harvesting there will not be any drastic alteration of this situation, and the current recommendation of no insecticide use will remain.

The froghopper, *Mahanarva fimbriolata*, represents a serious problem in areas of unburned sugar cane harvesting, demanding the adoption of control methods. The use of the entomopathogenic fungus, *Metarhizium anisopliae* has presented high control efficiency, at reduced costs, with no negative impacts in the environment.

The control of leaf-cutting ant species, *Atta spp.* and *Acromyrmex spp.*, in areas of unburned sugar cane will be done in the same way as in burned sugar cane, using thermal fogging with the insecticides applied inside the nests.

Figure 102

"Pit-fall" trap used for arthropod evaluation.

Adults of *Sphenophorus levis* beetle will be protected by trash left on the ground in areas of unburned sugar cane harvesting. In areas infested with this pest, larger amounts of insecticide will be used, although there are no efficient products for its control. Damage caused by *Elasmopalpus lignosellus* is frequent in areas of burned sugar cane harvesting under drought conditions. In areas of unburned sugar cane harvest, the trash layer present on the ground surface provides greater humidity and better plant development, reducing damage caused by this insect.

20.2. Effect of trash on insect population

20.2.1. Objective

The evaluation of insect pests (population levels and damage index) and arthropods with predator activity was done in two experimental areas, at Usina Da Pedra (Serrana, São Paulo State) and Usina São Francisco (Sertãozinho, São Paulo State), where trials of different sugar cane harvesting systems were performed. The harvesting systems tested were:

- Manually harvested burned cane
- Mechanically harvested burned cane
- Mechanically harvested unburned cane.

20.2.2. Methodology

The following five survey methods were used between October of 1997 and October of 1999:

1) Survey of insect pests on soil surface.
2) Survey of soil pests in trenches.
3) Evaluation of arthropod in "pit-fall" traps (**Figure 102**).
4) Survey of other sugar cane pests.
5) Population and damage evaluation criteria of sugar cane borer.

Constancy (%) and Frequency (%) indices were used to compare the arthropods populations collected.

Figure 103

Sugar cane borer larvae (*Diatraea saccharalis*).

Constancy (%) = (number of samples where the taxon is present / total of samples) * 100%

Frequency (%) = (number of organisms of a given taxon / total of collected organisms) * 100%

20.2.3. Results and discussion

The Frequency (%) and Constancy faunistic (%) indexes, number of individuals belonging to each taxon and the damage index were used to compare the data. The surveys allowed the identification of pests belonging to 15 taxa and of predatory arthropods included in 7 taxa (**Table 116**).

The resulting number of arthropods pests, predators and Frequency (%) obtained from experimental areas of sugar mills during two years of work is summarized in **Table 117** and **Table 118**.

The data collected in the two sugar mills indicate no significant differences in Frequency in relation to the arthropods pests and existing predators in these areas.

The Constancy data (%) indicate that the most constant predators in the collections were the ants, presenting Constancy in up to 58.3% of the collections in burned sugar cane (**Table 119**) and 60.0% in unburned sugar cane (**Table 120**).

The results indicate that there is no interference of the harvesting system on populations of predator arthropods. In spite of soil type differences among the areas studied there is no change in the taxa present in relation to either the insect pest or the predator arthropod. Ants (Hymenoptera; Formicidae) are the predators collected in largest quantities, with higher Frequency and Constancy.

Sugar cane borer, *Diatraea saccharalis* (**Figure 103**), considered the main sugar cane pest in Brazil, was not affected by the different sugar cane harvesting systems, in spite of a higher number of predators found in areas where sugar cane was not burned.

Table 116

Arthropods and taxa collected in sugar cane experimental areas using different harvesting systems.

Arthropods- Taxon	Common name	Order	Family	Status
	Evaluations in trenches			
Migdolus fryanus	Migdolus	Coleoptera	Cerambycidae	Pest
Several species	Whitegrubs	Coleoptera	Scarabaeidae	Pest
Naupactus spp.	Weevil	Coleoptera	Curculionidae	Pest
Scaptocoris castanea	Hemiptera bug	Hemiptera	Cydnidae	Pest
Several species	Wire worm	Coleoptera	Elateridae	Pest
Several species	Chrysomelidae beetle	Coleoptera	Chrysomelidae	Pest
Hyponeuma taltula	Worm	Lepidoptera	Noctuidae	Pest
	Collected on soil surface			
Several species	Ants	Hymenoptera	Formicidae	Predator
Several species	Earwigs	Dermaptera	Forficulidae	Predator
Several species	Carabid beetle	Coleoptera	Carabidae	Predator
Several species	Spiders	Aracnida	Several	Predator
Several species	Chrysomelidae beetle	Coleoptera	Chrysomelidae	Pest
Several species	Staphylinidae beetle	Coleoptera	Staphylinidae	Predator
Several species	Termites	Isoptera	Several	Pest
Several species	Armyworms	Lepidoptera	Noctuidae	Pest
Several species	Wire worm	Coleoptera	Elateridae	Pest
	Collected in pitfall traps			
Several species	Ants	Hymenoptera	Formicidae	Predator
Several species	Earwigs	Dermaptera	Forficulidae	Predator
Several species	Chrysomelidae beetle	Coleoptera	Chrysomelidae	Pest
Mahanarva fimbriolata	Froghoppers	Hemiptera	Cercopidae	Pest
Several species	Crickets	Orthoptera	Gryllidae	Pest
Several species	Staphylinidae beetle	Coleoptera	Staphylinidae	Predator
Several species	Carabid beetle	Coleoptera	Carabidae	Predator
Several species	Termites	Isoptera	Several	Pest
Several species	Armyworms	Lepidoptera	Noctuidae	Pest
Several species	Spiders	Araneae	Several	Predator
Several species	Whitegrubs	Coleoptera	Scarabaeidae	Pest
Several species	Mole crickets	Orthoptera	Gryllotalpidae	Pest
Metamasius hemipterus	Sugar cane weevil	Coleoptera	Curculionidae	Pest
Several species	Wire worm	Coleoptera	Elateridae	Pest
Several species	Planthopper	Orthoptera	Acrididae	Pest
Cycloneda sanguinea	Ladybeetle	Coleoptera	Coccinelidae	Predator
	Collection of other species			
Elasmopalpus lignosellus	Lesser corn stalk borer	Lepidoptera	Pyralidae	Pest
	Population and damage of sugar cane borer			
Diatraea saccharalis	Sugar cane borer	Lepidoptera	Crambidae	Pest
Cotesia flavipes	Cotesia wasp	Hymenoptera	Braconidae	Parasitoid

Table 117

Number and frequency (F%) of arthropods pests and predators obtained in surveys on the soil surface of areas of Usina Da Pedra, 1997 to 1999.

Taxa	Mechanically harvested unburned cane		Mechanically harvested burned cane		Hand cut burned cane		Total	
	Nº	F(%)	Nº	F(%)	Nº	F(%)	Nº	F(%)
Arthropods-pests								
Chrysomelidae	22	51.2	19	51.4	23	51.1	64	51.2
Mahanarva fimbriolata	8	18.6	3	8.1	11	24.4	22	17.6
Noctuidae (leaf-eaters)	4	9.3	9	24.3	8	17.8	21	16.8
Elateridae	9	20.9	6	16.2	3	6.7	18	14.4
Subtotal	**43**	**100.0**	**37**	**100.0**	**45**	**100.0**	**125**	**100.0**
Arthropods-predators								
Formicidae	832	94.2	624	93.1	912	96.5	2368	94.8
Araneae	20	2.3	24	3.6	23	2.4	67	2.7
Forficulidae	18	2.0	12	1.8	7	0.7	37	1.5
Carabidae	13	1.5	6	0.9	3	0.3	22	0.9
Coccinelidae	0	0.0	3	0.5	0	0.0	3	0.1
Staphylinidae	0	0.0	1	0.2	0	0.0	1	0.0
Subtotal	**883**	**100.0**	**670**	**100.0**	**945**	**100.0**	**2498**	**100.0**

Table 118

Number and frequency (F%) of arthropods pests and predators obtained in surveys on soil surface areas of Usina São Francisco, 1997 to 1999.

Taxa	Mechanically harvested unburned cane		Mechanically harvested burned cane		Hand cut burned cane		Total	
	Nº	F(%)	Nº	F(%)	Nº	F(%)	Nº	F(%)
Arthropods-pests								
Chrysomelidae	9	33.3	5	25.0	6	33.3	20	30.8
Mahanarva fimbriolata	12	44.4	7	35.0	4	22.2	23	35.4
Noctuidae (leaf-eaters)	6	22.2	7	35.0	7	38.9	20	30.8
Elateridae	0	0.0	1	5.0	0	0.0	1	1.5
Metamasius hemipterus	0	0.0	0	0.0	1	5.6	1	1.5
Subtotal	**27**	**100.0**	**20**	**100.0**	**18**	**100.0**	**65**	**100.0**
Arthropods-predators								
Formicidae	704	86.4	631	86.2	507	84.1	1842	85.7
Araneae	56	6.9	72	9.8	68	11.3	196	9.1
Forficulidae	52	6.4	24	3.28	26	4.3	102	4.7
Carabidae	1	0.1	0	0.0	1	0.2	2	0.1
Coccinelidae	0	0.0	0	0.0	0	0.0	0	0.0
Staphylinidae	0	0.0	0	0.0	0	0.0	0	0.0
Hemiptera	2	0.3	5	0.68	1	0.2	8	0.4
Subtotal	**815**	**100.0**	**732**	**100.0**	**603**	**100.0**	**2150**	**100.0**

Table 119

Constancy (%) of arthropods collected on soil surface in areas of Usina Da Pedra, 1997 to 1999.

Taxa	MU	MB	HB	TO
Arthropods-pests				
Chrysomelidae	14.2	10.8	12.5	12.5
Mahanarva fimbriolata	3.3	2.5	4.2	3.3
Noctuidae (leaf-eaters)	3.0	4.2	4.2	3.9
Elateridae	3.3	4.2	2.5	3.3
Isoptera (Termites)	2.5	3.3	4.2	3.3
Metamasius hemipterus	0.8	0.0	0.0	0.3
Arthropods-predators				
Formicidae	57.5	51.7	58.3	55.8
Araneae	15.0	14.2	10	13.1
Forficulidae	10.0	8.3	4.2	7.5
Carabidae	5.8	2.5	1.7	3.3
Coccinelidae	0.0	1.7	0.0	0.6
Staphylinidae	0.0	0.8	0.0	0.3
Hemíptera	3.3	3.3	3.3	3.3

MU= Mechanically harvested unburned cane; MB= Mechanically harvested burned cane; HB= Hand cut burned cane; TO= Total

Table 120

Constancy (%) of arthropods collected on soil surface in areas of Usina São Francisco, 1997 to 1999.

Taxa	MU	MB	HB	TO
Arthropods-pests				
Chrysomelidae	6.7	3.3	4.2	4.7
Mahanarva fimbriolata	6.7	5.8	2.5	5.0
Noctuidae (leaf-eaters)	2.5	2.5	5.8	3.6
Elateridae	0.0	0.8	0.0	0.3
Isoptera (Termites)	8.3	10.8	6.7	8.6
Metamasius hemipterus	0.0	0.0	0.8	0.3
Arthropods-predators				
Formicidae	60	55.0	55.0	56.7
Araneae	25.8	30.8	32.5	29.7
Forficulidae	28.3	15.8	11.7	18.6
Carabidae	0.8	0.0	0.8	0.6
Hemiptera	0.8	1.7	0.8	1.1

MU= Mechanically harvested unburned cane; MB= Mechanically harvested burned cane; HB= Hand cut burned cane; TO= Total

Table 121

Number and frequency (F%) of arthropods pests and predators obtained in the population surveys of soil pests in trenches in areas of Usina Da Pedra, 1997 to 1999.

Taxonomy	Mechanically harvested unburned cane		Mechanically harvested burned cane		Hand cut burned cane		Total	
	Nº	F(%)	Nº	F(%)	Nº	F(%)	Nº	F(%)
Arthropods-pests								
Chrysomelidae	22	12.2	28	13.9	34	15.3	84	13.9
Elateridae	20	11.1	27	13.4	32	14.4	79	13.0
Scarabaeidae	126	69.6	112	55.5	80	35.9	318	52.5
Naupactus sp.	10	5.5	30	14.9	72	32.3	112	18.5
Hyponneuma taltula	1	0.6	0	0.0	2	0.9	3	0.5
Scaptocoris castanea	2	1.1	5	2.5	3	1.4	10	1.7
Subtotal	181	100.0	202	100.0	223	100.0	606	100.0

Table 122

Number of arthropod pests, predators and frequency (F%) obtained in population surveys of soil pests in trenches in areas of Usina São Francisco, 1997 to 1999.

Taxonomy	Mechanically harvested unburned cane		Mechanically harvested burned cane		Hand cut burned cane		Total	
	Nº	F(%)	Nº	F(%)	Nº	F(%)	Nº	F(%)
Arthropods-pests								
Chrysomelidae	55	30.4	37	30.8	37	34.9	129	31.7
Elateridae	16	8.8	12	10.0	7	6.6	35	8.6
Scarabaeidae	98	54.1	46	38.3	52	49.1	196	48.2
Naupactus sp.	0	0.0	2	1.7	5	4.7	7	1.7
Scaptocoris castanea	12	6.6	23	19.2	5	4.7	40	9.8
Subtotal	181	100.0	120	100.0	106	100.0	407	100.0

The data of number and Frequency of arthropods pests collected in trenches in the experimental areas of the sugar mills are summarized in **Table 121** and **Table 122**, indicating larger number of *Scarabaeidae* and *Naupactus sp.* in Usina Da Pedra and larger number of Crysomelidae and *S.castanea* in the Usina São Francisco.

In relation to predators collected in "pit-fall" traps, there was a larger number and Frequency of ants, Carabidae and spiders, in this order. The number of Hemiptera predators, that occurred in larger number in the parcels with harvested unburned cane deserves to be mentioned (**Table 123** and **Table 124**). It is important to mention that this type of trap collects only the arthropods that have the habit to walk on the ground, mainly in the night, in search for food.

A comparison between areas shows an inversion in the number of individuals and Frequencies of collection of Crysomelidae, larger at Usina Da Pedra, and termites, larger at Usina São Francisco. The Crysomelidae were the most constant among pests collected at Usina Da Pedra, with 37.3% in the unburned cane. Ants were the most constant among predators, followed by Carabidae, spiders and Dermaptera (**Table 125**).

Similar results were obtained in relation to the taxa Constancy at the experimental area of Usina São Francisco, with larger indices for Crysomelidae pests, termites, predator's ants, Dermaptera, Carabidea and spiders (**Table 126**).

The number of coleoptera pests, belonging to the Chrysomelidae and Elateridae families, was similar for the different treatments.

A larger number of termites were observed in areas not burned, where they can feed on trash left on soil surface, but without an increase in the damage index of the sugar cane root system.

The number of shoots damaged by *Elasmopalpus lignosellus* was higher in plots where sugar cane was burned before harvest. A beneficial effect of trash on control of *E. lignosellus* population was observed.

The number of nymphs and adults of the froghopper *Mahanarva fimbriolata* (Homiptera; Cercopidae) (**Figure 104**) was high in areas where sugar cane was not burned.

Figure 104

Froghopper adult (*Mahanarva fimbriolata*).

Table 123

Number of arthropods pests, predators and frequency (F%) obtained in "pit-fall" traps in areas of Usina Da Pedra, 1997 to1999.

Taxonomy	Mechanically harvested unburned cane		Mechanically harvested burned cane		Hand cut burned cane		Total	
	Nº	F(%)	Nº	F(%)	Nº	F(%)	Nº	F(%)
Arthropods-pests								
Chrysomelidae	114	69.1	81	63.8	122	70.5	317	68.2
Mahanarva fimbriolata	3	1.8	2	1.6	1	0.6	6	1.3
Noctuidae (leaf-eaters)	3	1.8	5	3.9	6	3.5	14	3.0
Elateridae	4	2.4	3	2.4	5	2.9	12	2.6
Isoptera	20	12.1	12	9.5	10	5.8	42	9.0
Scarabaeidae	10	6.1	8	6.3	8	4.6	26	5.6
Naupactus sp.	3	1.8	1	0.8	0	0.0	4	0.9
Gryllidae	4	2.4	8	6.3	16	9.3	28	6.0
Acrididae	1	0.6	1	0.8	0	0.0	2	0.4
Gryllotalpidae	3	1.8	6	4.7	5	2.9	14	3.0
Subtotal	165	100.0	127	100.0	173	100.0	465	100.0
Arthropods-predators								
Formicidae	614	77.1	517	81.6	841	86.2	1972	82.0
Araneae	33	4.2	26	4.1	25	2.6	84	3.5
Forficulidae	38	4.8	17	2.7	28	2.9	83	3.5
Carabidae	77	9.7	64	10.1	65	6.7	206	8.6
Coccinelidae	3	0.4	1	0,2	4	0.4	8	0.3
Staphylinidae	6	0.8	5	0,8	5	0.5	16	0.7
Hemiptera	25	3.1	4	0,6	8	0.8	37	1.5
Subtotal	**796**	**100.0**	**634**	**100.0**	**976**	**100.0**	**2406**	**100.0**

Table 124

Number of arthropods pests, predators and frequency (F%) obtained in "pit-fall" traps in areas of Usina São Francisco, 1997 to1999.

Taxonomy	Mechanically harvested unburned cane		Mechanically harvested burned cane		Hand cut burned cane		Total	
	Nº	F(%)	Nº	F(%)	Nº	F(%)	Nº	F(%)
Arthropods-pests								
Chrysomelidae	27	17.9	13	12.5	10	14.9	50	15.5
Mahanarva fimbriolata	6	4.0	10	9.6	5	7.5	21	6.5
Noctuidae (leaf-eaters)	13	8.6	10	9.6	13	19.4	36	11.2
Elateridae	1	0.7	5	4.8	2	3.0	8	2.5
Isoptera	89	58.9	37	35.6	27	40.3	153	47.5
Scarabaeidae	9	6.0	11	10.6	1	1.5	21	6.5
Metamasius hemipterus	1	0.7	0	0.0	0	0.0	1	0.3
Gryllidae	5	3.3	15	14.4	9	13.4	29	9.0
Acrididae	0	0.0	2	1.9	0	0.0	2	0.6
Gryllotalpidae	0	0.0	1	1.0	0	0.0	1	0.3
Subtotal	151	100.0	104	100.0	67	100.0	322	100.0
Arthropods-predators								
Formicidae	676	84.5	758	85.8	688	85.3	2122	85.2
Araneae	23	2.9	26	2.9	23	2.9	72	2.9
Forficulidae	42	5.3	37	4.2	41	5.1	120	4.8
Carabidae	50	6.3	47	5.3	46	5.7	143	5.7
Coccinelidae	1	0.1	1	0.1	0	0.0	2	0.1
Staphylinidae	7	0.9	13	1.5	7	0.9	27	1.1
Hemiptera	1	0.1	1	0.1	2	0.3	4	0.2
Subtotal	800	100.0	883	100.0	807	100.0	2490	100.0

Table 125

Constancy (C%) of arthropods collected in "pit-fall" traps in areas of Usina Da Pedra, 1997 to 1999.

Taxa	MU	MB	HB	TO
Arthropods-pests				
Chrysomelidae	37.3	32.7	33.6	34.5
Mahanarva fimbriolata	2.7	0.9	0.9	1.5
Noctuidae (leaf-eaters)	2.7	2.7	4.5	3.3
Elateridae	2.7	2.7	3.6	3.0
Isoptera	6.4	2.7	4.5	4.5
Scarabaeidae	7.3	7.3	6.4	7.0
Naupactus sp.	2.7	0.9	0.0	1.2
Griyllidae	3.6	7.3	11.8	7.6
Acrididae	0.9	0.9	0.0	0.6
Gryillotalpidae	2.7	5.5	4.5	4.2
Arthropods-predators				
Formicidae	86.4	85.5	90.0	87.3
Araneae	24.5	22.7	17.3	21.5
Forficulidae	23.6	10.9	13.6	16.1
Carabidae	23.6	24.5	24.5	24.2
Coccinelidae	2.7	0.9	2.7	2.1
Staphylinidae	5.5	4.5	3.6	4.5
Hemiptera	8.2	2.7	5.5	5.5

Table 126

Constancy (C%) of arthropods collected in "pit-fall" traps in areas of Usina São Francisco, 1997 to 1999.

Taxa	MU	MB	HB	TO
Arthropods-pests				
Chrysomelidae	22.1	11.6	9.5	14.4
Mahanarva fimbriolata	6.3	8.4	4.2	6.3
Noctuidae (leaf-eaters)	9.5	7.4	10.5	9.1
Elateridae	1.1	5.3	2.1	2.8
Isoptera	12.6	16.8	13.7	14.4
Scarabaeidae	5.3	4.2	1.1	3.5
Metamasius hemipterus	1.1	0.0	0.0	0.4
Gryllidae	4.2	11.6	8.4	8.1
Acrididae	0.0	2.1	0.0	0.7
Gryllotalpidae	0.0	1.1	0.0	0.4
Arthropods-predators				
Formicidae	75.8	77.9	80.0	77.9
Araneae	15.8	22.1	17.9	18.6
Forficulidae	32.6	26.3	23.2	27.4
Carabidae	25.3	23.2	27.4	25.3
Coccinelidae	1.1	1.1	0.0	0.7
Staphylinidae	6.3	10.5	6.3	7.7
Hemiptera	1.1	1.1	2.1	1.4

MU = Mechanically harvested unburned cane MB = Mechanically harvested unburned cane TO = Total

The trash present on the soil surface protects the nymph population and this condition allows this species to cause serious damage to sugar cane shoots and stalks. In these areas, the adoption of a technical control is necessary mainly through the use of the fungus *Metharhizium anisopliae*.

20.2.4. Conclusions

Surveys performed in the present work allowed the conclusion that there is no interference of the sugar cane harvesting system on:

a. Populations of Chrysomelidae (Coleoptera), Elateridae (Coleoptera), Cydnidae (Hemiptera), and Noctuidae (Lepidoptera).
b. Populations of the main arthropod predators.
c. Populations and damage caused by *Diatraea saccharalis* (Lepidoptera; Crambidae).
d. Parasitism of *Cotesia flavipes* (Hymenoptera; Braconidae) on larvae of *Diatraea saccharalis*.

On the other hand, unburned sugar cane harvesting favors:

a. Establishment of froghopper populations of the species *Mahanarva fimbriolata* (Hemiptera; Cercopidae) and an increase in the probability of economical losses in areas where this harvesting system is adopted.
b. An increase in the presence of termites, not meaning that they are responsible for a larger percentage of damaged stools, since many species are only decomposers of cellulosic material deposited on the soil surface.
c. A decrease in populations and damage caused by *Elasmopalpus lignosellus* (Lepidoptera; Pyralidae).

20.3. Agricultural Insecticides

20.3.1. Objective

The objective of this work was to evaluate changes occurring in areas where cane is harvested unburned, looking at the interference on pest populations and the need to increase the use of insecticides to control the main pests in this culture.

20.3.2. Methodology

A literature review and an evaluation of the effect of unburned sugar cane harvesting on the main pests were performed, determining the implications in relation to control methods and use of insecticides.

20.3.3. Results and discussion

The species *Diatraea saccharalis* (Lepidoptera; Crambidae) occurs throughout Brazil. Results comparing borer populations and damage in unburned vs. burned sugar cane showed variable results, sometimes favoring areas where cane was burned but other times favoring unburned cane areas.

The parasitoid used with more frequency on borer control is the wasp *Cotesia flavipes* and biological control will remain, with no changes, due to the harvesting system.

Chemical control is recommended only in special situations where *D. saccharalis* population level is above 20,000 borers/ha. This recommendation is also valid for areas of unburned sugar cane harvesting (**Table 127**).

Froghopper (*Mahanarva fimbriolata*) populations on sugar cane supeficial roots will increase in areas of unburned cane harvesting with the probability of high population densities requiring adoption of control measures not previously used. The priority will be on

Figure 105

Leaf-cutting ant.

Table 127

Insecticides, active ingredient, dose, chemical group and registration status at Brazilian Department of Agriculture (M.A.) for the control of sugar cane pests, in Brazil (1999).

Pests/Insecticide	Active ingredient	Dosage	Chemical group	Register in M.A.
Diatraea saccharalis				
Decis 25CE	Deltamethrin	0.3 L/ha	Pyrethroid	Not registered
Alsystin 250 PM	Triflumuron	0.1 kg/ha	Benzoylurea	Not registered
Dimilin	Diflubenzuron	0.2 kg/ha	Benzoylphenylurea	Not registered
Regent 800WG	Fipronyl	0.25 kg/ha	Phenylpyrazole	Registering
Migdolus fryanus				
Thiodan 350CE	Endosulfan	11.5 L/ha	Organochlorine	Registered
Regent 800 WG	Fipronyl	0.50 kg/ha	Phenylpyrazole	Registered
Sphenophorus levis				
Counter 150 G	Terbufos	16.7 kg/ha	Organophosphate	Not registered
Regent 800 WG	Fipronyl	0.50 kg/ha	Phenylpyrazole	Not registered
Furadan 350 SC	Carbofuran	6.5 L/ha	Carbamate	Not registered
Actara 10 G	Thiamethoxam	30.0 kg/ha	Neonicotinoid	Not registered
***Atta* spp.**				
Mirex - S	Sulfluramid	10 g/m^2 ant nest	Fluorinated sulfonamide	Registered
Blitz	Fipronyl	10 g/m^2 ant nest	Phenylpyrazole	Registered
Lakree Fogging	Chlorpyrifos	4 mL/m^2 ant nest	Organophosphate	Registered
Sumifog 70	Fenitrothion	4 mL/m^2 ant nest	Organophosphate	Registered
Mahanarva fimbriolata				
Actara 10G	Thiamethoxam	30.0 kg/ha	Neonicotinoid	Registering
Actara 25WG	Thiamethoxam	0.3 kg/ha	Neonicotinoid	Registering
Counter 150G	Terbufos	16.7 kg/ha	Organophosphate	Not registered
Regent 800WG	Fipronyl	0.25 kg/ha	Phenylpyrazole	Not registered
Furadan 350 SC	Carbofuran	6.5 L/ha	Carbamate	Not registered
Furadan 5G	Carbofuran	60.0 kg/ha	Carbamate	Not registered
Termites				
Regent 800WG	Fipronyl	0.25 kg/ha	Phenylpyrazole	Registered
Thiodan 350SC and similars	Endosulfan	8.0 L/ha	Organochlorine	Registered
Counter 150G	Terbufos	16.7 kg/ha	Organophosphate	Registered
Confidor 700 GRDA	Imidacloprid	0.4 kg/ha	Nitroguanidine	Registered
Elasmopalpus lignoselus				
Lorsban 480BR	Chlorpyrifos-ethyl	1.0 L/ha	Organophosphate	Not registered
Decis 25 CE	Deltamethrin	0.5 L/ha	Pyrethroid	Not registered
Acefato Fersol 750 PS	Acephate	1.0 kg/ha	Organophosphate	Not registered

development of microbiological control measures, although chemical control will be necessary in many areas and situations. There has been no development of insecticides for froghopper control in the last 25 years since cane burning always eliminated eggs of this insect.

Thermal fogging is the method of choice for control of leaf-cutting ants (**Figure 105**) with efficiency above 90%. This method is harder to apply in areas of unburned cane harvesting since the trash blanket formed turns difficult finding feeder holes and evaluation of the size of the colonies and increases the risk of fire. However, there should not be an increase in the use of insecticides in these areas if control efficiency is to be maintained.

Control of *Migdolus fryanus* (**Figure 106**) is done using insecticides with high soil persistence. Use of these compounds will be restricted to the same areas where infestation occurs nowadays and in new areas where new insect foci are discovered.

Chemical control of *Sphenophorus levis* (**Figure 107**) is being tested using different forms of application of different insecticides. However, there are no products in the market recommended for an efficient control of this pest.

Figure 106

Female and eggs of Migdolus fryanus.

Figure 107

Adult of Sphenophorus levis.

20.3.4. Conclusions

The data obtained about each insect allows the following conclusions:

Froghopper (*Mahanarva fimbriolata*) populations will find favorable development conditions in areas of unburned sugar cane harvesting with the need of control measures. Biological control methods will be emphasized but chemical control will be needed in many different situations.

Control of other pests such as sugar cane borer, *Diatraea saccharalis*, root borer, *Migdolus fryanus*, leaf cutting ants of the genus *Atta* and *Acromyrmex*, leaf eating caterpillars and most termite species will not suffer significant changes. No changes should occur that will demand an increase in the use or the introduction of new insecticides.

Sphenophorus levis populations will benefit from the presence of the trash blanket which will restrict some of the control measures currently used and will cause an increase in the use of insecticides for its control.

Populations of the lesser corn stalk borer *Elasmopalpus lignosellus* will present a significant reduction in unburned cane areas with a decrease in insecticide use.

21. Impact on jobs

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21.1. Introduction

Sugar cane agribusiness in Brazil plays an important role in job generation in the country. It directly employs about one million people, approximately 80% in the agricultural area. Sugar cane is one of the cultures that generates more jobs per unit of cultivated area. In the State of São Paulo it represents around 35% of rural jobs, totaling 400,000 workers. The investment required to create one job in the sugar cane sector, about US$ 10,000, is one of the lowest among economic activities in the country. The estimated values for other sectors are, for example, US$ 200,000 for petrochemicals and US$ 98,000 for automakers.

Considering the importance of sugar cane in job generation, any changes in the cane production process, mainly in the harvest, can generate important impacts on field labor demand. In the factory, the increasing level of process automation and the improvement of management and maintenance practices are gradually reducing labor requirements.

This fact has already been observed with the progress of crop mechanization in the State of São Paulo, motivated by technological evolution and mainly by legal prohibition of sugar cane burning (São Paulo State law 19/09/02 and the Federal government decree 08/07/98). The harvesting mechanization in the country should reach, in the year 2018, 100% of the cultivated area in fields with slopes compatible with this practice.

The federal decree does not forbid burning in cultivated areas with slopes higher than 12%, while the actual law in São Paulo State forecasts the end of cane burning in 30 years. Since these areas do not allow the mechanized harvesting and cost of unburned cane manual harvesting reduces its competitiveness, it is reasonable to expect production displacement to areas with better topographical characteristics. It is also probable that there will be a drive for production increases in mechanized areas through incorporation of new technologies.

The increasing power generation levels at mills, producing surplus power for sale, is opening new job opportunities; the possible use of sugar cane trash to extend power generation to year round operation will certainly have a positive impact on jobs at the mills.

» Objective

To evaluate the changes in labor demand in the sugar cane agribusiness, due to the use of crop residues for energy generation.

21.2. Methodology

Labor demand in sugar cane production will be affected by harvest and planting mechanization (reduction) and the introduction of trash recovery process (increase).

The impact of harvesting mechanization will happen, independent of the use of the trash for energy generation, motivated mainly by legislation. The subject will be discussed bellow.

The basic assumptions are:

General parameters (actual and future):

- Sugar cane production: 300 x 10^6 t (São Paulo 190 x 10^6 t and other states 110 x 10^6 t);
- Material (trash) available: 0,14 t dry matter/t cane (average value);
- Labor productivity in hand cut burned cane: 8 t/man day.

Future situation without the project (baseline)

- Total cane harvested without burning: 245 x 10^6 t (100% in São Paulo State and 50% in the others states);

Future situation with the project

- Total cane without burning: 245 x 10^6 t (100% in São Paulo State and 50% in the others states).

Alternative 1 – Trash recovery in the field after harvesting (baling):
- Trash recovery in the field after harvesting without burning = 64% of total available trash in the field before harvesting;
- Duration of season = 201 days (see **Table 31**).

Alternative 2 - Partial cleaning in the harvester and trash transport with cane to the industry:

- Increase in material transported due to vegetal impurity = 11.10% (see **Table 27**, comparing the delivered cane for Alternative 3 and the Baseline);
- Duration of season = 199 days (see **Table 31**);
- The trash recovered will be used to supplement bagasse as fuel to be used in BIG-GT systems in the mills.

21.3. Results and discussion

21.3.1. Mechanization

An increase of harvesting mechanization, reaching in the future 245 x 10^6 t, will imply in labor reduction in relation to the current situation. Labor used in mechanical cut, loading and transport should reach approximately 39,000 workers including operators, mechanics, truck drivers and assistants. If the cane is harvested manually, approximately 203,500 workers would be employed, presenting a difference of 164,500 workers.

Part of this impact has already happened since a reasonable amount of cane is already being mechanically harvested. The projected mechanization level will happen even if the trash is not used for power generation.

21.3.2. Trash recovery

With the evolution of mechanization of cane cutting without burning, trash availability in the field will be:

245 x 10^6 t x 0.14 t dry matter/t cane = 34.3 x 10^6 t dry matter from trash per crop season.

The recovery of 64% (cleaning efficiency at the harvester of 76% and baler recovery efficiency of 84% - see chapter 11) of this material during season (109,214 t/day), using balers, loaders and trucks for transport will generate a labor demand of around 15,400 workers, including operators, drivers, mechanics and assistant (**Table 128**).

Table 128

Trash recovery with balers - Manpower requirement.

	Operational capacity (t/day)	Equipment quantity	Shifts	Labor			
				Operators	Replacement	Maintenance	Total
Baler	55	1,986	1	1,986	398	596	2,980
Loader	155.2	704	3	2,112	423	212	2,747
Windrower	87.8	1,244	1	1,244	249	374	1,867
Transport	77.5	1,410	3	4,230	846	423	5,499
Tractor	186.2	587	3	1,761	353	177	2,291
Total		**5,931**		**11,333**	**2,269**	**1,782**	**15,384**

21.3.3. Partial cleaning

Partial cleaning of harvested material allows the transport to the mill of part of the cane trash, corresponding to an increase of approximately 11.10% in the transported material weight, or:

245 x 10^6 t + 11.10% impurities = 272.2 x 10^6 t.

Labor used for harvesting and transport of cane harvested with conventional cleaning (**Table 129**) is very similar to that used in the same processes for the cane with partial cleaning (**Table 130**); only 1,453 additional workers are required, in spite of the 11.10% increase in transported material. This is because the operational capacity of the transport equipment is limited today by road legislation, leaving room in truck volume to transport a larger amount of material with lower density.

Table 129

Conventional crop - Manpower requirement.

	Operational capacity (t/day)	Equipment quantity	Shifts	Labor			
				Operators	Replacement	Maintenance	Total
Harvester	577	2,112	3	6,336	1,268	634	8,238
Tractor	310	3,938	3	11,814	2,363	1,182	15,359
Transport	310	3,939	3	11,817	2,364	1,182	15,363
Total				**29,967**	**5,995**	**2,998**	**38,960**

Table 130

Mechanical harvesting with partial cleaning - Manpower requirement.

	Operational capacity (t/day)	Equipment quantity	Shifts	Labor			
				Operators	Replacement	Maintenance	Total
Harvester	617	2,217	3	6,651	1,330	665	8,646
Tractor	361	3,789	3	11,367	2,274	1,137	14,778
Transport	314	4,356	3	13,068	2,614	1,307	16,989
Total				**31,086**	**6,218**	**3,109**	**40,413**

Table 131

BIG-GT manpower requirement for three shifts.

	Baled trash		Trash from dry cleaning station	
	Season	Off-season	Season	Off-season
BIG-GT manager	1	1	1	2
BIG-GT superviser	3	3	3	3
BIG-GT operators	14	14	14	14
Trash handling	6[(a)]	-	-	-
Trash/bagasse reclaiming	6	6	6	6
Auxiliary plant operators	6	3	6	3
Replacement	6	6	6	6
Total	**42**	**33**	**36**	**33**

(a) Three operators in two shifts

21.3.4. BIG-GT System operation

The BIG-GT package, based on the gas turbine GE LM 2500, considered in the development of this project, when operating in the cogeneration mode, fully integrated with the mill, would require the manpower shown in **Table 131**.

The indirect manpower required for maintenance, chemicals transportation, effluents handling, etc. is estimated in 25 workers, in addition to the totals in Table 131.

21.4. Conclusions

The evolution of mechanical harvesting in unburned fields is already occurring, motivated by new specific legislation, environmental pressures and technical evolution of the production process independently of the use of the trash as an energy source. This mechanization might cause a job offer reduction of 164,500 jobs, taking 100% manual cut as a reference.

The use of trash as an energy source will be directly responsible for the creation of approximately 15,400 jobs in the agricultural area, using the trash baling alternative, or approximately 1,450 jobs using the partial cleaning alternative.

The corresponding increase in industry labor demand has been estimated in approximately 16,000 new jobs based on the following assumptions:

Quantity of BIG-GT plants installed (theoretical potential): 250 (80% of the 307 existing mills).

- No of direct jobs 10,000 (40 per plant)
- No of indirect jobs 6,250 (25 per plant)

In this work, indirect impacts in the generation of jobs was not considered such as labor increase for production of harvesters, balers, loaders, BIG-GT equipment among others.

22. Impact analysis and mitigation measures

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22.1. Introduction

For many years, the practice of burning cane fields to remove cane trash is being used to increase productivity of the hand harvesting operation. However, environmental agencies and public pressure have led to the approval of laws establishing time schedules for cane burning phasing out at state and federal levels.

These regulations resulted from extensive discussion between the sugar cane sector, government and civil society representatives, where the following aspects were taken into consideration:

- Cane burning results in degradation of the local air quality mainly due to fly ash emissions.
- Cane burning is a traditional practice used by the sector to facilitate harvesting.
- Mechanical harvesting is the technology being adopted to make unburned cane harvesting feasible, with high cost penalties.
- Hand harvesting of sugar cane employs the largest workforce in the rural area of the State of São Paulo.
- Mechanical harvesting, if adopted abruptly, can cause serious social problems due to loss of thousands of jobs in the rural areas.
- Sugar cane harvesting mechanization requires substantial investments in equipment and adaptation of the cane fields to this technology (the cane life cycle of five years must be taken into account).

The present awareness of the society and sugar cane growers and pressure of environmentalist entities have lead to studies aiming on eliminating gradually cane burning and research on trash use for power generation.

The recently approved Law No 47700 of March 11, 2003, establishes the pace for cane burning phase out in the State of São Paulo, setting deadlines of 2021 for cane fields that can have mechanized harvesting and 2031 for the areas not adequate for mechanized harvesting, that is, areas with less than 150 hectares or with ground slope higher than 12%.

The present project deals with the technology of trash recovery and use in a gaseification process to generate electric power in the sugar cane mills.

» Objective

The main objective of this section is to summarize the environmental impacts identified during the development of the project and to suggest mitigation actions to reduce those impacts to reasonable levels. It will be considered impacts on the atmosphere, soil, biological environment and anthropic environment, specially with respect to jobs.

22.2. Methodology

The environmental impacts analyses were carried out in this work for the following sugar cane mechanical harvesting and trash recovery routes.

Alternative 1: chopped unburned cane with cane cleaning performed by harvester in operation, with trash remaining in the field.

Alternative 2: chopped unburned cane with cane cleaning performed by harvester in operation, with most trash baled and transported to the mill to be used as fuel.

Alternative 3: chopped unburned cane without cane cleaning by harvester (cleaning fans off), with trash transported to mill with the cane; trash separation at the mill in a cane dry cleaning station.

The recovered trash will be used as fuel in a BIG-GT system operating either as an independent thermal power plant or integrated with a mill in cogeneration mode.

The scenarios and mitigation measures considered were:

Scenario 1: Present situation: mechanical harvesting of burned cane without use of trash; bagasse used in conventional boilers to provide the energy required to process cane in the mill.

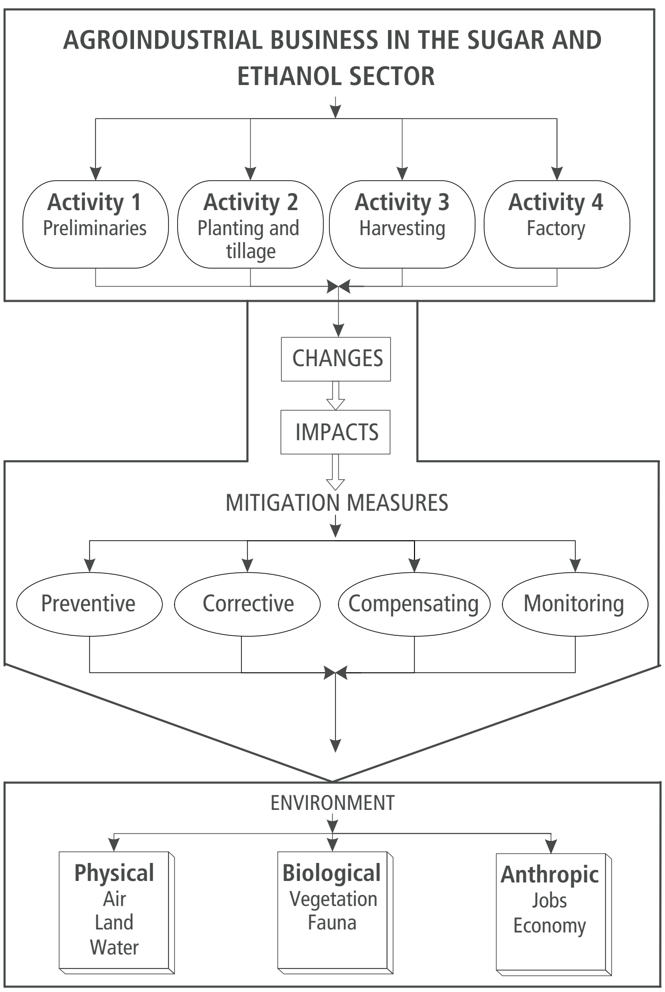
Scenario 2: Future situation without this project and legal requirement and public pressure to stop cane burning (very pessimistic scenario): mechanical harvesting of mostly burned cane; no use of trash.

Scenario 3: Mechanical harvesting of chopped unburned cane, with cane cleaning performed by the harvester in operation, with most of the trash baled and transported to the mill to be used as fuel in BIG-GT systems.

Scenario 4: Mechanical harvesting of chopped unburned cane, without cane cleaning by harvester (cleaning fans off), with trash transported to the mill with the cane; trash separation at the mill in a cane dry cleaning station and trash used as fuel in BIG-GT systems.

Several mitigation measures have already been adopted by the sugar cane sector and have become normal practices. As an example, a sugar/ethanol mill will not be viable if it does not have adequate areas close to the mill for application of effluents in cane fields, if it does not use conservationist techniques to avoid, or limit, loss of fertile land due to erosion, if it does not use biological control of pests, if it does not minimize the use of water by reuse and recirculation of process water streams or if it does not practice crop rotation to fertilize and rest the soil.

Figure 108



Environmental analysis structure diagram.

Figure 108 presents a diagram of the structure normally used by CTC to analyze the environment impact required in the Environmental Impact Analysis/Environmental Impact Report that are legal documents for application toward operating licenses. In these analyses it is first necessary to verify the origin and destiny of the impacts since the installation. There are activities of use and occupation of space, directly or indirectly affecting the physical (air, land, water), biological (vegetation and fauna) and anthropic environment.

The origin of the impacts can be more easily identified when the undertaking activities are grouped and connected to different phases and steps, since the implementation, expansion or even change of technology. In this project, activities were grouped as follows:

- **Group 1 – Preliminary activities:** contract suppliers, buy or rent agricultural machinery and implements, design industrial and civil installations, contract construction and erection companies, build or improve infrastructure; execute the construction and erection operations.
- **Group 2 – Agricultural activities of planting and tillage**: soil preparation, nursery, planting, fertilizer use and irrigation, use of pesticides and herbicides and crop rotation.
- **Group 3 – Harvesting activities**: cane burning, harvesting, loading and transportation to the mill.
- **Group 4 – Industrial activities**: cane processing, energy generation, water use, effluents production, storage and shipping of products.

The impact matrix is obtained by relating the activities to be developed with the environments affected. It is a preliminary impacts identification, without attempting to quantify or qualify them, that will guide the preparation of the impacts network.

The interaction and onset of impacts network is the result of the crossing of each activity to be developed with the environments that will eventually be affected. It must be pointed out that the impact network does not allow assessment of importance or probability of impact to occur, since, at this stage, existence and importance of such impacts are only suspected.

After that the quality and magnitude of the impacts, remains to be established, either positive or negative, considering the following assumptions:

• Space effect: local impact – when activity affects only the place where it occurs or its immediate neighborhood; regional impact – when impact propagates beyond areas of activity and its neighborhood.

• Temporality: temporary impact – when it remains for a determined period of time after activity takes place; permanent impact – when it remains after the time horizon considered, even after activity ceases to take place.

• Reversibility: reversible impact – when affected environment can be returned to its original condition, after the end of the activity; irreversible impact – when affected environment can never be returned to its original conditions, after end of activity.

• Intensity: high intensity impact – when there is a significant change in affected environment; medium intensity impact – when there is a relative change in affected environment; low intensity impact – when no significant change occurs in affected environment.

• Tendency: to grow – when the impact increases when the cause increases; to stagnation – when the impact stabilizes after the cause is stabilized; to decrease – when the impact is reduced when the cause decreases.

• Relevance: is a weighted qualification of impacts considering each item above. This process depends on a series of available technical knowledge and on a subjective evaluation. The relevance, prior and after the mitigation measures, will be classified as high, medium and low (according to the degree assigned to the environmental change; or negligible (when the mitigation has full effect on the impact).

Once the negative and positive impacts are identified, qualified and quantified, measures shall be taken to maximize them, if positive, or mitigate them or even eliminate them, if negative. The mechanisms adopted to accomplish this task are classified as follows: Preventive Mitigation Measures – action taken prior to impact appearance; Corrective Mitigation Measures – action taken when the impact is taking place; Monitoring Mitigating Measures – action intended to follow up the changes in the affected environment; Compensating Mitigation Measures – action taken to counteract the negative environmental changes, bearing in mind that this type of measure is not taken directly on the affected environment.

22.3. Impacts identification and analysis

Table 132 summarizes the outstanding activities proposed for this project in accordance with the various scenarios, considering or not the introduction of the new technology (trash recovery and use of BIG-GT). The environmental impact matrix is presented in **Table 133** and it initially lists activities that will have impacts on the environment. It is important to point out that impacts considered are only those resulting from the implementation of the new technology (unburned cane harvesting and trash recovery for power generation) and not those resulting from implementation of the sugar cane production and processing as a whole.

Table 134 shows the interaction and onset of impact network considering those environmental impacts that will be directly or indirectly affected by the new technology under consideration.

22.4. Physical environment

A summary of the impact evaluation for the physical environment is presented in **Table 135**.

22.4.1 Decrease in Green House (GH) effect

The partial introduction of unburned cane harvesting and the use of advanced power generation systems (biomass integrated gasification/gas turbine – BIG-GT) increase the benefits from the sugar cane agroindustry reducing global emissions of CO_2, thus maximizing the benefits of the use of the associated renewable energy with respect to Green House effect (fuel ethanol and cogeneration from cane residues).

Table 132

Activities relevant aspects according to each scenario.

Activity	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Group 1 – Preliminaries				
Contract suppliers	There is no interference in this activity			
Purchase/rent machinery and equipment	No	Purchase new ones		
Design civil and industrial buildings	No	No	Installation of new energy generation system	
Contract construction and erection	No	No	Yes	Yes
Implement /improve infrastructure	No	Yes	Yes	Yes
Construction and erection	No	No	Yes	Yes
Group 2 – Planting and Tillage				
Soil preparation	Conventional			
Nursery	There is no interference in this activity			
Planting	There is no interference in this activity			
Fertirrigation	There is no interference in this activity			
Fertilizer application	Conventional	Partial trash effect	Trash effect	Conventional
Herbicides and pesticides application	Conventional	Partial trash effect	Trash effect	Conventional
Crop rotation	Conventional	Partial trash effect	Trash effect	Conventional
Group 3 – Harvesting				
Cane burning	Yes	Yes partial	No	No
Cane harvesting	Hand	Mechanical	Mechanical	Mechanical
Trash / cane separation	Trash is lost (burned)		Yes	No
Cane loading	Conventional	Mechanical: chopped cane		
Trash loading	No trash recovery		Bailing	Cane and trash together
Cane transportation	Whole cane	Chopped cane	Chopped cane	Chopped cane
Trash transportation	No trash recovery		Trash bales	Cane and trash together
Group 4 – Industrial Processing				
Sugar production	No change			
Alcohol production	No change			
Trash separation	No trash use		By harvester	Dry cleaning station at the mill
Energy generation	Conventional bagasse fired boilers		BIG / GT	
Water use	Normal	Elimination of cane washing (chopped cane		
By products	No change	No change	Use of trash	Use of trash
Effluents production	No change	No change	New and more efficient air pollution control	
Storage and shipping	No change	No change	No change	No change

The use of fuel ethanol substituting for gasoline decreases the impacts on the biological environment. In Brazil it is estimated that such a practice avoids the emission of approximately 35 million tons of CO_2 annually, which represents around 16% of the country's total CO_2 emission from the use of fossil fuels.

Table 133

Environmental impact matrix.

Enviroment	Preliminary-Group 1	Planting-Group 2	Harvesting-Group 3	Industry-Group 4
Physical enviroment				
Air				
Climate	-	-	-	-
Air quality	-	-	S1 ; S2	S1 ; S2
Land				
Geology	-	-	-	-
Geomorphology	-	-	-	-
Pedology	-	S3 ; S4	S3 ; S4	-
Agricultural aptitude	-	-	-	-
Water				
Ground water	-	S3 ; S4	-	-
Surface water	-	-	-	S1 ; S2
Multiple uses of water	-	-	-	-
Biological enviroment				
Vegetation	-	-	S1 ; S2	-
Fauna	-	-	S1 ; S2	-
Anthropic enviroment				
Demography				
Population	-	-	-	-
Migration	-	-	S1	-
Economics				
Primary sector	-	-	-	-
Secondary sector	S2 ; S3 ; S4	-	-	-
Tertiary sector	S2 ; S3 ; S4	-	-	-
Quality of life				
Education	-	-	-	-
Health	-	-	S1 ; S2	S1 ; S2
Jobs	S2 ; S3 ; S4	-	S2 ; S3 ; S4	-
Landscape, hystorical and cultural heritage	-	-	-	-

Environment under impact according to activity and scenario:
S1 = Scenario 1: Mechanical harvesting of burned cane without use of trash; bagasse used in conventional boilers to provide the energy required to process cane in the mill.
S2 = Scenario 2: Mechanical harvesting of mostly burned cane; no use of trash.
S3 = Scenario 3: Mechanical harvesting of chopped unburned cane, with cane cleaning performed by the harvester in operation, with most of the trash baled and transported to the mill to be used as fuel in BIG-GT systems.
S4 = Scenario 4: Mechanical harvesting of chopped unburned cane, without cane cleaning by harvester (cleaning fans off), with trash transported to the mill with the cane; trash separation at the mill in a cane dry cleaning station and trash used as fuel in BIG-GT systems.

This emissions reduction can be signifcantly increased by the implementation of alternatives such as the large scale use of sugar cane trash and vinasse anaerobic digestor (with the production of methane) for power generation in the mills. It is estimated that the recovery of a reasonable fraction of the available trash and using it together with bagasse in BIG-GT systems will reduce CO_2 emissions by an additional 38 million tons of CO_2 per year, considering that these renewable fuels will be displacing the use of natural gas in combined cycle thermal power plants. Other important green house gas emissions such as methane, NO_x and CO are also reduced by the use of this technology.

Table 134

Interaction and start up of environmental impact network.

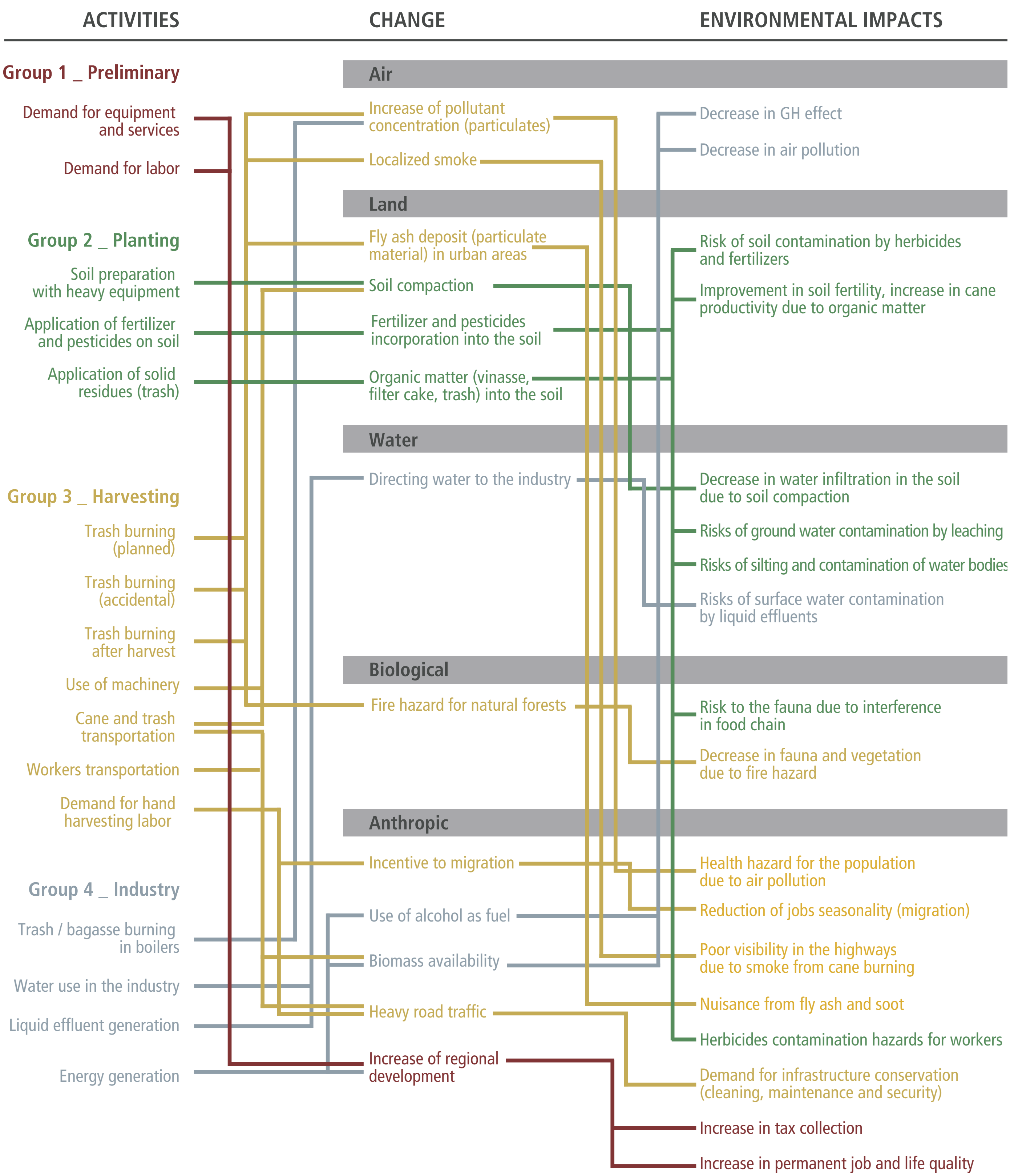


Table 135

Qualification of the impacts started by changes in physical environment.

Impacts	Group of activities	Type	Space effect	Temporality	Reversibility	Intensity	Tendency	Relevance	Mitigation measures	Relevance after mitig.
Air										
Decrease in GH effect	4	(+)	G	PE	I	L	S	M	-	M
Decrease in air pollution	4	(+)	G	PE	I	L	S	H	-	H
Land										
Soil contamination hazard by fertilizer and herbicides	2	(-)	L	TE	RE	L	G	L	P	N
Improvement in soil fertility and increase in productivity by the organic matter	2	(+)	L	PE	RE	M	S	M	-	M
Water										
Decrease in water infiltration due to soil compaction	2	(-)	L	PE	RE	M	S	M	C	L
Contamination hazard of the surface water by liquid effluents	2,4	(-)	R	TE	RE	G	G	H	P	N
Contamination hazard of ground water by leaching	2	(-)	R	PE	I	L	G	M	P,M	L
Silting up hazard and water body contamination hazard	1,2	(-)	R	PE	I	G	G	H	P,M	L

Symbols:

Type	Space effect	Temporality	Reversibility	Intensity	Tendency	Relevance	Measures
(+) positive	L -local	TE-temporary	RE-reversible	L-low	G-growth	N-nihil	P-preventive
(-) negative	R -regional	PE-permanent	I-irreversible	M-medium	S-stagnation	L-low	C-corrective
	G -global			H-high	D-decrease	M-medium	M-monitoring
						H-high	T-compensating

The present study considers the impacts of biomass displacing natural gas for power generation. Nevertheless, the substitution of the electric hydro-power produced in large dams, with the many forests flooding impacts, is another study that could be carried out.

22.4.2 Decrease in air pollution

The introduction of unburned cane harvesting with trash recovery and BIG-GT will maximize the benefits of reducing air pollution in urban areas, especially those located near the cane fields. The main effects derive from stopping cane burning and using bagasse and trash in gasifiers and burning the clean product gas in efficient and low emission gas turbines; these combined effects will have a substantial impact mainly in the reduction of particulate levels in the atmosphere (see Chapter 18).

22.4.3 Risks of soil contamination by fertilizers and herbicides.

Use of chemical fertilizers (NPK formulation) is an efficient way to replace the soil nutrient removed by the plants. If this practice is not used there is a danger of the soils loosing the fertility causing negative impacts on the land and anthropic environments.

One practice that reduces requirement for chemical fertilizers in sugar cane culture is use of vinasse and filter cake in cane fields. In the case of trash, it is known that it contains a reasonable amount of nitrogen and phosphorus, important ingredients in fertilizers formulation. Unfortunately these nutrients are not readily available to soil due to poor mineralization; therefore, a reduction of fertilizer requirement when trash is left on the soil is not considered here.

The use of herbicides in cane fields is a common and necessary practice due to negative effects of weeds on cane yield. Herbicide application is done once a year in areas of burned cane harvesting. The main possible negative impacts from the use of herbicides are the interference with the fauna, food chain, surface water contamination and the resulting effect on water flora and fauna and, finally, the risk of poisoning field workers.

Field tests conducted in the project have shown that the trash blanket inhibits weed growth on cane fields. Studies based on these tests results indicated that it is highly probable to have the herbicide effect with trash quantities above 7.5 t/ha (dry basis). Besides, the vegetal cover on the soil brings other benefits as moisture conservation, protection against erosion, increase in organic matter concentration and some nutrient recycling. Unburned cane harvesting can reduce chemical herbicide use by roughly 60% with trash blanketing.

22.4.4 Improvement in soil fertility and increase in cane productivity from the use of organic matter

A wise application of residues in cane fields avoids contamination of soils, surface and ground water since it is based on the principle of water and nutrients recycling to the system soil-plant, that were removed during harvesting. This rational management of residues provides a significant improvement in soil fertility that results in an increase of productivity and life cycle length.

Application of industrial residues (vinasse, waste water and filter cake) in cane fields is a common practice in the Brazilian sugar/ethanol mills and it can be considered as a mitigation measure of the impacts on the physical environment (soil and water) of such highly polluting potential residues.

In the case of unburned cane harvesting, field tests performed in the project did not lead to clear conclusions on the effects of trash blanket on cane yield due to the short duration and limitations that did not allow to cover all variables and conditions. The effect of trash blanket on cane yield and sugar content is affected by type of soil, cane productivity, trash blanket density, types of tillage, weather conditions, etc.

For this reason, trash blanket effect on cane field yield will not be considered.

22.4.5 Soil compaction

One important change in land environment is soil compaction resulting from use of machinery in mechanized cane harvesting and tillage. This soil compaction causes problems to normal culture development by increasing the resistance to root penetration, availability of moisture and nutrients and also by favoring water flow on soil surface, due to poor infiltration rate, causing erosion and removal of the soil top layer, which is the most fertile. The degree of compaction in a soil is a function of its type and traffic intensity, among others.

New technology that comes with mechanization of field operations brings a larger degree of heavy equipment traffic in the field, which is worsened when trash recovery by baling is practiced. All this will aggravate the soil compaction problem. Therefore, special attention should be paid to this point when designing these equipments.

Normally the soil decompaction is done with the use of subsoilers.

22.4.6 Risk of surface water contamination by liquid effluents

Liquid effluents from the industrial part of sugar cane sector have a very high pollution potential due to their large volumes and high concentration of organic matter. If these effluents were discharged in streams or lakes the organic matter concentration limits set by Federal Regulations for Class 2 rivers (CONAMA 20: BODmax = 5mg/L) would be exceeded; the levels of pH, solids concentration, nitrogen, phosphorus and temperature would also be extremely deleterious to the water fauna and flora as well as to downstream water users.

Fertirrigation is the solution adopted to mitigate effects of industrial effluents in the physical environment.

It is based on the principle of avoiding discharge of these effluents in water bodies by optimizing the reuse (internal recirculation) and using the surplus in cane fields. It is important to point out that this technique completely eliminates pollution of surface water and brings the benefit of a better use of water, energy and nutrients but it may cause other type of impact with a possible contamination of the ground water that will be discussed later.

Unburned cane mechanical harvesting will eliminate one potential source of pollution that is the cane washing water, with benefical effects on water resources.

22.4.7 Risks of ground water contamination by leaching

The applications of fertilizers and herbicides in cane fields are mandatory to assure good cane yield; for an average yield of 75 tons/ha, the nutrient balance in the stalks and leaves can vary from 60 to 100 kg/ha for nitrogen, 20 to 40 kg for phosphorus and 100 to 150 kg/ha for potassium.

When these values are compared with nutrient quantities provided by fertilizers it can be seen that there is no significant surplus and, therefore, it is not probable that ground water will be contaminated by leaching of these products. Besides they are fixed in the soil.

With respect to use of vinasse and waste water in fields, studies conducted by São Paulo State Environmental Agency (CETESB) in the region of Piracicaba have shown that cane acts as a filter, not allowing high concentration of polluting products to pass to the water table. The trash blanket left on the ground will increase this filter effect of the cane.

22.4.8 Risks of silting and contamination of the water bodies

Rain water carries particles and nutrients from exposed soil surface to water bodies. The nutrient inlet will cause eutrophication of these bodies and particles will result in silting and increase in turbidity.

Deposition of the material on the shores and in places of lower water flow destroys water habitat, covers organisms that live in the mud and fish eggs and favors the invasion by water and land plants. Besides, material either dissolved or suspended in water reduces the sunlight penetration indispensable to development of mud algae, food for herbivorous animal and important link in the food chain. The result is the rupture of the food chain and disappearance of several water species. Fertilizers and vinasse can be also carried out by rain water, reaching water bodies, increasing their nutrient concentration and causing their eutrophication.

With the new technology of unburned cane harvesting the trash cover will protect the soil from erosion reducing or eliminating the above described negative impacts.

22.5. Biological environment: Vegetation and fauna

The evaluation of the impacts resulting from changes in biological environment is summarized in **Table 136**.

22.5.1 Reduction of vegetation and fauna due to risk of fires

Besides mitigation measures suggested to decrease or prevent problems caused by loss of visibility resulting from planned or accidental fires (as described below) it makes necessary one more mitigation measure necessary, consisting of clearing of areas by the side of the cane field roads that borders the natural forests.

Avoiding cane burning is another mitigation measure that if adapted by the sugar cane sector will bring a significant contribution toward maintaining at least the existing conditions of vegetation and fauna, that are today under pressure from all agricultural sectors.

22.5.2 Risks to the fauna and interference in the food chain

It can be stated that monocultures are unstable ecosystems and are more vulnerable to competition, parasites attacks, diseases, predatory attacks and other negative interactions. With extreme reductions of vegetal species, animal diversity diminishes and, therefore, severe changes in the fauna are found in such environments.

Soil preparation destroys the vegetation cover that eventually existed which is the habitat providing food, shelter and reproduction grounds to the fauna. Birds and other vertebrates are specially hurt by this situation and they look for other places to live. As possible consequences are the disappearance of species, reduction in biodiversity and rupture of the food chain.

Table 136

Qualification impacts resulting from changes in the biological environment.

Impacts	Reduction of vegetation and fauna due to the risk of fires	Risks to the fauna and interference in the food chain
Group of activities	3	2, 3
Type	Negative	Negative
Space effect	Local	Local
Temporality	Permanent	Permanent
Reversibility	Irreversible	Irreversible
Intensity	Low	Low
Tendency	Growing	Growing
Relevance	High	Medium
Mitigation measures	Preventive, Corrective	Preventive, Corrective, Compensating
Relevance after mitigation	Low	Low

Other changes in soil characteristics such as pH and structure can result in similar impacts. Other habitats are created and new species can appear.

The fully grown cane plant will provide new habitats but certainly they will not be comparable to those provided by natural forests or even by other monocultures, such as coffee, due to the shape of the leaves and distribution of vegetal species. With respect to birds, only a few species of pigeon (Columbidae) can nest in cane fields. The phase out of cane burning will provide new niches for small animals.

Soil fauna can also suffer species substitutions. Herbicides and pesticides can be stored by some species and be lethal to others, which will cause the disappearance of some animals and rupture in the food chain with a final loss of biodiversity.

A trash blanket on the soil will provide adequate conditions for increased biological activity in the top layer of the soil favoring the activity of insects building tunnels and incorporating organic matter in the soil that adds to fungus action in decomposing the old roots leading to a new soil structure that will favor the food chain, attracting birds and other predators. Cane burning will kill or scare animals leading to vanishing of species.

The carry over of nutrients to water bodies, by erosion or effluent discharge, can also cause the eutrophication of water (uncontrolled algae growth) and creation of new habitats that will be occupied by other species of microorganisms, bringing negative impacts to water fauna and other waters users.

Mitigation measures taken in other environment to minimize impacts caused by cane culture, such as biological control, crop rotation, protection of shore vegetation among others, indirectly will mitigate the impacts on the fauna. However, cane burning phase out, when completed, will bring a significant contribution to maintain the existing vegetation and fauna conditions, that are already degraded by the use of land for agriculture in general.

22.6. Anthropic environment

The evaluation of impacts caused by changes in the anthropic environment is shown in **Table 137**.

22.6.1 Health hazard for the population due to air pollution

Air pollution can be produced by programmed or accidental cane burning, trash burning after harvesting and bagasse burning in boilers.

Cane burning is intended to facilitate manual harvesting. This is a common practice in most sugar cane producing countries.

However, the Evaluation Report of Air Quality in the State of São Paulo in 2000, published by state of São Paulo Environmental Protection Agency (CETESB – 2001), shows that the air quality in 17 cities forming the monitoring network in the state never exceeded the limits for NO_2, CO and smoke, which are the main pollutants from the sugar cane sector activities. In past years the smoke limits have been exceeded mainly in the city of Sorocaba, which is not in a cane growing area. Cities like Ribeirão Preto and Araraquara, located in major cane growing

Table 137

Qualification of the impacts caused by changes in the anthropic environment

Impacts	Group of activties	Type	Space effect	Tempo-rality	Reversi-bility	Inten-sity	Tendency	Rele-vance	Mitigation measures	Relevance after mitig.
Health hazard to the population from air pollution	2,3,4	(-)	L	TE	RE	L	G	L	P	N
Fly ash and soot nuisance	3	(-)	L	TE	RE	H	G	L	P	L
Loss of visibility in highways due to smoke from cane burning	3	(-)	L	TE	RE	M	G	M	P,C	L
Contamination risks for workers by herbicides and pesticides	2	(-)	L	PE	I	H	G	H	P	N
Increase in tax collection	1,2,4	(+)	R	PE	I	H	G	H	-	H
Increase in permanent employment level and standard of living	1,2,3,4	(+)	R	PE	I	H	G	H	T	H
Reduction in seasonality of jobs	3	(-)	R	TE	RE	M	G	M	P	L
Need for infrastructure conservation (cleaning, maintenance and security)	3	(-)	R	TE	RE	L	S	L	P,C	L

Symbols:

Type	Space effect	Temporality	Reversibility	Intensity	Tendency	Relevance	Measures
(+) positive	L -local	TE-temporary	RE-reversible	L-low	G-growth	N-nihil	P-preventive
(-) negative	R -regional	PE-permanent	I-irreversible	M-medium	S-stagnation	L-low	C-corrective
	G -global			H-high	D-decrease	M-medium	M-monitoring
						H-high	T-compensating

regions, have not shown air quality problems, what proves that the activities of the sector have not caused major negative impacts in the air quality of large cities, except in cane field border areas.

Of course, implementation of unburned cane harvesting technology will improve air quality, mainly in areas close to cane fields. Sugar cane field burning can also be caused by accident or even arson. This causes economics losses to the affected mill since the burned cane will have to be harvested without its best sugar content and without logistics optimization (harvesting front location, availability of transportation means and mill crushing capacity). Besides air pollution problems these unplanned fires have higher hazard for propagation to neighboring properties and forests and result in poor visibility in highways.

Trash that remains in the field after burned cane harvesting (specially the tops) is normally windrowed and burned. Those who defend this practice state that it destroys places where pests could develop; on other hand the availability of organic matter decreases, soil protection against erosion is lost, the need for herbicides increases and air pollution increases. The case is even stronger for case of unburned cane harvesting. Fire hazard is greater with negative impacts of accidental fires, such as threat to workers and equipment, and damage to cane ratoon in the beginning of its development.

On the industrial side, boiler emissions are the major source of air pollution. The average flow of flue gas is 1.5 – 2 Nm^3/kg steam with approximate concentration of 4000 mg/Nm^3 for particulates (without any particulate control devices) and 0.3% for CO. NOx emissions are estimated as 0.27 kg NOx/t steam (USEPA). After abatement from use of emission control equipment such as scrubbers and dilution there are no significant changes in air quality and the limits set by the National Committee for Environment Regulation (CONAMA 3/1990), which are 320 mg/Nm^3 in one hour and 100 mg/Nm^3 for NOx annual average, are normally met by conventional systems and should be more easily met with the BIG-GT technology. BIG-GT system will have higher efficiency in power generation and will enable better emissions control.

22.6.2 Decrease in visibility in highways due to smoke from cane burning.

Accidental or arson fires in cane fields or trash blankets, besides danger of spreading into forests and neighboring properties, produce smoke that can reduce visibility in highways significantly increasing risk of accidents. Planned fires take into account the topography, prevailing winds direction and speed, proximity of other vegetation, roads, power transmission lines and other. During this operation two teams are used, one to set fire and the other to monitor and control its development, formed by specifically trained people and supported by an adequate infrastructure (water truck, tractor for cleaning areas, etc.). In cases of unplanned fires, emergency procedures are used to minimize negative impacts, including warning of highway patrol when the threat of visibility loss in highways exists.

22.6.3 Fly ash and soot nuisance for the population

Trash burning produces, besides polluting gases, fly ash and soot that are the major cause of complains from population of affected areas. These materials are normally carried by strong updraft currents and transported by wind to reasonably long distances, and when deposited on the ground, cars, laundry, swimming pools or even inside the houses, cause constant complains from the population. Unburned cane harvesting will eliminate this problem and will be welcome by the population of cane growing areas.

22.6.4 Workers risks of poisoning by pesticides and herbicide

Poisoning of field workers with pesticides and herbicides can occur by accident or by improper handling of these hazardous chemicals during transportation, storage, preparation, application, container disposal, equipment and cloth washing. Use of trash blanket to hinder weed growth will reduce substantially this contamination hazard and it can, therefore, be considered a mitigation of this negative impact.

22.6.5 Increase in tax collection

Mechanization of agricultural operations, specially harvesting, will increase demand for technical assistance services, fuels, lubricants and spare parts besides the initial call for equipment, agricultural implements and industrial equipment. This will increase business and trade with a consequent increase of state, federal and income taxes.

New buildings for parking and maintenance of the new fleet requires design, construction and erection services that call for specialized manpower and an increase in salaries and tax collection are to be expected.

22.6.6 Increase in permanet jobs and improvement of the standard of living

In general, sugar cane production, from soil preparation and planting to its delivery to the mill for processing generates a series of social and economic impacts mainly due to the considerable number of workers involved. Labor use occurs in mill owned, rented and independent cane growers land, with the highest mobilization during the six to seven months harvesting period of. This seasonality has caused temporary migration of people from poorer regions.

Sugar cane agroindustrial activity is considered a very important source of jobs in Brazil. The number is estimated to be one million with around 80% in the agriculture area. Sugar cane is one of the cultures with highest number of jobs per planted hectare.

The evolution of mechanical harvesting in unburned fields is already occuring, motivated by new specific legislation and environmental pressures, independently of the use of trash as an energy source, with a job offer reduction of 164,500 jobs.

The use of thash as an energy source will create approximately 15,400 jobs in the agricultural area, using trash baling or 1,450 jobs using the partial cleaning alternative. Labor increase in the industry has been estimated in 16,000 new jobs.

22.6.7 Reduction in labor seasonality (migration)

Labor seasonality is a reality in all types of agricultural activities. A report about impacts of PROALCOOL (Brazilian Alcohol Program) in São Paulo state points out that between 1974 and 1979, in the Ribeirão Preto region, there was an increase of approximately 24,000 ha in cane planted area 64% come from pasture land, 32% from rice, corn, beans and cassava plantations and 4% from cotton and castor bean. An analysis of the data indicates that if that area had remained with the original agricultural options, it would employ around 2,360 men-day per year, that is, 0.01 worker/ha. The sugar cane culture employs approximately 22,700 men-day per year, or 10 times more people.

The migratory movements represent, in general, population displacements from areas that do not offer jobs to areas with better job opportunities. This represents a negative impact from the migrant worker point of view since he is getting an income but remains without a job after the crop season. Also, counties that host these migrant workers are negatively affected since an infrastructure of assistance to such workers is needed but seldom available.

The technology of unburned cane mechanical harvesting will practically eliminate the need for temporary labor during the harvesting period. The number of workers needed in cane fields will remain nearly constant year round, resulting in permanent jobs. However, it must be considered that loss of jobs, even temporary ones, is a negative impact to the country, which can only gradually be mitigated.

22.6.8 Demand for infrastructure (cleaning, maintenance and security) conservation

The sugar cane culture produces high figures for weight of biomass per unit area, e. g. while grain crops produce around 3,000 kg/ha, sugar cane crop reaches 75,000 kg/ha of stalks.

Sugar cane transportation to the mill is a high cost activity representing roughly 25% of the total cane production cost. Therefore, a good and well planned road system is required to reduce operating and maintenance costs; the traffic safety rules shall not be overlooked.

As a consequence, county roads are improved and kept in reasonably good conditions in sugar cane areas. Normally county roads are poorly designed, and when subjected to heavy traffic tend to be at a lower level compared to neighboring land, making difficult rain water drainage. Improvement and maintenance of secondary roads, performed by the private sector, benefits the whole population in the area as they are also used for people transportation and also for products of other crops.

The most significant impacts of sugar cane in secondary road systems are fall of cane stalks on road surface, damages by heavy weight vehicles, mud accumulation in primary roads, safety hazard in machinery transportation and long trucks. The use of workers to collect fallen cane stalks has been a normal practice but this problem tends to disappear when mechanized chopped cane harvest is used.

22.7. Final discussion

22.7.1 Benefits and advantages

The elimination of sugar cane burning prior to harvesting and the formation of a trash blanked on the ground can bring benefits to the cane production system and to the environment. The main effects and their consequences are:

- Protect the soil against erosion caused by rain and wind. This protection has the following consequences:
  - Reduction of dust level in the air;
  - Elimination of silting, pollution and contamination of water bodies with herbicides;
  - Adaptation of soil conservation practices that are simple, more economic and effective;
  - Introduction of minimum tillage systems.
- Avoid the direct incidence of sun light on the ground surface, that would:
  - Decay organic matter by photodecomposition;
  - Increase surface temperatures causing higher water losses by evaporation.
- Supply organic matter and nutrients to soil and plants after vegetal matter decomposition, making it possible to:
  - Reduce necessity of chemical fertilizers and soil improve conditioners;
  - Reduce sugar cane production costs;

- Increase the activity of colloids in degraded soils.
- Decrease surface water flow.
- Increase biological activity in the soil top layer, favoring:
  - Activity of insects and worms, opening tunnels and incorporating vegetal matter, as well as fungus decomposing old roots improving water infiltration and soil aeration.
  - Reintroduction of insects and fungi that are predators of sugar cane pests.
- Control weeds and, consequently:
  - Reduce or even eliminate the use of herbicides;
  - Decrease production cost;
  - Reduce pollution from chemicals and risk to workers health.
- Reduce sucrose losses due to rotting of cane after burning.
- Reduce smoke, soot and gases emissions to the atmosphere, allowing:
  - Less negative impacts on environment;
  - Attenuation of public complains against the sector;
  - Adequate activity to environmental laws.

22.7.2 Problems and disadvantages

Among the problems and disadvantages caused by elimination of cane burning and creation of a trash blanket on soil the following deserve to be mentioned.

- Increase in fire hazard during and after harvesting that could:
  - Damage equipment in use in the operation;
  - Damage ratoon in the early period of sprouting;
  - Bring danger to field workers.
- Make some agricultural operations more difficult and expensive due to trash mass on the field.
- Reduction of hand harvesting productivity and increase in risks of accidents of workers, reptile and insect stings and virus transmission from rodents and other animals.
- Incorporation of part of the trash in the sugar cane transported to the mill, that causes:
  - Loss in quality of the raw material;
  - Loss in load capacity of trucks and loaders;
  - Difficulties in the industrial processing of sugar cane.
- Difficulties in sprouting of some sugar cane varieties may affect final cane yield.
- Difficulties in evaporation of excess water in soils with drainage problems:
  - Hindrance or delay in operations with machinery and mechanical equipment;
  - Delay the sprouting and development of ratoons under low temperature and high moisture conditions in the soil;
  - Damage to cane root systems in soils with high moisture content for long periods of time.
- Increase in biological activity on soil surface and in trash blanket:
  - Favor the growth of pests and dissemination of diseases in cane fields.

22.8. Scenarios

Implementation of unburned cane mechanical harvesting technology presents some highly positive impacts, exception made to loss of jobs associated with a preventive mitigation measure which is the programmed phase out of cane burning; these jobs, although temporary in nature and causing migration, are still important in a country with strong differences. What is left, assured by law, is that implementation of this new technology will be slow and gradual, softening the adverse consequences of the impact.

Possible scenarios for the sugar cane sector, based in possible environmental changes with and without the new technology and bearing in mind that only qualitative assessment is attempted.

22.8.1 Scenario 1

Present situation: Manual harvesting of burned cane is an alternative that produces only bagasse, the residue from cane milling for juice extraction, used as fuel for energy generation for industrial processing of sugar cane. If the present situation is maintained, a typical mill would have all of its environmental impacts balanced by mitigation measures widely used by the sugar cane sector. Clearly, the most important mitigation measures are an integrated part of the system. It is hard to imagine installation and operation of a sugar/ethanol mill without this equilibrium since the mill would be the first to suffer the consequences of not taking mitigation measures for soil protection, waste recycle, rational use of water, crop rotation, search for byproducts markets and many other that bring clear economic benefits to the sector. By not adopting those measures the business would very quickly become technically and economically unfeasible. Besides, a harsh relationship with social institutions and the population in general would be created, considering the environmental awareness existing today.

Local atmospheric conditions would continue to suffer effects of cane burning and the migratory fluxes of temporary workers would continue to put pressure on the infrastructure of cities and towns in cane growing areas, although employment levels would be maintained.

22.8.2 Scenario 2

Future situation: Trend without the implementation of this project and without legal requirement and popular pressures against cane burning (pessimistic scenario): mechanical harvesting of mostly burned cane and in areas harvestesd unburned, trash is left in the field without any use for energy generation.

It is important to point out that without any incentive to economic use of trash as a fuel, Scenario 1 would evolve to Scenario 2 in the medium term mainly due to quick development of mechanical harvesting technology that has advantages when used in burned cane. In this scenario the air pollution problem would persist and the loss of jobs would create social problems.

22.8.3 Scenario 3

Mechanical harvesting of chopped unburned come with cane cleaning by harvester (fans on), trash thrown on the ground, baled and transported to the mill separated from the cane, and used in BIG-GT units.

Implementation of this scenario will lead to incorporation of sugar cane trash use to the production process what can be considered an additional mitigation measure of the preventive type with the corresponding benefits. This would be added to those resulting from traditional measures, bringing a high environmental stability to the sector. The major apparent effects will be felt in the air quality and reduction in herbicide use. It was assumed that there would be equilibrium in the use of trash in the field and in the industry to maximize benefits. Loss of jobs should be mitigated by the slow and gradual penetration of this new technology, as required by law, giving time to create other jobs to absorb those unemployed by harvesting mechanization.

22.8.4 Scenario 4

Mechanical harvesting of chopped unburned cane with the harvester operating with the cleaning fans off and the separation of trash from cane taking place in a cane dry cleaning station installed at the mill, and the processed trash used as fuel in BIG-GT systems.

Environmental impacts and mitigation measures of this scenario are equivalent to those in Scenario 3, provided that the equilibrium in the use of trash in the field and in the industry is also maintained. Soil compaction problems will be smaller in this case since no balers and other trash recovery equipment will be used in harvesting.

22.9. Conclusions

Implementation of unburned cane harvesting and trash recovery technology and use of both to improve soil conditions and to increase power generation in the mill act as positive mitigation measure to the environmental effects of the sugar cane sector, specially concerning to air pollution, although the loss of jobs will have negative effects that could be kept low if implementation occurs slowly. Thus, the sugar cane sector moves in firm steps toward a sustainable production process.

23. Dissemination of project findings and information

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23.1. Introduction

The main purpose in dissemination of project findings is to increase the awareness of the world sugar cane and power generation sectors about the potential of sugar cane residues and advanced power generation technologies, such as integrated biomass gasification/gas turbine (BIG-GT), to provide significant amounts of renewable energy in technical and economically feasible conditions.

Considering that sugar cane is grown and processed in more than 100 countries around the world, the dissemination of good and consistent information would play an important role in opening opportunities for replication, increasing the use of CO_2 neutral power generation technologies.

Two ways were programmed to reach this objective:

- **Project newsletters**
- **Project workshops**

23.2. Project newsletters

The newsletters were intended to be the main written communication medium for the project results and information; during the most active part of the project they were prepared and distributed to a worldwide mailing list, on a quarterly basis, resulting in eight issues. The mailing list has 37 international and Brazilian addresses and several copies of the newsletters were distributed upon request and during main events such as Congresses, Seminars and Workshops dealing with biomass energy and sugar cane production and processing.

Beside the regular project newsletter, special topics have been included in other newsletters of reputable institutions such as the Centro Brasileiro de Referência em Biomassa – CENBIO (Brazilian Reference Center in Biomass, supported by, among others, the Brazilian Ministry of Science and Technology and the Univesity of São Paulo) and União da Agroindústria Canavieira de São Paulo – UNICA (Union of the Cane Agroindustry of São Paulo), which represents more than 80% of the sector in the state of São Paulo. The STAB Jornal (Brazilian Society of Sugar Technologists) published several short articles about the project.

Technical articles about the project have been published in important journals and magazines such as:

- **Energy for Sustainable Development (International Energy Initiative – India);**
- **International Sugar Journal.**

23.3. Project workshops

UNDP, MCT (Ministry of Science and Technology) and CTC agreed that instead of preparing two workshops, as planned in the original project scope, it would be more efficient to disseminate the project findings though presentations, by TPS and CTC, at key sugar sector conferences, seminars and workshops; the International Society of Sugar Cane Technologists (ISSCT) was considered to be one of the main targets, for this purpose.

Oral and poster presentations on the project were given in several events related to sugar cane agroindustry and renewable energy, the most important ones were:

- Fourth Meeting of the Permanent Forum on Renewable Energy, Recife, Pernambuco, Brazil; July, 1998.
- First Brazil / Germany Congress on Renewable Energies, Fortaleza, Ceará, Brazil; September 28 to October 2, 1999.
- First World Bioenergy Conference, Seville, Spain; June 2000.
- Progress in Thermochemical Biomass Conversion, Innsbruck, Austria; September 2000.
- International Society of Sugar Cane Technologists (ISSCT) Workshop on Energy and Cogeneration in the Sugar Mills, Reduit, Mauritius; October 2000.
- International Seminar on Energy in the Sugar Cane Agroindustry, Havana, Cuba; November 2000.

• International Seminar on Biomass for Energy Production (The State of the Art on Bioenergy Technologies), Rio de Janeiro, Rio de Janeiro, Brazil; June 2001.
• 24th Congress of the International Society of Sugar Cane Technologists, Brisbane, Australia; September 2001.
• First International Congress on Biomass for Metal Production and Electricity Generation, Belo Horizonte, Minas Gerais, Brazil; November 2001.
• International Seminar on Cane and Energy Ribeirão Preto, São Paulo, Brazil; November 2001 and August 2002.
• ISSCT Engineering Workshop on Energy Management in Row Cane Sugar Factories, Berlin, Germany; October 2002.
• Second Global Environment Facility Assembly Workshops, Beijing, China; October 2002.

Project funds were used only for participation in the ISSCT workshop in Mauritius and ISSCT Congress in Australia.

A major presentation of Project BRA/96/G31 to the São Paulo state sugar cane sector, power utilities, equipment manufactures and engineering companies was organized by the Ministry of Science and Technology – MCT and Companhia Paulista de Força e Luz – CPFL (the Power and Light utility that has around 80% of the São Paulo sugar/ethanol mills in its concession area). This event took place in the CPFL main office, in Campinas – São Paulo, on May 21, 2002 and made possible the discussion on the use of sugar cane trash and BIG-GT technologies among the main stakeholds.

Besides these main events, other Seminars and Workshops were used to promote the use of sugar cane trash to supplement bagasse and the potential of advanced cogeneration systems, and to increase the public, politicians and law makers awareness about the importance of the sugar cane agroindustry in the energy sector.

Among these events the following can be mentioned:

• Opportunities to Generate Power from Biomass, CENBIO, São Paulo, Brazil; March 1999.
• Third Meeting on Energy in the Rural Areas – AGRENER 2000, University of Campinas, Campinas São Paulo, Brazil; 2000.
• The Sugar Cane Sector and Power Generation, Forum on Brazilian Power Sector Rationalization and Expansion, São Paulo, São Paulo, Brazil; September 2001.
• Economic Uses of Sugar Cane Trash, Piracicaba, County Secretariat for the Environment, Piracicaba, São Paulo, Brazil, April 2002.
• Workshop on Unburned cane – Experience Gained, São Paulo State University, Jaboticabal, São Paulo, Brazil, June 2002.
• Agronomic Week, Espírito Santo do Pinhal Agronomy College, University of São Paulo, Espírito Santo do Pinhal, São Paulo, Brazil; August 2002.
• Workshop on Sugar Cane Cycle and the Environment, Lutheran University of Brazil, Itumbiara, Goias, Brazil; November 2002.

There has been a lot of interactions and information exchange related, to project findings with several important international and national institutions; among them the main ones were:

• Sugar Research Institute (SRI), Australia.
• Mauritius Sugar Industry Research Institute (MSRI).
• Sugar Milling Research Institute (SMRI), South Africa.
• Cenicanã, Colombia.
• Sugar cane Research Unit USDA, USA.
• University of Delft, Netherlands.
• University of Utrecht, Netherlands.
• Ministry of Sugar (MINAZ), Cuba.
• University of Campinas (UNICAMP), Brazil.
• São Paulo Institute of Technology (IPT), Brazil.
• Agricultural College Luiz de Queiroz (ESALQ), University of São Paulo, Brazil.
• Instituto Tecnológico de Aeronáutica (ITA), Brazil.
• Centro Técnico Aeroespacial (CTA), Brazil.
• Companhia Paulista de Força e Luz (CPFL), Brazil.
• Federal University of Itajubá (UNIFEI), Brazil.
• Princeton Environmental Institute, Princeton University, USA.

24. Methodology for economic analysis of high biomass sugar cane varieties

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24.1. Introduction

After the conclusion of all technical tests required for the release of a new variety for commercial use, the agroindustrial margin of contribution is calculated aiming to rank this variety, from the economic point of view. The effects of pol % cane, purity and fiber % cane are considered and given monetary values.

The existing model penalizes a variety with higher fiber % cane, if other parameters are similar, because of sugar carried over by the bagasse and the reduction of milling capacity. However, the model does not account for possible benefits of high bagasse production; the trash contribution is totally ignored.

Unburned sugar cane harvesting results in a large quantity of trash that can be left on the ground, forming a soil-protecting blanket, or can be taken to the mill for uses such as power generation.

Studies have been concentrated in selecting agronomic routes to recover this biomass from the fields and transport it to the mill, either together with or separated from the cane. The cleaning efficiency of the sugar cane harvester can be varied by adjusting the operation of the harvester cleaning system; variations from 0 to 76% have been obtained in the field tests performed and still maintaining the harvester performance at reasonable levels. Once the trash recovery route is defined, any variation in the trash % cane among the different varieties in the cane fields, as well as the changes in fiber % cane, will result in variations in the average fiber content of the material fed to the mill tandem, because part of the trash will be sent to the mill together with the sugar cane (vegetal impurity).

Thus, it has been considered that the existing economic model of variety ranking using the concept of agroindustrial margin of contribution shall take into account the effect of the trash amount in the variety and to evaluate in more detail the parameter fiber % cane.

This methodology analysis has been conducted to modify the model of variety ranking using the "agroindustrial margin of contribution" concept in such a way to take in account the influence of the variations in trash % cane and fiber % cane, allowing all parameters and peculiarities of the agroindustrial process to be considered.

» Objective

To calculate the effect of changes on trash % cane and fiber % cane on the material to be milled at the factory, as well as to obtain all parameters that can be affected in the sugar, ethanol and by products – bagasse and trash – production in such a way to be able to include them in the model to calculate the agroindustrial margin of contribution of the sugar cane variety.

24.2. Economic concept

After studying the influence of the parameters that interfere in the economic result of a sugar and ethanol producing plant it was decided that the best economic concept to be used in this analysis is that of margin of contribution. The agroindustrial margin of contribution (MC) of a sugar cane variety is basically a function of pol % cane, productivity (ton cane/ha), fiber % cane, purity and trash % cane (ton trash / ton cane).

The margin of contribution is the difference between the sale price of the products (free of taxes) and the variable production cost; the equation for MC that takes in account the variations of the above parameters, can be defined in a very simple way, for each hectare of harvested sugar cane, as an addition of terms related to cane, fiber and trash, as shown below:

$$\mathbf{MC = MC_{cane} + MC_{fiber} + MC_{trash}}$$

Where:

MC = agroindustrial margin of contribution of the variety (US$/t cane)

To rank the varieties from the economic point of view, the MC of a new variety, named "challenger", should be compared with the MC of the existing variety collection, in such a way to find its place in the ranking.

24.3. Effects of the variations in fiber % cane and trash % cane in the mill

It is known that variations in fiber % cane will affect directly the production of sugar, ethanol and bagasse in a similar way as variations in cane productivity, pol % cane and purity. The trash has a different effect from fiber % cane since changes in the trash production per hectare (ton trash/ha) will result in a variation of vegetal impurities in the material processed by the mill and in the quantity of recoverable trash. This latter effect is directly related to harvester cleaning efficiency (trash separation from the cane during the harvesting operation) and the efficiency of the baling machine in recovering trash from the ground (in the case of baling).

The trash fraction that is not separated from the cane by the harvester becomes vegetal impurity and is taken along with the cane to the mill. The variation in the amount of vegetal impurity in the material that is being milled will affect the production of sugar, ethanol and bagasse in a similar way as the variation of fiber % cane; however, the vegetal impurity participation in the total bagasse is much smaller than that of the stalk fiber.

For the sake of a better understanding of the fiber origin it is considered that the material milled is formed by cane stalks (with a fiber % cane) and vegetal impurities (the fractions of trash that is added to the cane stalks being milled).

This fact is very important because 100% of the variation in the fiber % cane is incorporated to the material processed by the mill tandem (13.44% fiber % cane is considered for the standard cane variety). Roughly, 92% of the milled material is cane stalks for unburned cane harvesting (8% is vegetal impurities) which results in 12.4 percent points (13.44% x 0.92) of the fiber % milled material. In a similar fashion, the impact of the trash % cane variation can be estimated. Vegetal impurities, with 40% fiber, represent around 8% of the milled material weight; so the trash fiber will participate with 3.2 percent points (8% x 0.40) of the total milled material fiber.

In this case, the resulting total milled material fiber is around 15.6% (12.4 fiber from stalks plus 3.2 fiber from trash) and, therefore, the stalk fiber represents around 80% of the total milled fiber and the importance of the stalk fiber variation will be of this magnitude.

Around 30% of the total trash is incorporated in the sugar cane, as vegetal impurity, as a consequence of the partial cleaning of sugar cane by the harvester in the field (the harvester efficiency is around 70%), therefore, any percentage unit variation in the quantity of trash has an impact of 0.06 on the fiber content of the material to be milled (1% x 0.30 x 0.20).

Other important impact of the fiber variation on the milled material is its effect on the capacity of the milling tandem. Some studies were carried out to produce technical information about this subject and the conclusion is that variations in fiber % material milled change the milling capacity by half of the fiber variation (inversely proportional).

New milling capacity / Old milling capacity = 1 - { (0.5 * [(New fiber - Old fiber) / Old fiber] }

It was reported that variation in fiber % cane and in the participation of trash in the processed material as vegetal impurity will result in changes in the final sugar, ethanol, bagasse and trash production and, consequently, it will have an effect in the MC of the sugar cane variety.

This total effect can be quantified by dividing it in two parts: variation in the sucrose extraction efficiency of the milling tandem and the carryover of sucrose by the bagasse; in this study only this latter effect has been considered and it was quantified considering that the amount of sucrose carried over is proportional to the total amount of bagasse produced (stalk and trash fibers).

As mentioned, an increase (decrease) in fiber % milled material results in a reduction (increase) in the milling capacity by 50% of the variation in fiber. Variation in the milling capacity will have direct impact in the length of the crushing period, for the same tonnage of cane stalks. This will have an effect in average pol % cane of the season as well as in the total cost of temporary labor (contracted for the crushing period only) in the factory (variation in temporary labor in the field is neglected, as it is more related to the cane tonnage).

Changes in the crushing season length, if significant, will result in more or less cane being harvested and milled in the season extremes (beginning and end), when the pol % cane is less than in the middle of the season. This fact will result in changes in the total sugar and ethanol production (factory recovery).

An average pol % cane curve for Copersucar mills along the crushing season, assuming the milling rate to be constant in the period, has been compared with another curve with the start 12 days after and the end 12 days before the extreme points of the original curve (24 days reduction in the crushing season length). The calculated pol % cane increase was around 0.075 percent points. Considering that the average pol % cane for the standard cane was 14.32% the resulting pol % cane due to this 24 days reduction in the season length would be 14.395%, which represents a 0.53% increase in sugar content of the total milled cane. The effects of fiber variation in the season length has been quantified and the corresponding changes in average pol % cane as a function of season length variation has been used to calculate the variation of total sugar in cane (**Table 138**).

Table 138

Impacts of the crushing season length variation on the average pol % cane.

Variation in season length	Impact on average pol % cane (in points % per day)	Variation in sugar and ethanol production
1 day to 5 days	0.0040	0.028% - 0.140%
6 days to 10 days	0.0045	0.189% - 0.314%
11 days to 15 days	0.0050	0.384% - 0.524%
16 days to 20 days	0.0055	0.615% - 0.768%

The variation in total temporary labor cost is known to be small but was considered. For the typical mill adopted in all modeling, the following temporary workers data have been considered.

a) Total workers: 150
b) Temporary workers: 20% of total
c) Average wages and social costs: US$ 647.06/month per worker
d) Working hours: 220 h/month or 7.33 h/day per worker

Variations in the season length from 1 to 20 days have been used to calculate the changes in temporary labor costs with the corresponding impacts on the agroindustrial margin of contribution in a range from US$ 0.092/t cane to US$ 1.843/t cane.

24.4. Detailing of the economic model

As mentioned before, the "agroindustrial margin of contribution" used to rank the sugar cane varieties is calculated based on the variations in the production of sugar, ethanol and by products bagasse and trash, and the corresponding margins of contribution (difference between selling price and production cost), as well as the variety productivity and the costs associated to the agricultural activities soil preparation, planting, tillage and harvesting. Therefore, the agroindustrial margin of contribution can be calculated from:

MC = Qsug * MCsug + Qaeth * MCeth + (Qbag + Qtrash) * MCbag - Ccane

Where:

- MC = margin of contribution of the sugar cane variety (US$/t cane)
- Qsug = amount of sugar produced (kg)
- MCsug = margin of contribution of sugar (US$/kg of sugar)
- Qeth = amount of ethanol produced (L)
- MCeth = margin of contribution of ethanol (US$/L ethanol)
- Qbag = amount of surplus bagasse (t)
- Qtrash = amount of recovered trash (t)
- MCbag = margin of contribution of bagasse and trash (US$/t)
- Ccane = sugar cane production cost (US$/t cane)

Defining factory margin of contribution (MCI) as:

MCI= Qsug * MCsug + Qeth * MCeth

Then, the previous equation will become:

MC = MCI + (Qbag + Qtrash) * MCbag - Ccane

For the sake of simplicity, the margin of contribution of trash is assumed to be equal to that of bagasse, since both by products will have the same end use – fuel.

As mentioned above, the variation of fiber % cane will impact on the crushing season length and the sucrose carryover by the bagasse. A change in the crushing season length has a direct impact on the temporary labor costs in the factory and in the average pol % cane of the season.

The variations in the sucrose carryover by the bagasse and in the average pol % cane will affect directly the total production of sugar and ethanol. The variation of the pol % cane will be incorporated in the economic model by the resulting change in total production of sugar and ethanol, since there is no other effect in the mill costs, except in the sugar and ethanol variable production costs; thus, it is directly related to the factory margin of contribution of each product.

As explained before, this factor could result in changes in total production of sugar and ethanol from 0.028% to 0.768% for season length variations from one to 20 days; this range corresponds to a linear variation of 0.0384% per day. Therefore the magnitude of this effect in the factory margin of contribution is:

NDays Effect= (-) 0.000384 * NDays * MCI

Where:

NDays = variation in number of days of season

It is important to point out that the number of days can be either positive or negative depending on how the fiber % cane has changed in relation to the standard fiber % cane of 13.44 and how the total fiber of the milled material varied in relation to the reference number of 14.03 (average vegetal impurity of cane 85% harvested burned and 15% harvested unburned). In other words if the fiber % cane increases the season length will increase and the pol % cane will decrease and vice versa.

For the sake of simplicity, the variation of the milled material fiber content is proportional to the increase of fiber % cane. With this simplification, the variation in the season length, in days (NDays), can be calculated as:

$$NDays = [(Fib_c - 13.44) / 13.44] * 0.5 * 180$$
$$NDays = 6.6964 * (Fib_c - 13.44)$$

Where:

- 0.5 = expected reduction of milling capacity
- 180 = average season length in days
- Fibc = fiber % cane

The expression of the number of days described above can be included in the equation of the impact of the fiber % cane variation in the season length as below:

$$NDays\ effect = (-)\ 0.000384 * (6.6964 * (Fib_c - 13.44)) * MCI$$
$$NDays\ effect = (-)\ 0.00257 * (Fib_c - 13.44) * MCI$$

The sucrose carryover by the bagasse is around 4.3% of the total sugar in the milled material, considering the reference fiber % cane of 13.44. Tests have shown that each one point percent of the fiber % cane variation represents a variation in the sucrose carryover by the bagasse around 0.287%. This effect will affect directly the total production of sugar and ethanol and, consequently, the factory margin of contribution of each product. This parameter can be added to the expression of agroindustrial margin of contribution and the effect is similar to the pol % cane variation:

$$Bagasse\ losses\ effect = (-)\ 0.00287 * (Fib_c - 13.44) * MCI$$

The minus sign is due to the fact that the increase of the fiber % cane should increase the sugar carryover by the bagasse and, consequently, cause the reduction of the factory margin of contribution.

The modification of the temporary workers quantity will be incorporated in the expression of the agroindustrial margin of contribution as US$ 0.092/ton cane, per working day. This value has been already detailed in this report, and will be negative or positive with the decrease or the increase in the season length, in relation to the standard fiber % cane of 13.44. This parameter can be introduced in the agroindustrial margin of contribution in the following way:

Workers effect = (-) 0.092 * NDays or

Workers effect = (-) 0.092 *6.6964 * (Fib_c - 13.44) or

Workers effect = (-) 0.6228 * (Fib_c - 13.44)

The minus sign in this expression results from the fact that an increase in the fiber % cane will increase the season length, consequently, it will increase the temporary labor cost and will decrease the agroindustrial margin of contribution of the sugar cane variety.

Several simulations have been executed and the conclusion is that for each one point percent of the fiber % cane variation corresponds to 25.78% increase in the amount of surplus bagasse (bagasse that exceeds the quantity needed to run the factory). This effect has a direct impact on the bagasse margin of contribution. Introducing this effect in the expression of the agroindustrial margin of contribution:

Bagasse amount effect = 0.2578 * (Fib_c - 13.44) * Qbag * MCbag

The variation of the trash quantity in the sugar cane variety can have, basically, two effects:

a) Quantity of trash available (it was adopted 14% of the sugar cane production that is equivalent to 11.65 ton dry matter per hectare).

b) Variation in the fiber % milled material (cane + vegetal impurity), since part of trash is not totally separated from the cane by the harvester in the field; it is incorporated to the material to be processed by the milling tandem.

Therefore, even if the fiber % cane does not change, the milled material fiber content can be modified, due the variation in the quantity of trash transported with the sugar cane sent to the mill.

The above effects have different impacts on the agroindustrial margin of contribution since a sugar cane variety that produces a larger amount of trash allows a recoverable trash amount that is approximately proportional to the trash content and it results in a higher sucrose carryover by the bagasse that is proportional only to the amount of trash that becomes vegetal impurities (around 30% of the total trash).

It has been determined that for each one percent point in variation in the trash % cane (around the reference value of 14%) results in a variation of:

a) 6.67% in the recoverable trash;
b) 1.66% in bagasse production;
c) 0.021% of sucrose carryover by the bagasse.

Since the change in fiber content of the milled material is small, the variation in milling capacity and the associated change in season length has been neglected. Therefore, the impacts of these effects on the agroindustrial margin of contribution can be quantified as:

Other effects = 0.0667 * ($Trash_c$ - 14.00) * Qtrash * MCtrash +
0.0166 * ($Trash_c$ - 14.00) * Qbag * MCbag +
(-) 0.00021 * ($Trash_c$ - 14.00) * MCI

Where:

$Trash_c$ = trash % cane.

24.5. Agroindustrial margin of contribution equation

The combination of all effects quantified in the previous items will provide the equation to calculate the agroindustrial margin of contribution of a sugar cane variety as (in US$/t cane):

MC = MCI + (Qbag + Qtrash) * MCbag - Ccane + (-) 0.00257 * (Fib_c - 13.44) * MCI + (-) 0.6228 * (Fib_c - 13.44) + (-) 0.00287 * (Fib_c - 13.44) * MCI + 0.2578 * (Fib_c - 13.44) * Qbag * MCbag + 0.0667 * ($Trash_c$ - 14.00) * Qtrash * MCtrash + 0.0166 * ($Trash_c$ - 14.00) * Qbag * MCbag + (-) 0.00021 * ($Trash_c$ - 14.00) * MCI

Assuming the same margin of contribution for trash and bagasse, the above equation will become **Equation 01**,

$$MC = MCI * [1 - 0,00257 * (Fib_c -13.44) - 0.00287 * (Fib_c - 13.44) - 0.00021 * (Trash_c - 14.00)] +$$
$$MCbag * [Qbag + Qtrash + 0.2578 * Qbag * (Fib_c - 13.44) + 0.0166 * Qbag * (Trash_c - 14.00) +$$
$$0.0667 * Qtrash * (Trash_c - 14.00)] (-) 0.6228 * (Fib_c -13.44) - Ccane$$

that can be simplified as **Equation 02**.

$$MC = MCI * [1 - 0,00544 * (Fib_c -13.44) - 0.00021 * (Trash_c - 14.00)] +$$
$$MCbag * \{ Qbag [1 + 0.2578 * (Fib_c - 13.44) + 0.0166 * (Trash_c - 14.00)] +$$
$$Qtrash *[1 + 0.0667 * (Trash_c - 14.00)] \} + (-) 0.6228 * (Fib_c -13.44) - Ccane$$

The variable Ccane (US$/t cane), that is entirely related to the agricultural aspects
of the sugar cane variety under consideration, can be expressed as:

$$Ccane = Charv + (Ctillage / Yield) + [(Cplant * CRF_{(n,i)}) / Yield]$$

Where:

- Charv = harvesting cost (US$/t cane)
- Ctillage = tillage cost (US$/ha)
- Yield = sugar cane variety yield (t cane/ha)
- Cplant = soil preparation and planting costs (US$/ha)
- $CRF_{(n, i)}$ = capital recovery factor, for n years and i interest rate

n = useful life of the cane field (it has been adopted as 5 years)

i = minimum interest rate considered attractive (assumed as 12%)

With these values for n and i the CRF has been calculated and substituted in the equation, resulting in:

$$Ccane = Charv + [(Ctillage + Cplant * 0.2774) / Yield]$$

Taking into account that:

$$MCI= Qsug*MCsug + Qeth*MCeth$$

And using the above expression for Ccane, the final equation for the agroindustrial margin of contribution is showed in **Equation 03**.

$$MC = (Qsug * MCsug + Qeth * MCeth) * [1 - 0,00544 * (Fib_c -13.44) - 0.00021 * (Trash_c - 14.00)] +$$
$$MCbag * \{ Qbag [1 + 0.2578 * (Fib_c - 13.44) + 0.0166 * (Trash_c - 14.00)] +$$
$$Qtrash *[1 + 0.0667 * (Trash_c - 14.00)] \} +$$
$$(-) 0.6228 * (Fib_c -13.44) - Charv - [(Ctillage + Cplant *0.2774) / Yield]$$

24.6. Quantification of agroindustrial margin of contribution

Using the production parameters of the typical mill, the data developed in the Project BRA/96/G31 and the reference cane data, the outstanding parameters values are (average harvesting conditions have been assumed as: 15% of unburned cane and 85% of burned cane).

- Qsug = 59.35 kg sugar/t cane
- Qeth = 47.38 L ethanol/t cane
- MCsug = US$ 0.080/kg sugar
- MCeth = US$ 0.095/L ethanol
- Fiber % cane = 13.44
- Trash % cane = 14.00
- Qbag = 57.93 kg bagasse/t cane
- Qtrash = 17.34 kg trash/t cane (same moisture content as bagasse)
- MCbag = US$ 0.005/kg bagasse (or trash)
- Charv = US$ 4.82/t cane
- Ctillage = US$ 144.74/ha

• Cplant = US$ 540.11/ha
• Yield = 83.23 t cana/ha

With this data MC can be calculated as

MC = 4.75 + 4.50 + 0.38 - 4.82 - 1.74 - 1.80

MC = US$ 1.27/t cana

The specific margins of contribution are:

• MCsug = US$ 4.75/t cane;
• MCeth = US$ 4.50/t cane;
• MCbag = US$ 0.38/t cane (bagasse plus trash);

The US$ 0.38/t cane corresponds to US$ 0.29/t cane for bagasse and US$ 0.09/t cane for trash.

24.7. Effects of fiber % cane and trash % cane on the agroindustrial margin of contribution

In this item it will be quantified the impacts of independent variations of one percent point in the fiber % cane (13.44% ± 1.00%) and trash % cane (14.00% ± 1.00%) in the agroindustrial margin of contribution of a sugar cane variety.

The variation of one percent point in the fiber % cane, keeping all other parameters the same (pol % cane, purity, productivity and trash % cane) will cause the following changes in the parameters listed before.

• Qsug = 59.14 kg sugar/t cane
• Qeth = 47.22 L ethanol/t cane
• MCsug = US$ 0.080/kg sugar
• MCeth = US$ 0.095/L ethanol
• Fiber % cane = 14.44 (13.44 + 1.00)
• Trash % cane = 14.00
• Qbag = 78.06 kg bagasse/t cane
• Qtrash = 17.34 kg trash/t cane (same moisture content as bagasse)
• MCbag = US$ 0.005/kg bagasse (or trash)
• Charv = US$ 4.82/t cane
• Ctillage = US$ 144.74/ha
• Cplant = US$ 540.11/ha
• Yield = 83.23 t cane/ha

The new MC will be:

MC = 9.171 + 0.497 – 0.623 – 4.82 – 1.74 – 1.80

MC = US$ 0.69/t cane

Thus, an increase of one point percent of the fiber % cane (13.44 to 14.44), with all the other parameters constant, resulted in a decrease of US$ 0.58/t cane, or 46% in the agroindustrial margin of contribution of the sugar cane variety considered. Needless to say that this is a significant impact.

In the same way, the increase of one point percent in the trash % cane (14.00 to 15.00) will result in the following set of parameters, when all other variables are kept constant:

• Qsug = 59.29 kg sugar/t cane
• Qeth = 47.40 L ethanol/t cane
• MCsug = US$ 0.080/kg sugar
• MCeth = US$ 0.095/L ethanol
• Fiber % cane = 13.44
• Trash % cane = 15.00
• Qbag = 58.91 kg trash/t cane

- Qtrash = 18.58 kg de trash/t cane (same moisture content as bagasse)
- MCbag = US$ 0.005/kg bagasse (or trash)
- Charv = US$ 4.82/t cane
- Ctillage = US$ 144.74/ha
- Cplant = US$ 540.11/ha
- Yield = 83.23 t cane/ha

The MC for this case is:

MC = 9.244 + 0.399 - 4.82 - 1.74 - 1.80

MC = US$ 1.28/t cane

It can be seen that the one point percent increase in the trash % cane resulted in an increase of the order of US$ 0.01/t cane. However, it is not included the cost of processing the trash, to be used as bagasse, that is estimated to be around US$ 1.00/t trash (dry basis). Any changes in the value of bagasse (or trash) has a direct impact on its margin of contribution (US$ 0.399/t cane) that will affect the value of MC.

24.8. Conclusion

The economic criterion to classify sugar cane varieties is the agroindustrial margin of contribution (MC). With the possible uses of bagasse and trash in power generation, it is important to verify the effects of fiber % cane and trash % cane in the result of the agroindustrial margin of contribution.

Fiber % cane of the material being milled (cane stalks and vegetal impurities) have a direct impact in the resulting bagasse and, consequently, in the amount of sugar losses as well as in the total number of cane milling days. Depending on the size of the crushing season the latter can change the average pol % cane of the processed sugar cane.

Variation of trash % cane also changes the fiber content of the material being milled due to changes in the vegetal impurity quantities. This effect is similar to the one caused by the change of fiber % cane in the sugar losses and crushing period length but at a much smaller extent since vegetal impurities amount for only around 10% in weight of the material being milled.

A detailed analysis of each one of these effects has lead to an equation to quantify the MC of a sugar cane variety (Equation 03).

Assuming the same average figures for prices, costs, total amount of sugar, ethanol, bagasse and trash produced by the typical mill, as well as the sugar cane characteristics (pol % cane, fiber % cane and trash % cane) of previous reports of the Project, the resulting agroindustrial margin of contribution of this sugar cane variety is US$ 1.27/t cane.

Simulations with independent variations of fiber % cane and trash % cane of this sugar cane variety with values around 13.44% and 14%, respectively, have shown that one point percent increase (7.5% increase in these values) results in a reduction of the agroindustrial margin of contribution of this sugar cane variety of the order of 46% for fiber % cane and in an increase of the margin of contribution of 0.8% for trash % cane.

Thus, it can be concluded that a sugar cane variety with higher fiber % cane is unlikely to increase the economic gains of the sugar cane sector.

Therefore, a program to develop high biomass cane should prioritize these varieties with high trash % cane, without changes in the other characteristics (yield, pol % cane, fiber % cane and purity); this is only justifiable if trash has high value. For this to become justifiable, an increase in the value of trash must take place. Project studies have indicated trash recovery costs in the order of US$ 8.00/t trash (50% moisture content) and a margin of contribution of US$ 5.00/t for this trash, which implies in a selling price above US$ 13.00/t trash (50% moisture content).

25. Final comments

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Project BRA/96/G31 – "Biomass Power Generation: Sugar Cane Bagasse and Trash" has been planned to be an extension of Project BRA/92/G31 - "Brazil Biomass Gasifier/Gas Turbine Power Plant Demonstration", known as WBP project, whose objective was to build a woody biomass fueled gasification/gas turbine (BIG-GT) demonstration plant in Northeast Brazil. Using technical information developed in the WBP project the BRA/96/G31 intended to investigate the possibility of promoting a significant reduction in atmospheric CO_2 accumulation by performing technical and economic analyses of the feasibility of the utilization of BIG-GT technology for power generation using sugar cane bagasse and trash as fuels.

Use of funds would be optimized by doing that since a single demonstration plant would be used to test both fuels: woodchips from planted forest and sugar cane residues from sugar/ethanol mills. The idea proved to be good but delay and cancellation of the demonstration plant of the WBP project, could have jeopardized Project BRA/96/G31 development, if the gasification technology selection and engineering/design of the BIG-GT had not been developed to the point of providing the required technical information.

Another point is that Project BRA/96/G31 did not foresee implementation of a real demonstration plant but rather directed the efforts to investigate integration of BIG-GT technology with a typical selected mill only for engineering development.

In spite of that, it can be assumed that the project has been successful in reaching the objectives and in generating good and consistent data to allow technical and economic evaluations of the concept, to disseminate the findings throughout the world sugar cane industry. This can be credited mostly to the adaptive management of the project, that provided flexibility to continue under changing conditions.

A self evaluation by project developers will be presented below.

25.1. Relevance

The main assumptions made in the project design phase were:

• There is a clear trend to increase mechanization in sugar cane harvesting.

• Environmental laws and public awareness of environmental problems will push toward cane burning reduction.

• Increasing demand for electric power will open space for thermal power generation.

• Sugar mills could become an important alternative for electric power supply specially if sugar cane trash could be recovered to supplement bagasse as fuel.

• Advanced cogeneration systems such as BIG-GT could increase considerably power generation in sugar mills.

An analysis of present national context and project results show that:

• Mechanization of cane harvesting in Brazil has passed the 35% mark, as an average, and there are several mills, mainly in the state of São Paulo, harvesting 100% of their own cane mechanically.

• A state law in São Paulo and a Federal decree have established a firm time schedule for phasing out cane burning.

• The threat of power shortage forced the Federal Government to launch, in 1999, the Priority Program on Thermal Electricity. It did not take off fast enough to provide energy to face the hydropower shortage in 2001. There is a Government decision to bring the thermal power generation to increase its market participation from less than 10%, of the total power consumption, to around 20%. Federal Law 10.480 creates a market share of 3300 MW for renewable energy (wind power, biomass and small hydro) in the short term and of 10% of the new capacity in the medium term (beyond 2006). Distributed power generation will be favored to relieve the already limited transmission lines.

• Power generation in sugar mills have increased from nearly nihil surplus power in 1999 to around 500 MW in 2004; the installed capacity, including the required power for self consumption, in the Brazilian sugar cane sector is estimated to be around 1600 MW.

Power generation in a sugar/ethanol mill is still limited to the crushing season (6-7 months/year). A few mills are already extending this power generation period using sugar cane trash as the main supplemental fuel; the information and knowledge generated in Project BRA/96/G31 are being used in implementation of these alternatives.

Gasification tests in the TPS pilot plant have shown that both bagasse and trash are good gasifier fuels and the BIG-GT - mill integration studies have indicated that this technology can nearly double the surplus power generation. Further optimization will certainly increase this advantage.

The direct beneficiaries of project results will be:

- The Federal Government who will have an additional option for thermal power generation that will use an indigenous renewable fuel to replace imported natural gas.
- The sugar cane sector who will have an additional source of income with the surplus power and access to financial resources to invest in the modernization of the mills.
- The country population for having a source of renewable power with smaller environmental impacts and by the improvement of the quality of jobs.

25.2. Performance

The original scope of work for CTC in the project included 115 activities leading to 23 products; an extension of this scope, approved by MCT/UNDP, added 19 activities and 7 products, totaling 134 activities and 30 products. A total of 98 technical reports have been issued, attesting the completion of all these activities and presenting the products.

TPS contract foresaw products in the form of 9 reports that have been issued by TPS and reviewed and approved by CTC.

The time schedule has been reasonably followed with few delays, caused by bureaucratic problems and others, that had no impact on the deadline for project completion of December 31 rst, 2003. All 98 CTC reports and all 9 TPS reports have been completed prior to this deadline. Only this report, not foreseen in the contracts, has passed that date.

The project budget has also been followed.

25.2.1 Success

Although no benchmarks were determined to measure the degree of success in the project conception, some subjective evaluations can be made based on attainment of the objectives and impacts. It is, however, to soon to have a clear picture of these issues.

25.2.2 Impacts

The main impact is the increase in awareness of the stakeholders about climate change, environmental impacts, renewable energy in general and, in particular, about the possibility of economic recovery and use of sugar cane trash as a supplemental fuel to bagasse and the advantage of advanced cogeneration systems, such as BIG-GT, in sugar/ethanol mills. An extensive dissemination of information about the project findings have been presented to the sugar/ethanol mills, equipment manufacturers, government agencies, universities, research centers and to the general public. The figures, based on solid engineering and extensive field tests, show that the surplus power generation can be raised from the present limit level of 50 to 60 kWh/TC to 100 to 120 kWh/TC, with existing conventional technology, or 250 to 300 kWh/TC with BIG-GT systems.

The estimated trash cost at the mill of about US$ 1 per million BTU makes this fuel a good alternative to extend power generation beyond the crushing season, avoiding the use of fossil fuels as it happened in Mauritius, Reunion, Guadalupe and Guatemala, and perhaps in other cane producing countries that have opted to generate power in the mills year round.

The most serious barrier to use of BIG-GT technology with cane residues as fuel was shown in the project to be the high investment cost. This problem derives from the fact that it is a new technology still having to go through technical and economic maturation process to bring such investment costs to competitive levels. To remove this barrier, commercial demonstration program for the BIG-GT technology needs to be established and supported, based on the construction and operation of a minimum number of demonstration plants, that would permit a continuous process of cost reduction and increase in efficiency and reliability, through systems optimization and build up of an economy of scale for equipment production.

25.3. Sustainability

The sugar cane industry has existed for centuries and it is expected to continue to exist for many decades, or even centuries, to come; it will even grow stronger when a really free international sugar market creates conditions for cane sugar to take over beet sugar space.

Considering the present size of the sugar cane industry in Brazil (more than 300 million tons of cane/year) and worldwide (1.3 billion tons of cane/year) and that unburned sugar cane harvesting is slowly, but steadily, becoming more used and has a fully developed and mature technology, the replication potential for the BIG-GT technology with bagasse and trash is enormous. Besides, the use of this technology use can spillover to other renewable fuels such as different agricultural (rice, corn, wheat, etc.) and forestry residues as well as woodchips, from short rotation coppice or planted forests.

The interest in power generation in sugar mills is growing worldwide. In Brazil, it is estimated that an additional 500 MW have been installed in mills in the past three years. In Mauritius and Reunion energy from sugar mills represents a significant fraction of the total electric energy consumption in the islands; in India there is a strong push from Federal and State Governments to implement new power generation capacity in sugar mills.

Therefore, the forces and conditions favoring power generation in sugar/ethanol mills are likely to persist or even grow stronger in the mid and long terms.

25.4. Capacity development (CD)

Capacity building goals and milestones were not clearly established during project design but its CD has always been one of the major objectives of the project.

The initial focus was at the institutional level, aiming to supplement existing know how in CTC in the areas of sugar cane harvesting and other agricultural practices, transportation, sugar cane processing and conventional power generation, and by adding knowledge in trash availability, quality and recovery, gasification technology and environmental impacts of the sugar cane agroindustry and power generation.

During project implementation the system level became predominant due to frequent and positive interface with policy makers (stimulated and facilitated by MCT), and public meetings on cane burning and trash use issues. The interaction with several universities and research centers resulted in the development of research programs related to the theme (energy from cane). Also, dissemination of information to the mills have created a favorable environment to start to recover and use trash in conventional systems.

The approach used can be summarized as:

- CD effort strongly directed to fill gaps and with clear targets;
- Detailed planning of activities to meet targets;
- Multidisciplinary implementation teams (learning by doing);
- Cross sectorial exchanges;
- Search for partnerships;
- Information dissemination and awareness increasing efforts;
- Identification of spillovers;
- Concern with sustainability and replicability.

All these activities and efforts in CD are widening knowledge horizons on the issues investigated, and creating a critical mass of people working in the area of biomass energy, specially of cane energy, that will sustain future development and increase practical use.

25.5. Private sector involvement

Since the beginning, private sector involvement in the project was assured by the participation of Copersucar in cofunding the project on an even basis with GEF, and Copersucar Technology Center and TPS action in project development.

The original project budget was US$ 7.4 million, where US$ 3.75 would come from GEF and US$ 3.65 million from Copersucar. Copersucar, through CTC, ended up spending a lot more than it was committed, with an estimate total of US$ 5.3 million.

Other resources and funds were brought to the project such as EURO 575,000 from the European Commission DG XVII and SEK 3.4 million from the Swedish National Energy Administration (STEM). Expendings by the mills during field tests (labor, equipment use, fuels and chemicals) have been estimated in the range of US$ 800,000 to US$ 1.5 million, not including the Cane Dry Cleaning Station Prototype that costed US$ 2.2 million to build and improve; this item had all costs born by Usina Quatá.

25.6. Future steps

A large package of knowledge was acquired in the project development, as summarized above. However, analyses during development phase and, mainly, at the project end have shown gaps, areas to be strengthened and spillovers that deserve further development in the form of well defined projects.

Some of the topics that should be considered for additional work are:

High biomass sugar cane varieties.
- How should the existing sugar cane breeding programs be adapted to include fiber content (stalk and leaves) as an important parameter in selection process.
- Develop an economic model, using the margin of contribution concept, to compare varieties with different fiber contents by establishing economic value for bagasse and trash.
- Find better correlations between fiber content and cane productivity.

Optimization of unburned cane harvesting with trash recovery.
- Evaluate other alternatives such as extra large bales (10 t range), trash and cane discharged separately from the harvester, trash collection by foragers, trash compaction, trash shredding by harvester.
- Trash processing and handling at the mill.
- Trash and bagasse long term storage.

Agricultural impacts of trash
- Herbicide effect: study dynamics of weed population in the long term, specially those species not controlled by trash blanket; cost of controlling these species by chemical or mechanical methods.
- Effect of trash blanket on population of important pests such as froghopper.
- Cost of agricultural impacts under different climate, soil and harvesting conditions.

Commercial scale test of trash recovery and use in conventional cogeneration system (high pressure boiler and steam turbine generator).
- Trash recovery by conventional large bales (200 – 500 kg), foragers and partial cleaning.
- Trash feeding with modified equipment developed for bagasse
- Long term effects of trash firing in bagasse boilers (corrosion, slagging, erosion, etc.).
- Trash recovery costs.

Appendix 1

Field data collection form.

Mill: ______________________________

Farm: ____________________________

Field: ____________________________

Area: ___________________________

Spacing: ___________

Soil: ______________

Variety: ____________

Stage of cut: ________

Date of last harvesting:___/___/____

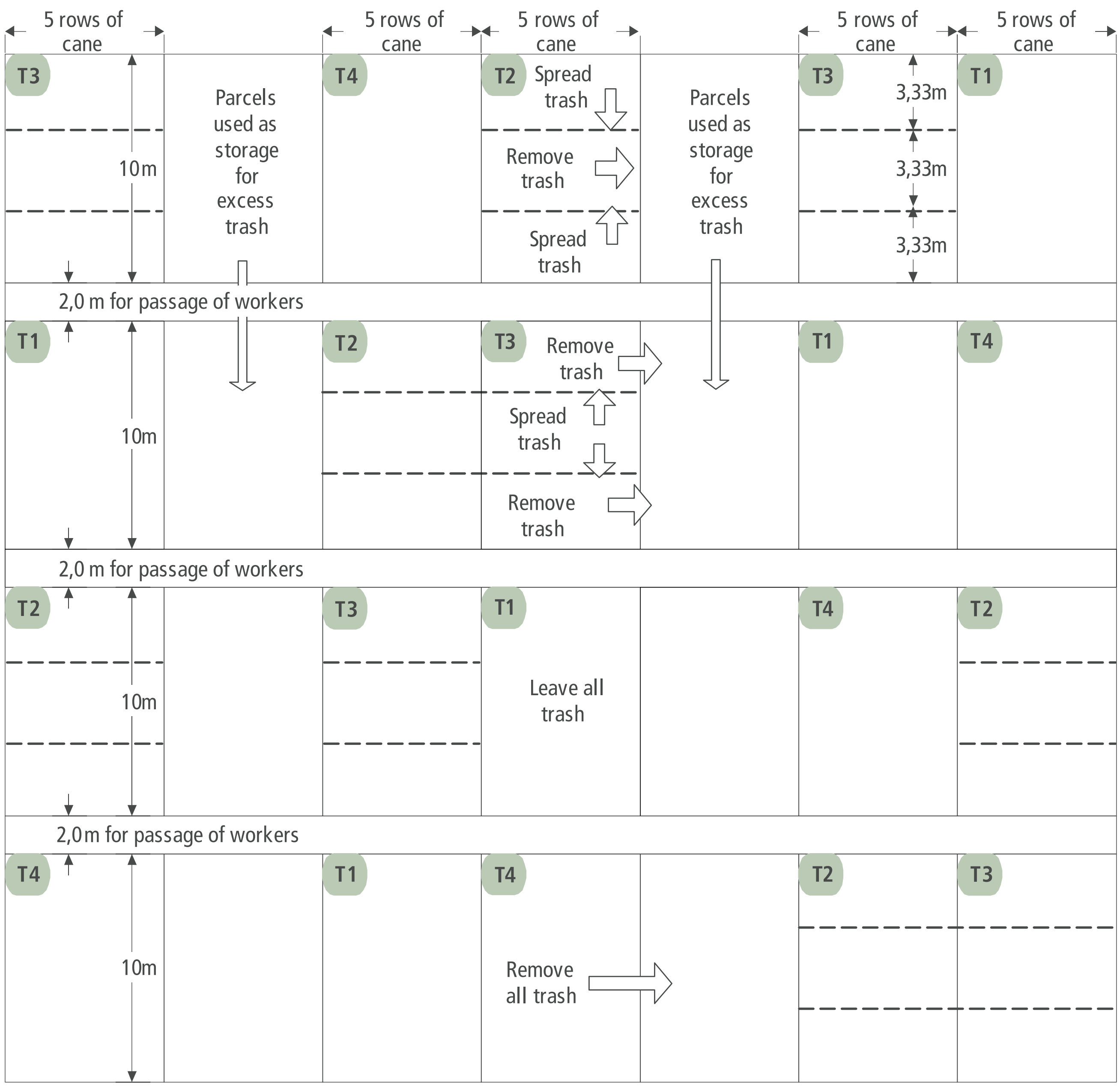
Age: _________

Test date: ____/_____/_____

Plot	Row	Number of canes in 10 meters	Weight of 20 cane stalks (kg)	Weight of dry leaves for 20 canes (kg)	Dry leaves moisture(1) (%)	Weight of green leaves for 20 stalks (kg)	Green leaves moisture(1) (%)	Weight of tops for 20 canes (kg)	Tops moisture(1) (%)
1	A								
	B								
	C								
2	A								
	B								
	C								
3	A								
	B								
	C								
..	.								
	.								
	.								
10	A								
	B								
	C								
Average									

(1) Wet basis

Diagram for the set up for the experiments of the effect of different amount of trash (T1= 100%, T2=66%, T3=33% and T4=no trash) on weed control and sugar cane yield.



Appendix 3

Weed population determination card. Total plants per treatment (5 repetitions). Usina São Martinho - 98/99 crop, 02/feb/99.

Popular name (Portuguese)	Scientific name	Treatments (t of dry matter/ha) T1 (11.30 t)	T2 (7.53 t)	T3 (3.77 t)	T4 (0)
Amendoim bravo	*Euphorbia heterophylla*	131	48	110	69
Assa-peixe	*Vernonia sp*		1	2	2
Beldroega	*Portulaca oleracea*	21		0	
Buva	*Conyza sp*	23	121	261	2340
Capim amargoso	*Digitaria insularis*		3	16	224
Capim colchão	*Digitaria horizontalis*			2	57
Capim marmelada	*Brachiaria plantaginea*		1	3	7
Capim olímpio	*Leptochloa virgata*			0	2
Capim pé-de-galinha	*Eleusine indica*			1	2
Capim tapete	*Mollugo verticillata*			0	8
Caruru amargoso	*Erechtites valerianaefolia*			0	1
Caruru rasteiro	*Amaranthus deflexus*	1		0	
Caruru	*Amaranthus sp*	1	2	4	19
Corda de viola	*Ipomoea sp*	3	1	3	
Couvinha	*Porophyllum ruderale*		11	16	15
Erva andorinha	*Chamaesyce hyssopifolia*			0	1
Erva de Sta. Luzia	*Chamaesyce hirta*			1	
Falsa serralha	*Emilia sonchifolia*	1	5	29	9
Fedegoso	*Senna occidentalis*			0	2
Gervão branco	*Croton glandulosus*		1	2	29
Guanxuma branca	*Sida glaziowii*			1	1
Guanxuma	*Sida rhombifolia*		1	0	31
Joá-de-capote	*Physalis viscosa*		1	0	
Maria gorda	*Talinum patens*			0	4
Mentrasto	*Agerantum conizoides*	11	54	33	443
Picão preto	*Bidens pilosa*			1	
Quebra-pedra	*Phyllantus niuri*			6	1
Serralha brava	*Erechtites hieracifolia*	1		10	4
Tiririca	*Cyperus rotundus*	6 536	11 953	27 514	45 747
Trapoeraba	*Comelina sp*	1		0	
Total including *Cyperus rotundus*		6 730	12 203	28 215	49 019
Total excluding *Cyperus rotundus*		194	250	701	3 272
Plants per parcel including *Cyperus rotundus*		1 346	2 441	5 643	9 804
Plants per parcel excluding *Cyperus rotundus*		39	50	140	654
Plants per m^2 excluding *Cyperus rotundus*		0.52	0.67	1.87	8.72
Trash control efficiency (%)		94.04	92.35	78.59	-

Yield components for the variety test at Usina Santa Luiza – June 1999 (means and analysis of variance).

Varieties	Average plot weight[1] kg	Number of stalks	30 stalks weight A kg	Green leaves B kg	Dry leaves C kg	Cane tops D kg	Total trash B+C+D kg	Total biomass A+B+C+D kg	Estim. millable stalks[2] kg	Total trash kg	Total fresh biomass[3] kg
SP76-112	1 684	1 043	51.4	6.4	2.3	2.4	11.1	62.5	1 787	386	2 173
RB72454	1 631	885	59.2	6.0	2.9	3.0	11.9	71.1	1 746	351	2 097
SP88-817	1 600	948	52.7	6.4	2.0	3.1	11.5	64.2	1 665	363	2 028
SP88-725	1 575	1 070	39.1	5.4	2.0	2.1	9.5	48.6	1 395	339	1 734
SPUP83-87	1 498	1 024	47.5	4.5	2.1	2.2	8.8	56.3	1 621	300	1 921
SP87-579	1 466	831	55.7	5.0	1.9	2.5	9.4	65.1	1 543	260	1 804
IAC873/396	1 432	809	56.8	5.9	2.2	2.1	10.2	67.0	1 532	275	1 807
SP80-1520	1 431	775	57.7	4.7	2.3	2.3	9.3	67.0	1 491	240	1 731
SP88-766	1 428	735	59.4	4.7	1.8	2.3	8.8	68.2	1 455	216	1 670
SP88-819	1 413	1 139	41.6	4.3	1.8	1.6	7.7	49.3	1 580	292	1 872
SP88-724	1 392	850	59.7	5.1	1.7	1.9	8.7	68.4	1 692	247	1 938
SP88-757	1 375	1 109	40.8	5.6	2.5	2.8	10.9	51.7	1 508	403	1 911
SP88-720	1 316	1 095	35.5	5.3	2.3	2.3	9.9	45.4	1 296	361	1 657
SP88-749	1 296	1 070	39.1	3.7	1.9	1.8	7.4	46.5	1 394	264	1 658
SP87-580	1 282	883	47.8	4.8	1.9	2.9	9.6	57.4	1 406	282	1 689
SP80-1842	1 268	679	57.5	4.4	2.2	1.8	8.4	65.9	1 302	190	1 492
SP88-823	1 268	962	42.1	3.8	1.9	1.8	7.5	49.6	1 350	240	1 590
SP88-840	1 267	812	45.3	3.9	1.9	2.3	8.1	53.4	1 226	219	1 445
PO853	1 254	948	39.5	5.9	2.2	1.3	9.4	48.9	1 248	297	1 545
SP88-717	1 237	878	42.8	2.5	0.8	1.5	4.8	47.6	1 253	141	1 394
SP80-1816	1 231	866	43.5	4.1	2.2	2.0	8.3	51.8	1 256	240	1 496
SP88-711	1 154	809	49.3	3.7	1.8	1.9	7.4	56.7	1 329	200	1 529
SP87-572	1 141	692	60.0	4.6	2.0	2.1	8.7	68.7	1 383	201	1 584
SP87-587	1 103	820	45.4	4.4	1.8	1.7	7.9	53.3	1 241	216	1 457
SP79-2233	957	984	33.6	4.2	3.1	2.1	9.4	43.0	1 102	308	1 410
Mean	1348	908.6	48.1	4.8	2.1	2.2	9.1	57.1	1 457	276	1 729
C.V. (%)	6.3	4.2	8	15.2	23.7	18.1		8.3	8.2		8.6
LSD (5%)	270	119.8	12.2	2.3	1.6	1.2		15.1	374		464
PVAR	0	0	0	0	0.006	0		0	0		0
Maximum	1 684	1 139	60	6	3	3		71	1 787	403	2 173
Minimum	957	679	34	3	1	1		43	1 102	141	1 394

(1) Average plot harvested weight obtained with a load cell equipped truck

(2) Estimated weight of millable stalks

(3) Estimated total fresh biomass per plot

C.V. (%) - Coefficient of variation

LSD (5%) - Least significant difference at 5% probability value

PVAR - Probability value (significance) for varieties

Appendix 5

Means and analysis of variance of yield components for the test harvested at Usina da Pedra (July 2000).

Variety	Average plot harvested weight* (kg)	Number of stalks	Weight 30 stalks (kg)			Total fresh weight (kg)				Fiber		Pol % clean cane	Total fiber weight (kg)**		
			Clean cane	Trash	Total	Clean cane	Trash	Trash %cane	Total	% cane	% trash		Clean cane	Trash	Total
IAC873396	1 082	659	59	10	68	1 287	214	17	1 501	10	60	15.7	131	125	257
PO853	1 027	949	44	9	53	1 390	278	20	1 668	9	60	14.3	125	163	288
RB72454	1 125	862	49	9	58	1 417	266	19	1 682	9	69	15.3	126	182	308
SP760112	1 144	892	37	8	45	1 128	252	22	1 380	10	61	14.9	111	155	266
SP792233	573	765	29	8	37	762	195	26	957	8	60	16.7	60	117	177
SP801520	1 085	727	57	9	67	1 392	229	16	1 621	9	60	15.5	128	139	267
SP801816	1 132	778	54	10	64	1 389	262	19	1 651	11	54	15.8	148	140	288
SP801842	1 208	722	61	11	71	1 464	254	17	1 718	11	67	16.6	161	169	329
SP870572	955	670	52	9	61	1 161	200	17	1 362	9	65	15.4	104	130	234
SP870579	1 307	683	72	11	83	1 633	246	15	1 879	11	59	13.6	184	146	330
SP870580	698	587	42	8	50	815	162	20	977	8	58	16.1	69	92	161
SP870587	1 025	817	45	8	53	1 238	227	18	1 465	10	62	16.0	122	139	261
SP880711	817	695	43	8	51	1 000	181	18	1 181	8	69	15.4	76	126	202
SP880717	1 080	567	61	7	68	1 144	135	12	1 279	10	56	15.6	116	76	192
SP880720	1 080	1 040	37	9	47	1 294	315	24	1 609	10	62	13.6	127	198	325
SP880724	1 090	687	61	9	70	1 407	201	14	1 607	9	64	15.9	124	130	254
SP880725	1 045	914	41	8	49	1 259	230	18	1 490	10	63	15.3	120	144	264
SP880749	890	879	41	7	49	1 210	215	18	1 425	10	58	15.5	116	124	240
SP880757	927	821	38	9	47	1 053	256	24	1 309	10	48	15.4	100	118	219
SP880766	855	636	52	9	60	1 092	181	17	1 273	10	62	14.9	104	112	215
SP880817	698	564	48	10	58	928	190	21	1 118	10	60	15.2	95	115	210
SP880819	1 092	878	43	6	49	1 268	179	14	1 447	9	59	14.9	114	107	221
SP880823	950	791	42	8	49	1 096	197	18	1 292	10	65	14.4	106	127	233
SP880840	945	722	49	7	57	1 182	176	15	1 359	10	63	16.2	115	111	225
SPUP830087	1 245	768	60	10	70	1 544	244	16	1 788	10	65	13.8	154	160	314
Mean	1 003	763	49	9	57	1 222	219	18	1 442	10	61	15	117	134	251
C.V. (%)	17	10	14	15	14	20	21		20	5	13	3.9	20	21	19
LSD (5%)	545	247	22	4	25	766	145		895	1	24	1.9	73	88	152
PVAR	0.0	0.0	0.0	0.006	0.0	0.0	0.0		0,0	0,0	0,394	0.0	0	0	0
Maximum	1 307	1 040	72	11	83	1 633	315	26	1 879	11	69	17	184	198	330
Minimum	573	564	29	6	37	762	135	12	957	8	48	14	60	76	161

* Weighing with a load cell equipped truck

** Estimated total fiber weight, dry basis (kg)

C.V. (%) - Coefficient of variation

LSD (5%) - Least significant difference at 5% probability value

PVAR - Probability value (significance) for varieties

Means and analysis of variance of yield components for the test harvested at Usina Santa Luiza (July 2000).

Variety	Average plot harvested weight* (kg)	Number of stalks	Weight 30 stalks (kg)			Total fresh weight (kg)				Fiber		Pol % clean cane	Total fiber weight (kg)**		
			Clean cane	Trash	Total	Clean cane	Trash	Trash %cane	Total	% cane	% trash		Clean	Trash	Total
IAC873396	868	661	43	11	54	945	243	26	1 188	12	59	15.5	109	144	253
PO853	597	850	21	8	30	611	234	38	844	10	57	15.2	61	135	195
RB72454	983	898	37	10	47	1 118	283	25	1 401	10	63	16.4	111	179	290
SP760112	930	997	28	9	37	945	292	31	1 236	10	58	15.5	95	170	265
SP792233	402	807	18	6	24	489	156	32	645	8	63	17.6	40	98	138
SP801520	788	757	35	7	42	863	184	21	1 047	10	61	17.8	82	112	194
SP801816	912	785	29	6	35	774	157	20	931	11	60	16.9	86	94	179
SP801842	888	694	40	9	48	912	196	21	1 108	11	65	18.5	103	127	230
SP870572	700	677	36	9	45	806	203	25	1 008	10	63	15.8	78	128	206
SP870579	1 087	787	47	10	57	1 213	264	22	1 477	12	61	14.8	140	161	302
SP870580	768	719	35	9	44	841	218	26	1 059	9	57	17.1	77	122	199
SP870587	723	796	32	8	40	854	208	24	1 062	10	66	17.1	87	137	224
SP880711	447	550	30	8	38	562	144	26	706	8	63	17.4	47	90	136
SP880717	618	596	36	6	42	707	117	17	825	10	67	16.8	69	79	148
SP880720	557	865	20	7	27	592	189	32	782	10	61	15.5	61	116	177
SP880724	680	595	40	8	48	785	167	21	951	9	62	16.4	72	103	174
SP880725	995	947	32	7	39	995	222	22	1 217	11	65	16.8	105	144	249
SP880749	575	804	27	6	33	715	158	22	873	10	65	14.9	72	103	175
SP880757	563	922	21	6	27	637	197	31	835	9	65	16.7	57	126	184
SP880766	938	844	33	8	41	929	222	24	1 151	11	65	16.8	99	144	242
SP880817	920	750	38	10	47	947	237	25	1 183	11	49	15.5	108	117	225
SP880819	815	1 113	26	6	32	949	232	24	1 181	11	62	15.8	103	144	247
SP880823	710	832	30	8	38	838	222	27	1 060	10	60	16.3	85	134	219
SP880840	769	769	33	8	41	850	194	23	1 045	11	66	16.9	90	128	218
SPUP830087	918	881	34	8	42	987	239	24	1 226	10	61	14	100	146	245
Mean	766	796	32	8	40	835	207	25	1 042	10	62	16.3	85	127	213
C.V. (%)	13,8	10,3	10	8	9	13	12		13	5	8	3.4	15	15	13
LSD (5%)	336	260	10	2	12	349	81		414	2	15	1.8	40	60	91
PVAR	0	0	0	0	0	0	0		0	0	0.023	0	0	0	0
Maximum	1 087	1 113	47	11	57	1 213	292		1 477	12	67	19	140	179	302
Minimum	402	550	18	6	24	489	117		645	8	49	14	40	79	136

* Weighing with a load cell equipped truck
** Estimated total fiber weight, dry basis (kg)

C.V. (%) - Coefficient of variation

LSD (5%) - Least significant difference at 5% probability value

PVAR - Probability value (significance) for varieties

Appendix 7

Means and analysis of variance of yield components for the test harvested at Usina Cresciumal (July 2001).

Variety	Average plot harvested weight* (kg)	Number of stalks	Weight 30 stalks (kg) Clean cane	Weight 30 stalks (kg) Trash	Weight 30 stalks (kg) Total	Total fresh weight (kg) Clean cane	Total fresh weight (kg) Trash	Total fresh weight (kg) Trash %cane	Total fresh weight (kg) Total	Fiber % cane	Fiber % trash	Pol % clean cane	Total fiber weight (kg)** Clean	Total fiber weight (kg)** Trash	Total fiber weight (kg)** Total
IAC873420	1 025	765	41.4	8.4	49.8	1 057	214	20	1 271	10.6	57.0	16.9	113	122	234
Q138	764	819	29.2	8.2	37.3	799	223	28	1 022	9.8	46.6	17.2	78	105	183
RB72454	1 203	914	34.8	7.2	42.0	1 068	219	21	1 287	9.8	56.5	17.1	105	124	229
SP773291	927	738	40.0	7.6	47.6	984	188	19	1 172	8.5	54.4	15.9	84	101	185
SP800185	1 059	895	33.7	9.2	42.9	1 006	274	27	1 281	12.2	48.0	17.0	123	131	254
SP801816	1 544	1 018	36.9	8.3	45.3	1 253	283	23	1 535	12.4	58.0	17.5	155	164	319
SP801842	1 286	842	44.4	7.9	52.3	1 249	221	18	1 470	11.7	57.0	18.3	146	127	273
SP803280	1 336	885	42.9	9.3	52.2	1 270	274	22	1 544	12.2	55.3	17.2	156	152	308
SP803480	1 314	920	44.0	10.8	54.7	1 343	328	24	1 671	11.9	52.8	17.2	160	173	333
SP813250	1 256	880	35.9	8.7	44.6	1 059	256	24	1 314	10.6	54.4	17.4	114	139	252
SP880869	993	930	31.2	9.3	40.5	973	288	30	1 260	10.1	49.1	16.6	97	142	238
SP880878	1 224	886	39.1	7.0	46.1	1 152	207	18	1 359	11.7	55.5	16.4	135	115	250
SP880882	890	973	27.6	7.0	34.6	894	228	25	1 122	10.0	53.4	16.1	90	121	211
SP880908	1 042	1 025	30.3	8.1	38.4	1 030	275	27	1 305	8.7	45.3	17.5	90	125	214
SP891003	1 100	933	33.6	7.1	40.8	1 044	222	21	1 266	10.4	57.6	16.5	109	128	236
SP891056	953	1 069	24.7	6.4	31.1	882	226	26	1 108	11.1	57.1	17.9	98	129	227
Mean	1 120	906	35.6	8.2	43.8	1 066	245	23	1 312	10.7	53.6	17.1	116	131	247
C.V. (%)	11	7	8.4	8.9	7.7	11	9		10	5.4	10.3	2.9	13	13	11
LSD (5%)	363	190	9.1	2.2	10.3	353	69		400	1.8	16.8	1.5	44	52	84
PVAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.11	0.00	0.00	0.00	0.00
Maximum	1 544	1 069	44	11	55	1 343	328		1 671	12.4	58.0	18.3	160	173	333
Minimum	764	738	25	6	31	799	188		1 022	8.5	45.3	15.9	78	101	183

* Weighing with a load cell equipped truck

** Estimated total fiber weight, dry basis

C.V. (%) - Coefficient of variation

LSD (5%) - Least significant difference at 5% probability value

PVAR - Probability value (significance) for varieties

Means and analysis of variance of yield components for the test harvested at Usina Santa Luiza (July 2001).

Variety	Average plot harvested weight* (kg)	Number of stalks	Weight 30 stalks (kg) Clean cane	Weight 30 stalks (kg) Trash	Weight 30 stalks (kg) Total	Total fresh weight (kg) Clean cane	Total fresh weight (kg) Trash	Total fresh weight (kg) Trash %cane	Total fresh weight (kg) Total	Fiber % cane	Fiber % trash	Pol % clean cane	Total fiber weight (kg)** Clean	Total fiber weight (kg)** Trash	Total fiber weight (kg)** Total
IAC873420	715	602	40.2	9.4	49.6	807	188	23	995	10	64	16.6	84	121	204
Q138	721	737	39.3	12.3	51.7	963	302	31	1 266	10	53	16.8	93	162	256
RB72454	795	658	35.1	10.0	45.1	769	220	29	989	10	63	17.1	77	138	215
SP773291	656	512	52.8	11.8	64.6	903	201	22	1 104	9	64	16.9	78	127	205
SP800185	567	736	29.0	9.3	38.3	705	225	32	930	11	60	16.7	76	136	212
SP801816	803	676	39.8	10.0	49.8	896	224	25	1 120	11	66	17.6	102	150	252
SP801842	798	596	45.8	9.1	54.9	913	182	20	1 095	11	69	17.9	104	125	228
SP803480	971	697	44.2	13.4	57.6	1 022	311	30	1 334	12	65	16.9	128	204	331
SP803280	861	608	49.0	10.1	59.0	990	204	21	1 194	11	70	17.3	108	142	250
SP813250	752	716	31.6	9.4	41.0	757	225	30	982	11	62	18.5	79	140	220
SP880869	670	722	28.7	10.0	38.7	695	241	35	936	10	64	17.6	66	154	220
SP880878	913	838	34.6	8.0	42.6	968	223	23	1 191	11	65	16.2	102	146	247
SP880882	711	798	31.4	7.7	39.1	834	204	24	1 038	10	63	17.0	83	128	212
SP880908	700	756	31.7	9.7	41.5	796	244	31	1 040	9	60	17.9	68	148	215
SP891003	643	684	29.0	7.5	36.5	666	171	26	837	11	63	16.3	69	107	176
SP891056	535	748	20.2	6.8	27.0	502	169	34	671	11	61	18.4	53	102	155
Mean	738	693	36.4	9.7	46.1	824	221	27	1 045	10	63	17.3	86	139	225
C.V. (%)	13	8	11.0	10.8	10.3	14	12		13	5	10	2.9	15	17	14
LSD (5%)	286	169	12.2	3.2	14.4	342	83		407	2	20	1.5	39	71	98
PVAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.41	0.00	0.00	0.00	0.00
Maximum	971	838	53	13	65	1 022	311		1 334	12.4	70.2	18.5	128	204	331
Minimum	535	512	20	7	27	502	169		671	8.5	53.4	16.2	53	102	155

* Weighing with a load cell equipped truck

** Estimated total fiber weight, dry basis

C.V. (%) - Coefficient of variation

LSD (5%) - Least significant difference at 5% probability value

PVAR - Probability value (significance) for varieties

This book opens the series "Caminhos para a Sustentabilidade", promoted by United Nations Development Programme (UNDP). This series aims to disseminate results and to promote the debate on strategic subjects for the sustainable development advancement.

We expect that the subjects approached by this series can contribute to build the road to sustainable development, including through the achievement of the Milleniun Development Goals proposed by the United Nation (UN).

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APPENDIX E

Life-cycle energy use and greenhouse gas emission implications of Brazilian sugarcane ethanol simulated with the GREET model

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abstract

By using data available in the open literature, we expanded the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory to include Brazilian-grown sugarcane ethanol. With the expanded GREET model, we examined the well-to-wheels (WTW) energy use and greenhouse gas (GHG) emissions of sugarcane-derived ethanol produced in Brazil and used to fuel light-duty vehicles in the United States. Results for sugarcane ethanol were compared with those for petroleum gasoline. The sugarcane-to-ethanol pathway evaluated in the GREET model comprises fertilizer production, sugarcane farming, sugarcane transportation, and sugarcane ethanol production in Brazil; ethanol transportation to U.S. ports and then to U.S. refueling stations; and ethanol use in vehicles. Our analysis shows that sugarcane ethanol can reduce GHG emissions by 78% and fossil energy use by 97%, relative to petroleum gasoline. The large reductions can be attributed to the use of bagasse in sugarcane mills, among other factors. To address the uncertainties involved in key input parameters, we developed and examined several sensitivity cases to test the effect of key parameters on WTW results for sugarcane ethanol. Of the total GHG emissions associated with sugarcane ethanol, the five major contributors are open-field burning of sugarcane tops and leaves, N_2O emissions from sugarcane fields, fertilizer production, sugarcane mill operation, and sugarcane farming. Brazil is going to phase out open-field burning in the future. This action will certainly help further reduce GHG emissions of sugarcane farming, together with reductions in emissions of criteria pollutants such as NO_x and particulate matter with diameters smaller than 10 microns. The eventual elimination of open-field burning in sugarcane plantations will result in additional GHG emission reductions by sugarcane ethanol of up to 9 percentage points.

Keywords: **greenhouse gases, life-cycle analysis, sugarcane ethanol, well-to-wheels analysis**

El ciclo de vida del uso de energía y las consecuencias de las emisiones de gas del etanol derivado de caña azucarera en Brasil, simulado con el modelo GREET

La utilización de datos disponibles en la literatura abierta al público, nos permitió extender el alcance del modelo GREET desarrollado por el Argonne National Laboratory (Laboratorio Nacional de Argonne) para abarcar el etanol de la caña azucarera cultivada en Brasil. Con el modelo GREET – cuyo nombre se deriva de Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (Gases de Invernadero, Emisiones Reguladas, y Uso de Energía en Transporte) - ampliado, hemos analizado el uso de energía desde el pozo a las ruedas (well-lo-wheels o WTW) y las emisiones de gas de invernadero (greenhouse gas = GHG) del etanol derivado de caña de azúcar producido en Brasil y que se utiliza como combustible para vehículos livianos en los Estados Unidos. Los resultados obtenidos para el etanol de caña fueron comparados con los de la gasolina de petróleo. La ruta que enlaza la caña de azúcar y el etanol, fue evaluada en el modelo GREET e incluye el estudio de la producción de fertilizante, el cultivo de la caña, el transporte de la caña, y la producción de etanol de caña en Brasil; el transporte de etanol a puertos de los Estados Unidos y de ahí a estaciones de abastecimiento en EE.UU.; y el uso de etanol para vehículos de transporte. Nuestro análisis muestra que, cuando se compara con la gasolina derivada del petróleo, el etanol proveniente de caña de azúcar puede reducir las emisiones GHG en un 78% y el uso de energía fósil en un 97%. Estas reducciones considerables pueden ser atribuidas al uso del bagazo en los ingenios azucareros. Con el objetivo de hacer frente a las incertidumbres resultantes de los parámetros clave, hemos desarrollado y examinado varios casos de sensibilidad para estudiar el efecto de los parámetros clave sobre los resultados del WTW para el etanol derivado de la caña azucarera. Del total de emisiones de GHG asociadas con el etanol de caña de azúcar, los cinco contribuyentes principales son: la quema en campo abierto de los cogollos y hojas de la caña, las emisiones de N_2O proveniente de los campos de caña, la producción de fertilizante, la operación del ingenio azucarero, y el cultivo de la caña azucarera. Brasil tiene la intención de erradicar la práctica de quema en campo abierto en el futuro. Estas actividades ayudarán por seguro a la reducción de las emisiones de GHG en el cultivo de la caña de azúcar junto con la reducción de contaminantes importantes como el NO_x y la materia en partículas de diámetro menor de 10 micrones. Cuando se elimine la quema a campo abierto en la plantaciones de caña azucarera esto resultará en una reducción adicional de las emisiones de GHG por el etanol de la caña de azúcar, en aproximadamente nueve puntos porcentuales.

Lebenszyklus-Energieverbrauch und Treibhausgas-Emissionsimplikationen von brasilianischem Zuckerrohrethanol, simuliert mit dem GREET-Modell

Unter Hinzuziehung von in veröffentlichten Schriften enthaltenen Daten erweiterten wir das vom Argonne National Laboratory entwickelte GREET-Modell (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) um Zuckerrohrethanol aus brasilianischem Anbau. Mit dem erweiterten GREET-Modell untersuchten wir den WTW-Energieverbrauch (Well-to-Wheels = vom Brunnen zum Rad) und die Treibhausgas-Emissionen (GHG) von aus Zuckerrohr gewonnenem Ethanol, das in Brasilien produziert und zum Antrieb von leichten Nutzfahrzeugen in den USA verwendet wird. Die Ergebnisse für Zuckerrohrethanol wurden mit denen für Mineralölbenzin verglichen. Der im GREET-Modell evaluierte Weg von Zuckerrohr zu Ethanol umfasst die Düngemittelproduktion, den Zuckerrohranbau, den Zuckerrohrtransport und die Zuckerethanolproduktion in Brasilien, den Ethanoltransport zu US-amerikanischen Häfen und dann zu US-amerikanischen Tankstellen sowie die anschließende Ethanolnutzung in Fahrzeugen. Unsere Analyse zeigt, dass Zuckerrohrethanol, verglichen mit Mineralölbenzin, die GHG-Emissionen um 78% und den Fossilenergieverbrauch um 97% reduzieren kann. Die großen Reduktionen sind der Verwendung von Bagasse in den Zuckerrohrmühlen zuzuschreiben. Um Ungewissheiten bei den wichtigsten Eingabeparametern Rechnung zu tragen, entwarfen und untersuchten wir mehrere sensitive Fälle, um die Auswirkungen von Schlüsselparametern auf die WTW-Ergebnisse für Zuckerrohrethanol zu testen. Von den GHG-Gesamtemissionen, die mit Zuckerrohrethanol verbunden waren, waren die fünf Hauptbeitragsfaktoren: Verbrennung von Zuckerrohrblättern und Pflanzenteilen auf offenem Feld, N_2O-Emissionen der Zuckerrohrfelder, Düngemittelproduktion, Zuckerrohrmühlenbetrieb und Zuckerrohranbau. Brasilien beabsichtigt das Abrennen von Feldern allmählich einzustellen. Diese Maßnahme wird sicherlich – ebenso wie eine Reduktion der Emissionen von gefährlichen Schadstoffen (Criteria Pollutant Emissions) wie z.B. NO_x und Feststoffteilchen mit einem Durchmesser von unter 10 Mikrometer – dazu beitragen, die GHG-Emissionen des Zuckerrohranbaus weiter herabzusetzen. Das schließliche Ende des Abbrennens der Felder von Zuckerrohrplantagen wird weitere GHG-Emissionsreduktionen für Zuckerrohrethanol von bis zu 9 Prozentpunkten mit sich bringen.

Introduction

Brazil began its sugarcane fuel ethanol program in 1975 after the first oil crisis and has since expanded it significantly. Brazil is now the number two fuel ethanol producer and consumer after the United States. Ethanol has become a mainstream motor fuel in Brazil, accounting for 40% of its gasoline market. More than 80% of new cars sold in 2006 were ethanol flexible-fuel vehicles (FFVs).

Brazil has vast land available for sugarcane farming. About five million hectares of land are currently used for sugarcane farming in Brazil (Macedo 2005), and some in Brazil maintain that an additional five million hectares can be made available for sugarcane farming. Brazil expects that its sugarcane ethanol industry will continue to expand. In fact, companies from other countries are beginning to invest in the sugarcane ethanol industry in Brazil. In addition to its own consumption, Brazil seeks to export fuel ethanol to other countries, including the United States, the European Union, and Japan.

Biofuels are being promoted for their potential for reductions in greenhouse gas (GHG) emissions, relative to those of petroleum-based gasoline. Sugarcane-based ethanol has been reported to achieve more than 80% reductions in GHG emissions (see Macedo *et al.* 2004; International Energy Agency 2004; Concawe *et al.* 2007). However, systematic, detailed evaluation of sugarcane ethanol and comparison of it with other biofuels and alternative fuels are needed.

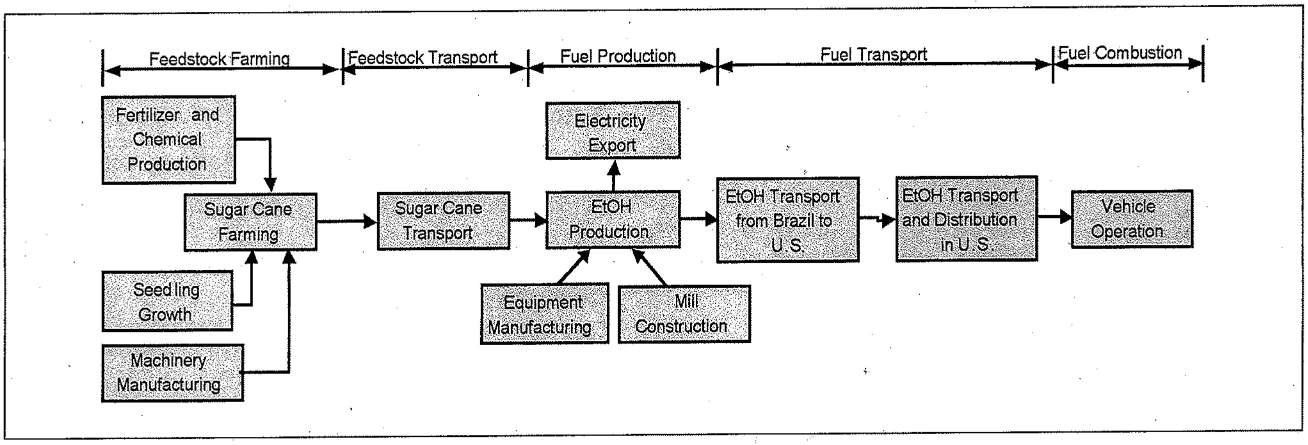
Argonne National Laboratory has been developing and applying the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to examine energy and emission benefits of advanced vehicle technologies and new transportation fuels (see Brinkman *et al.* 2005 for the GREET model and its applications). The GREET model features many fuel ethanol production pathways from feedstocks such as corn, fast-growing trees, switchgrass, crop residues, and forest residues. Through this study, we expanded the GREET model to include the production of sugarcane ethanol in Brazil and the use of it in the United States. Doing so enables GREET users (more than 4,000 of them as of December 2007) to examine sugarcane ethanol together with ethanol produced from other feedstocks and with other potential transportation fuels. We then used the expanded GREET model to systematically simulate energy and GHG emission effects of sugarcane ethanol.

System boundary and analysis cases for the sugarcane-to-ethanol pathway

The GREET model is a life-cycle, or well-to-wheels (WTW), analytical tool that parties can use to examine energy and emission effects of different vehicle/fuel options. Argonne National Laboratory has been developing and applying the model since 1995. The most recent version - GREET1.8a - was released in August 2007. The model and its major publications are posted at the GREET website (http://www.transportation.anl.gov/software/GREET/index.html). For a given vehicle and fuel system, GREET evaluates total energy use, fossil fuel use, natural gas (NG) use, coal use, and petroleum use; emissions of carbon dioxide (CO_2)-equivalent GHGs, including CO_2, methane (CH_4), and nitrous oxide (N_2O); and emissions of six criteria pollutants - volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO_x), particulate matter with diameters smaller than 10 microns (PM_{10}), particulate matter with diameters smaller than 2.5 microns ($PM_{2.5}$), and sulfur oxides (SO_x). The criteria pollutant emissions are further separated into total and urban emissions to reflect human exposure to air pollution caused by emissions of the six criteria pollutants.

We conducted a WTW analysis of Brazilian sugarcane-derived ethanol based on the system boundary depicted in Figure 1. The life cycle of sugarcane-derived ethanol begins with the manufacture of fertilizer and farming machinery and the preparation of cane setts for transplanting. Farming operations include chemical application, irrigation, tillage and harvest. The current sugarcane farming practice involves open-field burning of sugarcane leaves and tops before and after harvest to facilitate the manual harvest and to control disease. We included these factors in our analysis.

Figure 1. Stages of the sugarcane-to-ethanol pathway



Harvested sugarcane is transported via trucks to sugarcane mills. At sugarcane mills, sugarcane undergoes sugar juice extraction, followed by fermentation of juice for ethanol production (and/or sugar production). The residues from juice extraction - called "bagasse" - are combusted to generate steam and electricity to meet the demand for heat and power. Since 2000, sugarcane mills in Brazil have made major efforts to export their excess electricity to the electric grid.

Ethanol is then transported and distributed from plants to refueling stations. Ethanol is transported from sugarcane mills to Brazilian ports via rails and pipelines (as being practiced in Brazil now), to U.S. ports by ocean tankers, and then to U.S. refueling stations via trucks.

Finally, ethanol is used during vehicle operation. Ethanol can be used either in low-level blends such as E10 (mixture of 10% ethanol and 90% gasoline by volume) in regular gasoline vehicles or high-level blends such as E85 (mixture of 85% ethanol and 15% gasoline by volume) in FFVs.

In our analysis of sugarcane ethanol, we included energy and GHG emissions of the manufacture of farming machinery and sugarcane mill equipment and the construction of sugarcane mills. These so-called infrastructure-related activities are usually not included in WTW analyses.

The gasoline life cycle, on the other hand, begins with crude oil recovery in oil fields and ends in gasoline combustion in gasoline vehicles, a pathway that is already in the GREET model.

Our analysis targeted the timeframe of 2006-2010. With this time frame, many factors play a key role in determining the overall energy use and GHG emissions of sugarcane ethanol. We examined these factors by developing several sugarcane ethanol cases, all of which produce ethanol and export electricity to the electric grid. In addition, we included petroleum gasoline, corn ethanol, and switchgrass ethanol for comparison.

The base case established for sugarcane ethanol was production in Brazil with use in the United States. Other cases were developed to test the importance of the following parameters: (1) whether sugarcane ethanol is used in the United States or Brazil (to assess the contribution of ocean tanker transportation of ethanol), and (2) whether energy embedded in farming equipment manufacturing and sugarcane mill construction makes a significant contribution to the WTW results of sugarcane ethanol. The sugarcane (SC) cases and the petroleum gasoline, corn ethanol, and switchgrass ethanol cases were as follows:

- SC Case 1 (the base case for sugarcane ethanol): sugarcane ethanol is produced in Brazil and used in the United States; energy embedded in farming equipment manufacturing and sugarcane mill construction is not included. (This case is consistent with the petroleum gasoline pathway.)

- SC Case 2: same as SC Case 1 except that energy embedded in farming equipment manufacturing and sugarcane mill construction is included.

- SC Case 3: same as SC Case 1 except that energy embedded in farming equipment manufacturing is included.

- SC Case 4: same as SC Case 3 except that sugarcane ethanol is used in Brazil. (This case shows the contribution of ocean tanker transportation of ethanol.)

- Petroleum gasoline production and use in the United States, excluding energy embedded in all infrastructure-related activities.

- Corn ethanol production and use in the United States, including energy embedded in the farming machinery.

- Cellulosic ethanol production and use in the United States with switchgrass as the feedstock, including energy embedded in the farming machinery.

Data sources and GREET assumptions

Sugarcane farming

We analyzed energy use and emissions for activities involved in sugarcane farming, including fertilizer, lime, and chemical production; sugarcane setts preparation; farming operations; farming equipment manufacturing; and open-field burning of sugarcane leaves and straws.

Chemical and energy inputs for sugarcane farming

Once sugarcane setts have been planted on sugarcane farms, the sugarcane can be harvested for five to seven seasons. After that, sugarcane farms are replanted. Traditionally, sugarcane is harvested

Table 1. Fertilizer and chemical inputs for sugarcane farming in Brazil

Input	Assuncao (2000)[a]	Macedo *et al.* (2004)[b]	GREET[e]
N fertilizer			
kg/ha/yr	77.2	71.6[c]/75[d]	
g/MT of sugarcane	1,152.2	1,042.2[c]/1,091.7[d]	1,091.7
P_2O_5			
kg/ha/yr		40.8[c]/8.3[d]	
g/MT of sugarcane		593.9[c]/120.8[d]	120.8
K_2O			
kg/ha/yr		120[c]/13.3[d]	
g/MT of sugarcane		1,746.7[c]/193.6[d]	193.6
Lime ($CaCO_3$)			
kg/ha/yr		366.7	
g/MT of sugarcane		5,337.7	5,337.7
Herbicide use			
g/MT of sugarcane		26.9	26.9
Pesticide use			
g/MT of sugarcane		2.21	2.21

[a] Assuncao assumed a nitrogen application of 28 kg/ha for planting of sugarcane and 87 kg/ha for each harvest season. We assumed a cycle of 6 years with five cuts. He further assumed a sugarcane yield of 80.4 MT/ha/cut, resulting in 67 MT/ha/year over the 6-year period. These values were used to derive nitrogen application per hectare per year and per metric ton of sugarcane harvested.
[b] Macedo *et al.* (2004) used a sugarcane yield of 68.7 MT/ha/year over a 6-year sugarcane cycle. We used this value to derive nitrogen application rates per metric ton.
[c] For farms that do not use filter mud cake and vinasse (the residues left in a still following distillation).
[d] For farms that use filter mud cake and vinasse.
[e] For GREET simulations, weighted average values between sugarcane fields without and with use of filter mud and vinasse would be ideal. Because of the lack of data regarding breakdown of the two types of sugarcane plantations, we adopted the values for the fields with use of filter mud and vinasse.

Table 2. Inputs of energy use for farming operation, sugarcane sett preparation and farming machinery manufacturing for sugarcane farming (MJ/MT of sugarcane)

Activity	Assuncao (2000)	GTZ (2005)	Macedo *et al.* (2004)	GREET
Farming operation[a]	30.1	38	38	38
Sugar-cane seedling preparation	5.76	6	5.88	5.88
Energy embedded in farming machinery	33.1	N/A	29.1	29.1

[a] The farming energy data include energy use for sugarcane harvesting, as well as for other farming activities. Data from the three cited sources are for combinations of manual and mechanical harvest. Although manual harvest now accounts for more of the total harvest than mechanical harvest, in the long term, mechanical harvest will account for more. Energy use between the two harvest methods could be different, but no data showing the difference are available. The difference in harvest energy use may be small, because manual harvest collection and loading activities are still performed by machines to a large extent.

by laborers ("sugarcane cutters"); this harvest is often referred to as the "manual harvest." To ease cutters' efforts, sugarcane fields are burned before harvest. After harvest, the remaining tops are often burned to control disease and promote cane growth in the next season. Primarily because of concerns about air pollution caused by open-field burning, the state of Sao Paulo will phase out open burning completely by 2018. As a result, mechanical harvest will replace manual harvest. As of 2005, 65% of the sugarcane harvest in Brazil was manual, and 35% was mechanical (Macedo 2005).

Table 1 summarizes the application rates of nitrogen (N) and phosphate (P_2O_5) fertilizer, potash (K_2O), lime ($CaCO_3$), herbicide, and pesticide on Brazilian sugarcane farms. Fertilizer and chemical use are usually reported in kilograms per hectare per year (kg/ha/yr); however, for GREET simulations, we need to use kilograms or grams per metric ton (kg/MT) of sugarcane harvested. We converted the former by using a sugarcane yield of 68.6 MT/ha (Macedo *et al.* 2004). The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007).

For sugarcane farming, energy use includes diesel fuels used to power farming equipment, energy spent preparing sugarcane setts, and energy embedded in farming equipment manufacturing (Table 2). Although GREET WTW analyses generally do not include energy embedded in equipment, we included it to be consistent with the pathways for ethanol production from different feedstocks, which include this energy. Nonetheless, we designed an option in GREET for including or excluding the energy embedded in farming equipment manufacturing and associated emissions.

Open-field burning of sugarcane leaves and tops

Sugarcane leaves and tops are typically burned in the field before and after harvest. Macedo *et al.* (2004) reported a yield of 280 kg of leaves and tops (with 50% moisture content, or 140 kg of dry leaves and tops) per metric ton of sugarcane harvest. 80% of sugarcane farms in Brazil are assumed to practice open-field burning in 2010. Because open-field burning will be gradually phased out, in developing the sugarcane ethanol pathway in GREET, we assumed burning of 80% of leaves and tops for 2010 and 0% in 2020.

For the GREET simulation, we took into account emissions from open-field burning - in particular, emissions of two pollutants:

methane (CH_4) and nitrous oxide (N_2O). Emissions of carbon dioxide (CO_2) from open-field burning were not taken into account, because the CO_2 is taken from the air during sugarcane growth. Emissions from open-field burning of sugarcane leaves and tops were estimated by assuming a carbon content of leaves and tops of 50% on a dry-matter basis (Macedo *et al.* 2004).

Table 3 lists our estimates of emissions generated from open-field burning. These were based on three sources: summaries of Macedo *et al.* (2004) and Assuncao (2000); results in Andreae and Merlet (2001); and data included in the Intergovernmental Panel on Climate Change guidelines (IPCC 2006a). The average emission values from open-field burning of agricultural residues listed in the IPCC guidelines appear higher than those from other sources. We used the IPCC data as our base case for emission factors of CH_4, N_2O, CO, NO_x, and $PM_{2.5}$. For PM_{10}, we estimated emission factors on the basis of a ratio of 2:1 between PM_{10} and $PM_{2.5}$, which was derived from coal combustion emission factors in GREET. Therefore, we used a value of 7.8 g/kg of leaves and tops burned for PM_{10}. For VOC and SO_x emission factors, we used values estimated by Andreae and Merlet (2001).

N_2O emissions from sugarcane fields

A major source of N_2O emissions from sugarcane farming is nitrification and denitrification of nitrogen fertilizer applications. In Brazil, the most frequently used type of nitrogen fertilizers is urea (Macedo 2007), from which N_2O is emitted directly and indirectly. When applied to soil, nitrogen fertilizer is volatilized and converted to N_2O; when oxidized, some of it is emitted directly to the air as N_2O. A large amount of nitrogen fertilizer leaches to groundwater or rivers through surface runoff, during which some of it is converted to N_2O via microbial nitrification and denitrification. Macedo *et al.* (2004) estimated that on an annual basis, 75 kg of nitrogen in nitrogen fertilizer applied to a 1-ha sugarcane field resulted in 1.76 kg of N_2O emissions in the Central-South region of Brazil, which resulted in 1.5% in weight (wt%) of nitrogen in N_2O per weight unit of nitrogen in nitrogen fertilizer applied.

The N_2O emissions from soil are highly uncertain; they depend on various conditions such as the amount of nitrogen fertilizer applied, soil type, soil moisture content, and soil temperature. According to the IPCC guidelines (2006b), the following are the N_2O emission factors for nitrogen in N_2O generated from the nitrogen in nitrogen fertilizer for generic applications: 1% for direct N_2O-N emissions, with a range of 0.3–3%; 1% for N_2O emissions from volatilization, with a range of 0.2-5% and a volatilization rate for nitrogen input of 10%, with a range of 3-30%; and 0.75% N_2O emissions from leaching and runoff, with a range of 0.05-2.5% and a leaching and runoff rate for nitrogen input of 30%, with a range of 10-80%. Using the average values in the IPCC guidelines (2006b), we derived a total N_2O-N rate of 1.325% [1% + (1% x 10%) + (0.75% x 30%)], which is close to the value of 1.5% derived from Macedo et al. (2004). We used the rate of 1.5% in our analysis.

In contrast, Crutzen *et al.* (2007) estimated a conversion rate of 3-5%, based on a global N_2O balance. While the top-down approach adopted in Crutzen *et al.* is sound, especially for checking and verifying results with the bottom-up approach used by the IPCC and others, data for the top-down approach needs to be closely examined in order to generate reliable N_2O conversion factors. In particular, Crutzen *et al.* adopted the global N_2O emission balance from a 2001 study but nitrogen inputs from a separate 2004 study for deriving N_2O conversion factors. Furthermore, Crutzen *et al.* did not deal with agricultural subsystems (such as crop farming, animal waste management, and crop residual burning), which are required for generating N_2O conversion rates for the nitrogen inputs into crop farming. Their allocation of aggregate N_2O emissions (even after subtracting N_2O emissions from industrial sources) to the aggregate agricultural system could result in overestimation of N_2O conversion rates from nitrogen inputs into crop farming systems. Nonetheless, N_2O conversion rates, which are subject to great uncertainties, need to be reconciled between the bottom-up and the top-down approach.

The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007). A gram of urea (NH_2CONH_2) contains 0.2 g of carbon, resulting in 0.43 g of carbon per gram of nitrogen in urea. This composition results in 1.577 g of CO_2 per gram of nitrogen in urea. We included this CO_2 emission source in GREET simulations.

Table 3. Emission factors of open-field burning of sugarcane leaves and tops

	Emission factors (g/kg of dry leaves and tops burned)					
	Andreae and	Macedo *et al.* (2004)		Assuncao	IPCC	GREET
Pollutant	Merlet (2001)	Low value[a,b]	High value[a,b]	(2000)[a]	(2006a)	
CO_2	1515 (±177)				1515 (±177)	NN[c]
CO	92 (±84)				92 (±84)	92
CH_4	2.7	0.1464	1.0214	0.2886	2.7	2.7
NO_x	2.5(±1)				2.5 (±1)	2.5
N_2O	0.07				0.07	0.07
$PM_{2.5}$	3.9					3.9
PM_{10}						7.8[d]
VOC	7.0					7.0
SO_x	0.4					0.4

[a] These sources reported CH_4 emissions in kg/MT of sugarcane harvested. We used the yield of 280 kg of sugar cane leaves and tops with 50% moisture content per MT of sugarcane harvested to convert the original values into values in g/kg of leaves and tops burned.

[b] Macedo *et al.* (2004) maintained that the low values represented the average Brazilian emission rates, and the high values were adopted from the IPCC guidelines.

[c] Data is not needed here. CO_2 emissions are calculated in GREET by using the carbon balance of sugar cane leaves and tops; see a section below.

[d] Data was not available. This value was estimated on the basis of the ratio of PM_{10} versus $PM_{2.5}$ for coal combustion.

Figure 2. Schematic representation of the sugarcane ethanol production process

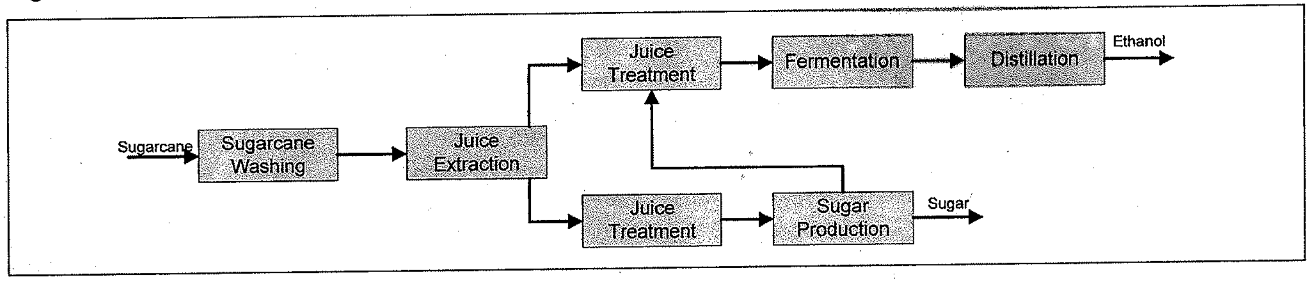


Table 4. Sugarcane composition

Parameter	Value (%)
Sucrose content	14.5
Fiber content	13.5
H_2O content	72.0

Source: Macedo *et al.* 2004.

Sugarcane transportation from farms to sugarcane mills

Harvested sugarcane contains about 70% water. Because sugarcane is bulky and heavy, sugarcane mills are built in the midst of sugarcane farms to minimize transportation distance. Sugarcane is transported via trucks an average one-way distance of 20 km (Macedo *et al.* 2004). The payload of a truck is 40-50 MT (Moreira and Goldemberg 1999). With these inputs, past studies in Brazil concluded that energy use for transporting sugarcane from farms to mills is 31-43 MJ/MT of sugarcane (Assuncao 2000; GTZ 2005; Macedo *et al.* 2004).

For GREET simulations, we assumed that sugarcane is transported by a diesel truck with a payload of 40 MT for a 20-km one-way trip from field to mill. Furthermore, we assumed a fuel economy of 4 miles per gallon (1.7 km/L) of diesel fuels for trucks transporting sugarcane. On the basis of these assumptions, the GREET model estimated an energy consumption of 24.4 MJ/MT of sugarcane transported. This value is lower than the values in the cited studies; those studies may have included direct energy use (as was the case in our estimate) and energy embedded in manufacturing the trucks.

Ethanol production in sugarcane mills

In sugarcane mills, sugarcane is washed and crushed, and cane juice is extracted. The juice is then treated to produce ethanol and/or sugar. The split between the two products is based on market demand. Table 4 presents the typical composition of sugarcane. The stream for ethanol production is then fermented, and the fermentation broth is subject to distillation, yielding product ethanol. CO_2 is emitted during fermentation. Figure 2 is a schematic of the sugarcane ethanol production process. To simplify this analysis, we assumed that a sugarcane ethanol mill is operated with 100% feed for ethanol production. The primary source of process fuel is bagasse with additional lubricant oil to support machinery operation.

Ethanol yield

Table 5 presents a summary of ethanol yield from several studies.

Table 5. Ethanol yields in sugarcane mills (liters per MT of sugarcane)[a]

Source	Ethanol yield	Notes
Moreira and Goldemberg (1999)	79.5	1996/97 season yield
Assuncao (2000)	73	1985 season yield
	85.4	2000 season yield
GTZ (2005)	80	
Macedo *et al.* (2004)	86	Average value
	91	Best value
GREET Input value	91	

[a] Assuming that all sugarcane goes to ethanol production, and sugarcane contains 72% of water.

We used a yield of 91 L of ethanol/MT of sugarcane, based on the best value reported in Macedo *et al.* (2004).

Energy requirements in sugarcane mills

Table 6 shows the amounts of electric, thermal, mechanical, and chemical energy required for production of ethanol in sugarcane mills. Sugarcane mills are self-sufficient in terms of thermal energy and electricity use. Heat demand represents the majority of energy use and is met through bagasse combustion. Most sugarcane mills generate their own electricity for internal use. The use of bagasse as the process fuel is discussed in a section below. We selected values for GREET input parameters on the basis of the latest data from the open literature. We estimated the total electricity use by the sugarcane mill to be 28.85 kWh/MT of sugarcane processed. Of this total, 16.84 kWh/MT is used to drive mechanical work with a conversion efficiency of 95% (Table 7).

We assumed that the thermal energy of 1,188 MJ per MT of sugarcane is supplied by bagasse combustion in a biomass boiler to produce steam with an efficiency of 80%. With these, about 1,485 MJ of bagasse is required per MT of sugarcane processed, which is about 16.3 MJ/L of ethanol produced (Table 7). A small amount of lubricants (6.36 MJ/MT of sugarcane) is used in sugarcane mills, which we assumed to be similar to residual oil in terms of energy and emission profiles.

Macedo *et al.* (2004) estimated a life-cycle energy use of 9.29 MJ/MT of sugarcane processed in construction of sugarcane mills and 24.16 MJ/MT in manufacture of sugarcane mill equipment (that is, embedded energy in mill equipment). We included these values in the GREET model. The equipment used was assumed to be 100% steel. Emissions from equipment manufacturing were estimated on the basis of process fuel shares for steel production as presented in the GREET model.

Bagasse as the process fuel in sugarcane mills

Bagasse is the residue of sugarcane after the juice has been extracted. Because of its high carbon content (46.3 wt% on a dry matter basis), it serves as an excellent source of process fuel in sugarcane mills. We assumed that bagasse is combusted in a biomass boiler to produce steam to meet the plant demand for steam and to generate electricity with a steam turbine to meet the plant requirement for electricity and for electricity export.

We used a bagasse yield of 280 kg (with 50% moisture content) per MT of sugarcane, which was reported by Macedo *et al.* (2004). The lower heating value (LHV) of bagasse in references ranged from 7.530 to 7.736 MJ/kg (with 50% moisture content, Macedo *et al.* 2004; Garcia 2007). One heating value reported by Assuncao (2000), 9.449 MJ/kg, was 2 MJ higher and was not specified as either high heating value (HHV) or LHV. We compared the data with the Chemical Engineers' Handbook (Perry and Green 1997), which lists an HHV of 8.37-11.63 MJ/kg for bagasse, suggesting that the value of 9.448 MJ/kg is most likely the HHV. For sugarcane ethanol simulations in GREET, we used a LHV of 7.53 MJ/kg (with 50% moisture content) for bagasse. On a dry-matter basis, the LHV for bagasse is 15.06 MJ/kg.

The steam and electricity balance for sugarcane ethanol processing is presented in Table 8. The total energy in bagasse, 23.17 MJ/L of ethanol produced, was determined by using a bagasse yield of 280 kg/MT sugarcane, bagasse energy content of 7.53 MJ/kg, and an ethanol yield of 91 L/MT of sugarcane. The steam needed for plant operation is 16.3 MJ/L of ethanol (Table 7).

We assumed the surplus energy, 6.87 MJ/L of ethanol, is used to generate electricity. With an electricity generation efficiency of 30% (the current Brazil industrial average), a total of 0.57 kWh of electricity can be generated for each liter of ethanol produced. After

Table 6. Energy consumption in sugarcane mills (MJ/MT of sugarcane processed)

Parameter	Energy use	Data source	GREET Input
Energy use			
Electricity	43.20	Macedo 2005	43.20
Mechanical energy	57.60	Macedo 2005	57.60
Thermal energy	1,188	Macedo 2005	1,188
Chemical and lubricant use			
Source 1	7.34	Assuncao 2000	
Source 2	6.00	GTZ 2005	
Source 3	6.36	Macedo *et al.* 2004	6.36
Energy embedded in sugar mill construction			
Average value	10.78	Assuncao 2000	
Average value	12.00	GTZ 2005	
Best value	8.07	Assuncao 2000	
Best value	9.00	GTZ 2005	
Average value	11.97	Macedo *et al.* 2004	
Best value	9.29	Macedo 2004	9.29
Energy embedded in sugar mill equipment			
Average value	27.96	Assuncao 2000	
Average value	31.00	GTZ 2005	
Best value	20.98	Assuncao 2000	
Best value	24.00	GTZ 2005	
Average value	31.07	Macedo *et al.* 2004	
Best value	24.16	Macedo *et al.* 2004	24.16

Table 7. Process energy use in sugarcane mills for ethanol production

	MJ/MT of sugarcane	kWh/MT of sugarcane	kWh/L of EtOH[a]	MJ/MT of sugarcane	MJ/L of EtOH[a]
Electricity	43.2[b]	12.00	0.132		
Mechanical	57.6[b]	16.84[c]	0.185		
Thermal	1,188[b]			1,485[d]	16.3
Lubricant oil	6.36[b]			6.36	0.070
Mill construction	9.29[b]				0.102
Equipment manufacturing	24.16[b]				0.265
Total		28.85	0.317		

[a] The conversion from sugarcane processed to ethanol produced is based on the ethanol yield of 91 L/MT of wet sugarcane.

[b] Data source: see Table 6.

[c] We assumed a conversion efficiency of 95% from electric energy to mechanical energy.

[d] This is the amount of energy in bagasse needed, which was estimated for a steam generation efficiency of 80%.

Table 8. Ethanol plant steam and electricity energy balance (per L of ethanol)

Bagasse energy yield (MJ)	Internal steam needs (MJ)	Extra energy for electricity generation (MJ)
23.17	16.3	6.87
Electricity generated from extra bagasse energy (kWh)	**Internal electricity needs (kWh)**	**Extra electricity for export (kWh)**
0.57	0.317	0.253

Table 9. Emission factors of bagasse combustion (g/1000 MJ of bagasse burned)

	From IPCC guidelines (2006b)			GREET input
	Low	Average	High	
CH_4	10.43	30.00	100.00	30.00
N_2O	1.50	4.00	15.00	4.00

Table 10. Average electricity generation mix in Brazil in 2004

	Electric generation share (%)
Petroleum	1.2
Natural gas	5.0
Coal	1.7
Biomass	4.2
Nuclear	3.0
Hydro	82.9
Others	2.0

Source: Ministry of Mine and Energy of Brazil (2005).

0.317 kWh (Tables 7 and 8) has been consumed in the process, an excess of 0.253 kWh/L of ethanol is available for export.

Bagasse combustion emissions

The IPCC guidelines (2006b) specify emission factors of CH4 and N2O from biomass combustion; see Table 9. Because of the large variations in the CH_4 and N_2O emission factors, we adopted the IPCC average values for GREET simulations.

Ethanol transportation from sugarcane mills to refueling stations

While some Brazilian sugarcane ethanol is exported to Japan, the European Union, and the United States, the majority of the sugarcane ethanol produced in Brazil is used in the Brazilian domestic market. We examined the case in which sugarcane ethanol is produced in Brazil and used in the United States market, so that we could compare its effects directly with those of ethanol production pathways already examined for the United States.

For the case of the domestic use of ethanol in Brazil, we assumed that ethanol is transported via pipeline and rail for 560 km (in each mode) from sugarcane mills to bulk terminals, then via truck for 130 km to refueling stations, where it is used either in its pure form or blended with gasoline.

For the case of ethanol exported to the United States, we accounted for ethanol transportation in both Brazil and the United States. Ethanol is first transported from mills to Brazilian ports in Southern Brazil. For this analysis we selected a representative port, Santos, a major port in Brazil. Most sugarcane mills are located in the two southern states near the Santos port, which provide about 50% of the nation's ethanol. In particular, we assumed that ethanol is transported via pipeline and rail on an average of 1290 km (in each mode) from sugarcane mills to the Santos port, where it is loaded onto ocean tankers for transport to the United States. We chose two U.S. ports, New York and Los Angeles, as entry points for Brazilian ethanol to the U.S. market. We used the average distance of 12,000 km from Santos to New York and from Santos to Los Angeles (see www.distance.com). Inside the United States, we assumed that ethanol is distributed regionally on the East and West Coasts, while the rest of the country receives domestic corn ethanol from the U.S. Midwest. In particular, we assumed that the imported ethanol is transported 160 km by truck to blending and storage facilities and further distributed to refueling stations.

Extraction and production of process fuels and electricity generation mix

For individual stages of the sugarcane ethanol pathway in Brazil, such as sugarcane farming, cane transportation, ethanol production, and ethanol transportation to U.S. ports, the energy use and emissions of primary energy recovery and processing, including coal, natural gas, and oil, were not available at the time of this study. We used GREET default values, which are based on U.S. industry averages. These values may be updated once Brazilian data become available.

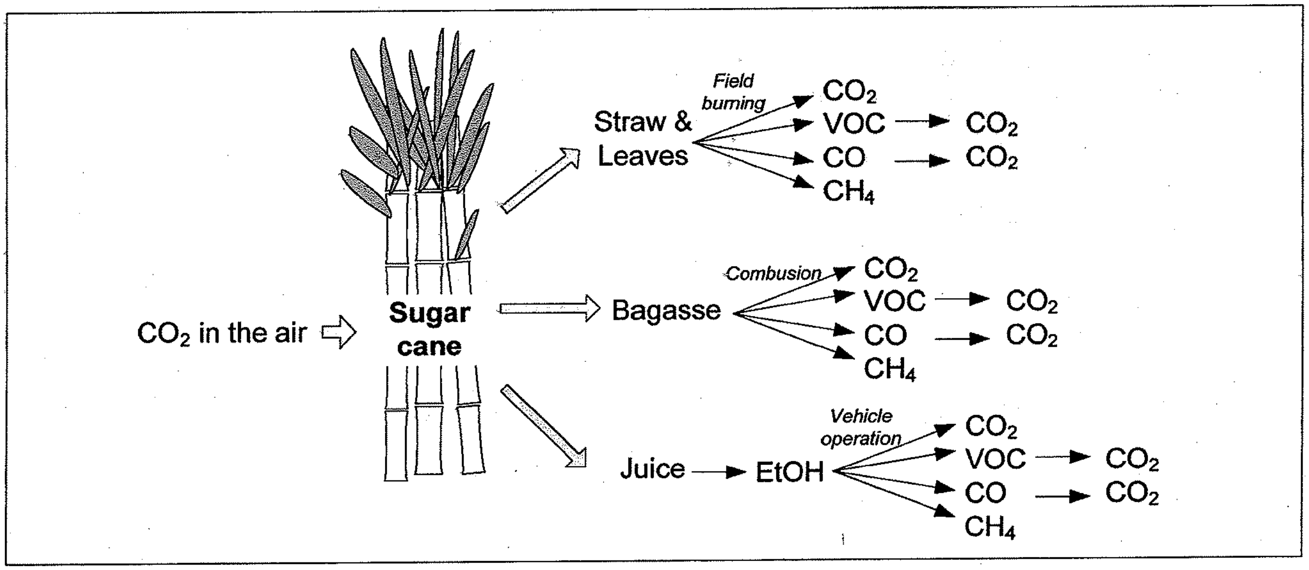
To estimate energy and emission credits of the exported electricity generated at sugarcane mills in Brazil, energy and emissions associated with electricity use in Brazil were estimated by assuming the electricity exported from sugarcane mills would replace electricity generation in natural gas plants. It is believed that the electric generation share of natural-gas power plants is marginal in Brazil. Table 10 shows the average power generation mix in Brazil.

Key issues in life-cycle analysis of sugarcane ethanol

CO_2 credits

During growth, sugarcane plants take CO_2 from the air for the photosynthesis process. The carbon taken in by sugarcane plants resides in them and is further converted to carbon in CO_2, CO, VOC, and CH_4, which are generated through various chemical and biological routes (fermentation, combustion, and the like) when sugarcane is processed to produce ethanol. The CO_2 from sugarcane that is emitted through a combustion process or through ethanol combustion in vehicles is considered zero CO_2 emissions to the air, since this is the carbon from the air that is taken in during sugarcane plant

Figure 3. Fate of renewable carbon in the sugarcane ethanol pathway



growth. In this case, the renewable carbon from sugarcane, rather than fossil fuel carbon, is used for combustion. Similarly, direct CO_2 emissions from sugar fermentation to ethanol are considered to be zero CO_2 emissions to the air.

We examined the fate of the renewable carbon in sugarcane, beginning with harvested sugarcane, by making several assumptions. First, all carbon in sugarcane plants is from atmospheric CO_2. Second, emissions from carbon in sugarcane plants end in four sources: CO_2, CO, VOC, and CH_4. Third, CO and VOC, which are emitted to the air during combustion of sugarcane tops and leaves in sugarcane fields and combustion of bagasse in ethanol plants, are converted to CO_2 in the air in a short time; these CO2 sources, together with direct CO_2 emissions from these combustion processes, are not included in CO_2 emission calculations for sugarcane ethanol, since they are ultimately from the air. Fourth, CH_4 from these combustion processes remains in the air for a long time, and these CH_4 emissions are accounted for as a GHG emission source for sugarcane ethanol. Finally, the organic carbon content of soil in sugarcane farms remains constant; however, this condition may not be the case if sugarcane ethanol production is expanded significantly and certain land uses are changed to accommodate such expansion.

Figure 3 is a schematic diagram of the fate of atmospheric carbon in the sugarcane ethanol pathway. The renewable carbon in sugarcane is utilized (combusted) in the sugarcane-to-ethanol pathway via three major routes: open-field burning of sugarcane leaves and tops, bagasse combustion in ethanol plants, and ethanol combustion during vehicle operation. All four forms of carbon emissions from these sources - CO_2, CO, VOC, and CH_4 - originate in carbon uptake from the air by sugarcane plants during growth. Among them, CO and VOC typically are oxidized to CO_2 within a few days after being released to the air. The amount of CO_2 generated is basically the carbon transformed from atmospheric CO_2; that is, the CO_2 emission sources shown in Figure 3 are actually CO_2 from the air during sugarcane growth.

Energy and emission credits of exported electricity

Bagasse is combusted to provide steam for meeting process heat requirements at sugarcane mills, and excess steam generates electricity to satisfy plant internal power demand. Excess power could be exported to the electric grid. In this case, we assumed that electricity generated from sugarcane mills displaces electricity generated with natural-gas electric power plants. On the other hand, if the exported electricity is assumed to displace the electricity with the Brazilian average electric generation mix, which is largely hydropower (82.9%, see Table 10), the energy and emission credits of the exported power would be smaller. In other words, the fact that the renewable power generated from bagasse displaces another primary renewable power reduces the benefit of the exported electricity from sugarcane ethanol plants.

Potential land use changes

It has been debated recently whether potential land use changes to be induced by large-scale biofuel production could result in significant changes in soil carbon and, therefore, could affect WTW GHG emission results of biofuels. This issue is especially relevant to GHG results of corn ethanol, sugarcane ethanol, soybean biodiesel, rapeseed biodiesel, and palm oil biodiesel, as their production is rapidly expanded.

Land use changes induced by biofuel production can be separated into direct and indirect components. Direct land use changes concern displacement of original land use directly by farming of feedstocks for biofuel production. Indirect land use changes concern secondary effects on land use changes by biofuel production. For example, as corn ethanol production may be increased significantly in the U.S., additional corn will be farmed in the land that is currently used for farming of soybeans and other crops (the direct land use change). In addition, corn use for ethanol production in the U.S. will result in reductions in U.S. corn export and in use of corn as a direct animal feed and for other purposes. The reductions in U.S. corn export, in the U.S. soybean production (as a switch of some soybean farms to corn farms), and in animal feed supply can result in an increase in production of corn and other agricultural commodities in some other parts of the world.

Limited efforts have been made to address direct land use

Figure 4. WTW fossil energy and petroleum reductions by ethanol relative to petroleum gasoline

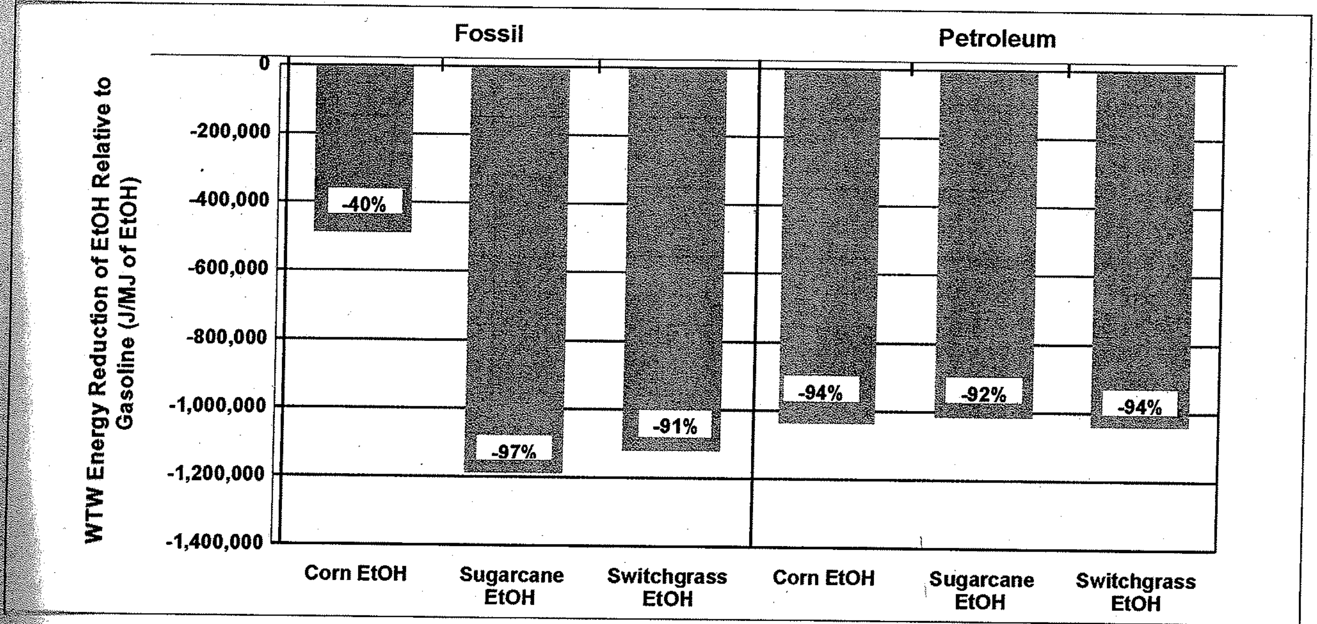
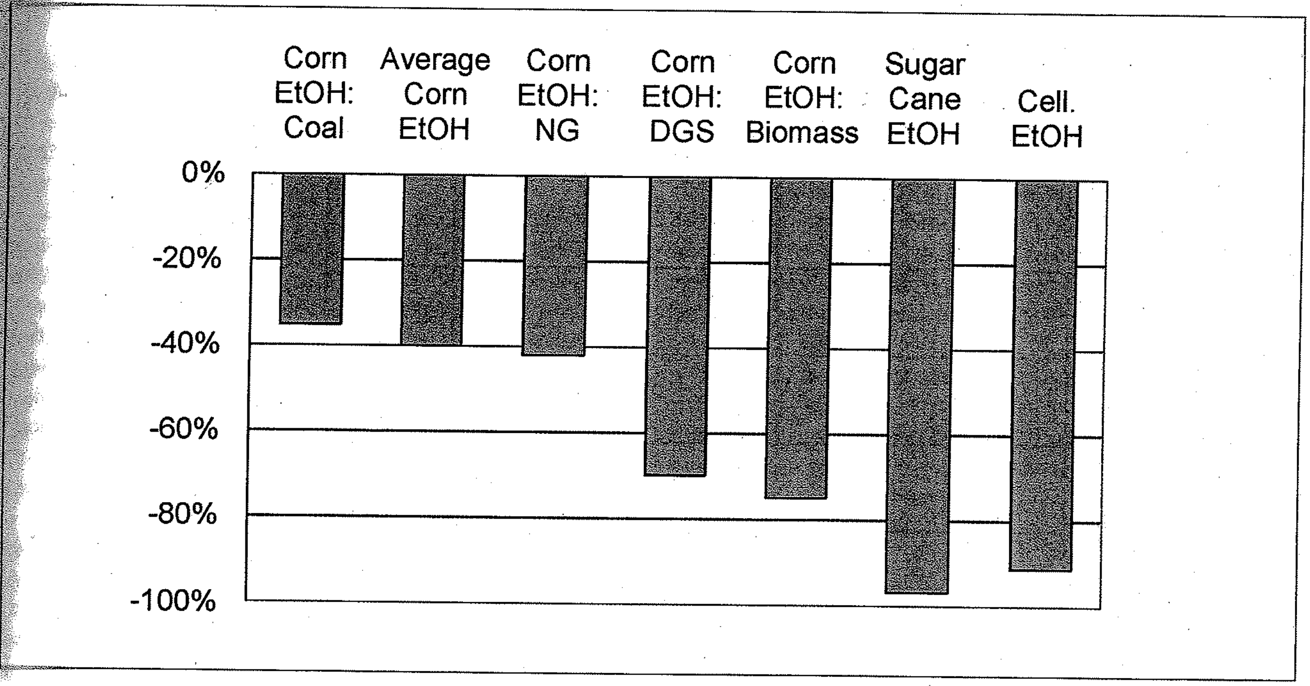


Figure 5. WTW fossil energy reductions of various ethanol production options relative to petroleum gasoline (NG = natural gas, DGS = distiller's grains and solubles)



changes from production of corn ethanol and cellulosic ethanol in the U.S. Results of those efforts were incorporated in life-cycle analyses of corn and cellulosic ethanol in the U.S. However, as corn ethanol production in the U.S. is to increase dramatically, those past results no longer reflect what will happen in the future regarding direct land use changes to be caused by corn ethanol production. On the other hand, we have not found any studies on potential direct land use changes caused by sugarcane ethanol production in Brazil.

Indirect land use changes are much more difficult to model. To do so requires use of general equilibrium models to take into account supply and demand of agricultural commodities, land use patterns, and land availability (all at the global scale), among many other factors. Efforts began only very recently to address both direct and indirect land use changes together with general equilibrium models or partial equilibrium models. It will be awhile before definitive results can be obtained. Nonetheless, land use changes could be a significant factor to determine GHG emission effects of certain biofuel types.

Results and discussion

As indicated in a section above, we established a base case for

Figure 6. Net energy balance of ethanol and petroleum gasoline

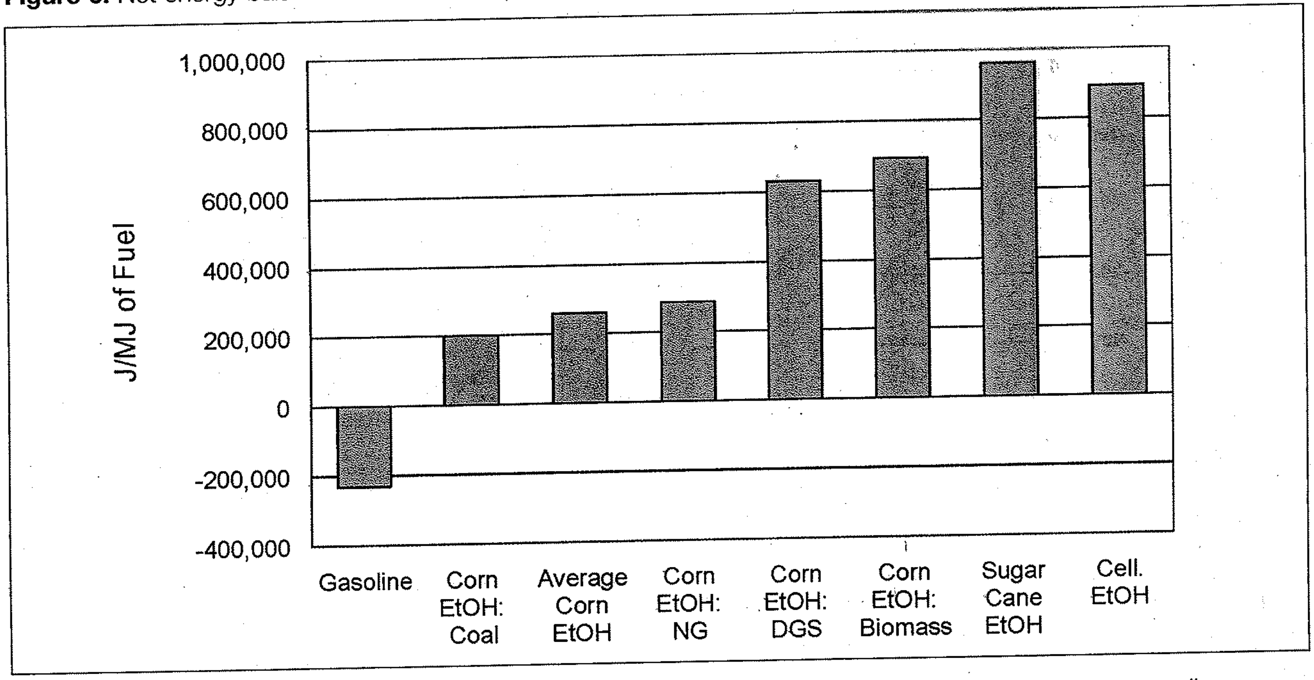


Figure 7. WTW GHG emission reductions by various ethanol production options relative to petroleum gasoline

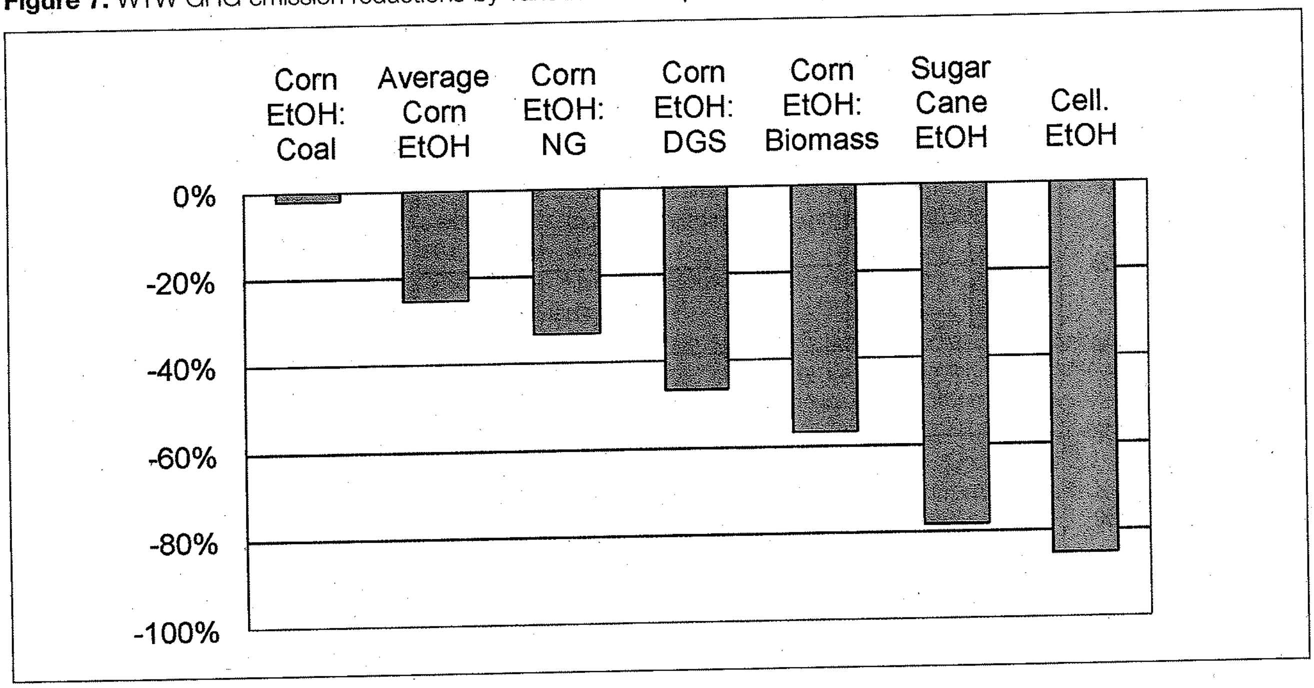


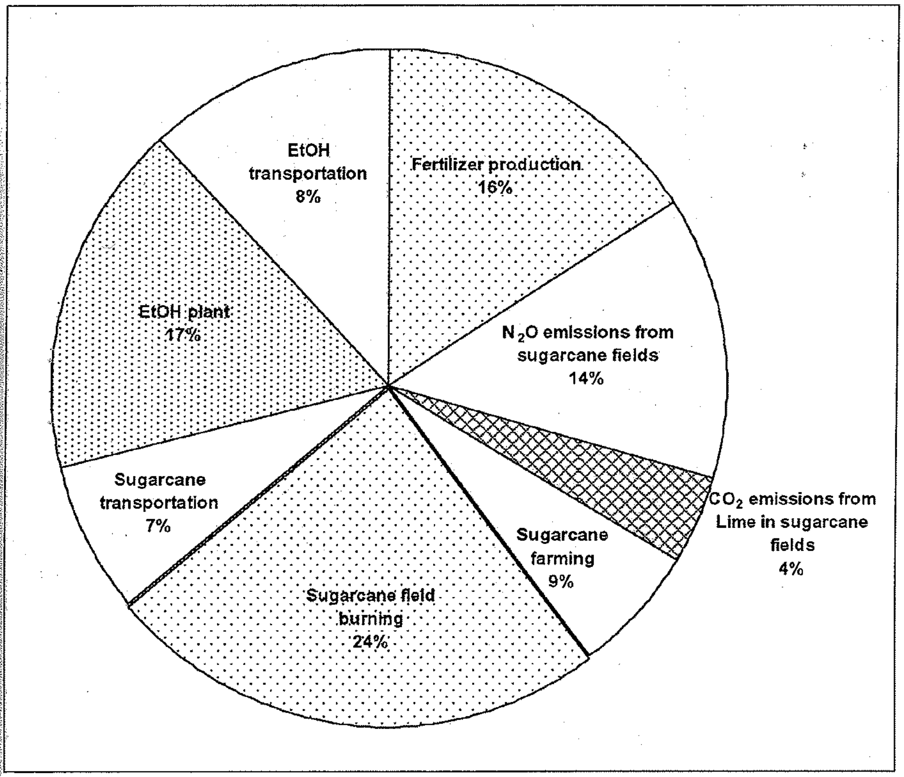
Table 11. WTW fossil energy use for ethanol (J/MJ of ethanol)

Fossil energy	Corn EtOH	Sugarcane EtOH
Natural gas	468,358	–96,097[a]
Coal	200,115	42,675
Petroleum	70,180	92,596
Total	738,653	39,174

[a] The negative value represents the reduction of natural-gas-based electricity generation that is displaced with the electricity exported from sugar cane mills.

production of sugarcane ethanol in Brazil and its use in the United States (SC Case 1). Three sensitivity cases were developed from the base case. For comparison, we selected the base case to compare sugarcane ethanol with corn ethanol, switchgrass-based cellulosic ethanol, and petroleum gasoline, since evaluation of these three cases does not include energy embedded in corn ethanol plants and

Figure 8. Shares of GHG emissions of sugarcane ethanol pathway activities



petroleum refineries. The WTW results of energy use and GHG emissions are presented in Figures 4-10 and in Table 11. Energy and GHG emission results are expressed for each MJ of fuel produced and used.

Energy use results for sugarcane ethanol, corn ethanol, and cellulosic ethanol are presented together in this section. While results for sugarcane and corn ethanol are based on operational data of many plants, results for cellulosic ethanol from switchgrass are based on projections and engineering simulations of switchgrass growth and cellulosic ethanol production. That is, in terms of commercial readiness, cellulosic ethanol is not at the same stage of development as sugarcane and corn ethanol.

Fossil and petroleum energy use results

Ethanol produced from Brazilian sugarcane achieves substantial reductions in fossil energy use (97%) relative to petroleum gasoline (Figure 4). The reductions are 2.6 times as much as those by corn ethanol. Fossil energy includes petroleum, natural gas, and coal energy; thus, the petroleum energy use presented here is a subset of fossil energy use.

Figure 4 shows that ethanol can provide reductions of more than 90% in petroleum energy compared to gasoline, regardless of the feedstocks for ethanol production (corn, sugarcane, or switchgrass). Figure 5 compares sugarcane ethanol with various ethanol production and feedstock options. Among the options evaluated, fossil energy reduction by sugarcane ethanol is similar to that by cellulosic ethanol. Figure 6 presents the net energy balance values of various ethanol production options and petroleum gasoline per MJ of fuel produced. The net energy balance (NEB) is the difference between the energy content of a fuel and the fossil energy input to the fuel production pathway. A positive value for the NEB represents an energy surplus for a fuel, while a negative value shows an energy deficiency. All the ethanol options show positive NEB values. For each MJ of ethanol produced from sugarcane grown in Brazil and utilized in the United States, there is a net gain of 0.96 MJ, in contrast to a net gain of 0.26 MJ for corn ethanol and 0.89 MJ for switchgrass-derived ethanol.

The unique advantage of the sugarcane ethanol pathway is that ethanol production in sugarcane mills is self-sustaining in terms of energy need: the juice is used for ethanol production, and the bagasse is used for heat and power generation. As a result, ethanol production requires 16.3 MJ of heat demand and 0.317 kWh of electricity per liter of ethanol. In addition, renewable power at the rate of 0.253 kWh can be exported to the electric grid for each liter of ethanol produced. This reduction in fossil energy use is the main cause of the marked difference in WTW results between sugarcane ethanol and corn ethanol. Table 11 indicates that approximately 564,453 J of natural gas and 157,740 J of coal per MJ of ethanol are saved by sugarcane ethanol production compared to corn ethanol. Recently, designers and operators started to address the issue of process fuel demand in corn ethanol plants by considering renewable sources such as wood chips or distiller's grains and solubles (DGS). With these renewable energy sources, corn ethanol could reduce an additional 30% (DGS as the process fuel) or 35% (wood chips as the process fuel) of fossil energy use (Figure 5).

Sensitivity analysis with the four sugarcane ethanol production options (as presented earlier) indicates that (a) energy embedded in sugarcane mills contributes 0.3% of total fossil energy use; (b) energy embedded in farming equipment contributes 2.3%; and (c) transportation of ethanol from Brazil to the United States contributes 3.0%.

Greenhouse gas emission results

Figure 7 shows WTW GHG emission reductions by sugarcane ethanol and several other ethanol production options, compared to petroleum gasoline. The GHG emission reductions by sugarcane ethanol are 3.1 times as much as those by corn ethanol and rank second only to those by cellulosic ethanol.

For the five corn ethanol production options, GHG emission changes range from a 2% reduction to a 57% reduction, depending on the process fuel used.

We examined key stages of the sugarcane ethanol pathway for their contributions to total GHG emissions. Similar to that for cellulosic ethanol, the sugarcane ethanol pathway generates heat and power from bagasse in sugarcane mills to displace natural gas or coal use. However, sugarcane farming differs considerably from cellulosic

Figure 9. Fossil energy reductions by four sugarcane ethanol cases relative to petroleum gasoline

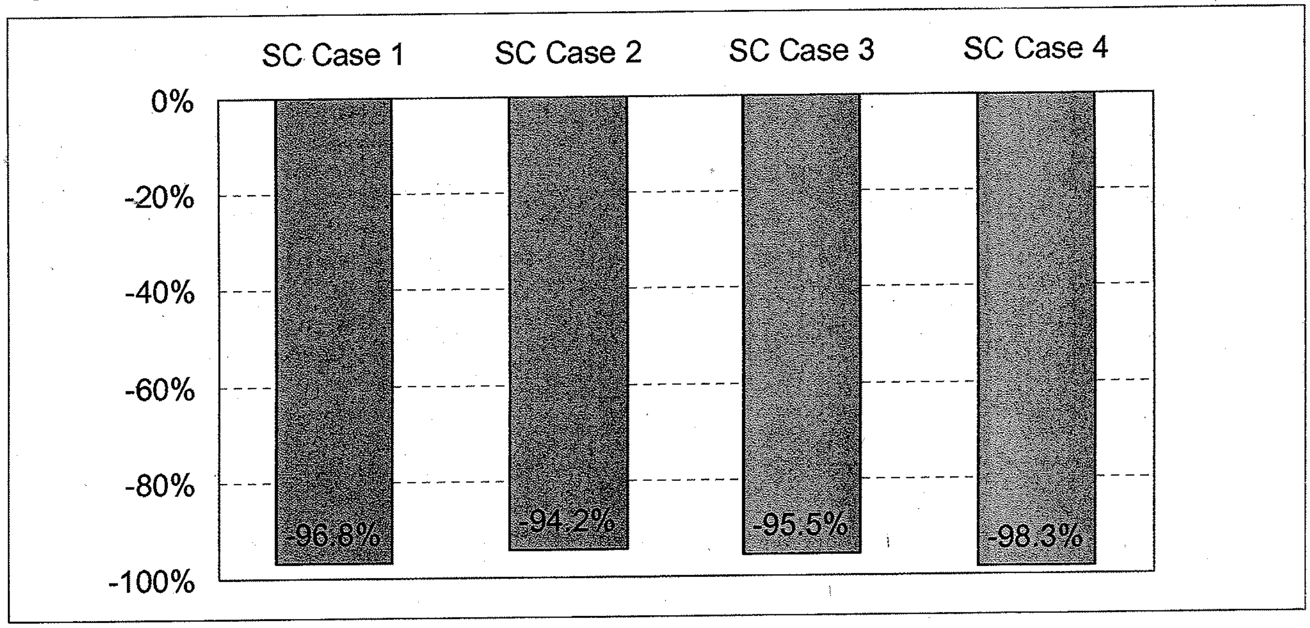
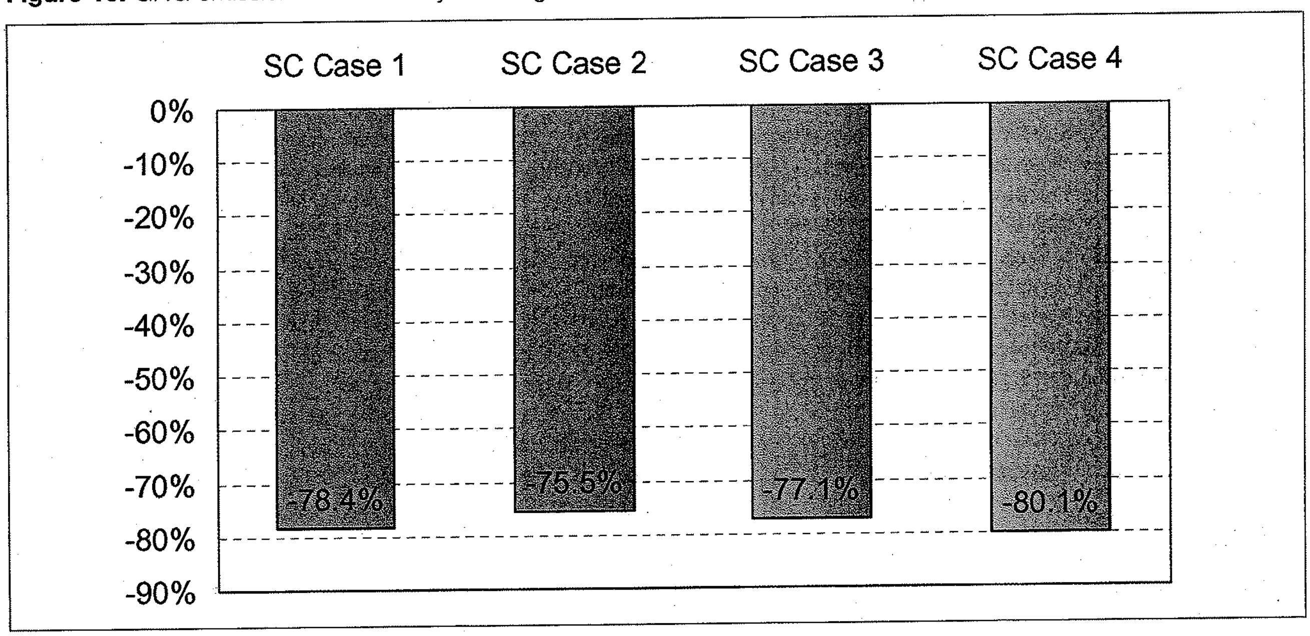


Figure 10. GHG emission reductions by four sugarcane ethanol cases relative to petroleum gasoline



biomass farming. For example, sugarcane farming is associated with open-field burning of sugarcane tops and leaves, a practice not used in either corn farming or cellulosic biomass farming. CH_4 and N_2O emissions from open-field burning alone are responsible for 24% of total GHG emissions for sugarcane ethanol (Figure 8). In particular, the five major contributors to sugarcane ethanol GHG emissions are open-field burning (24%), N_2O emissions from sugarcane fields (14%), fertilizer production (16%), GHG emissions from sugarcane mills (17%), and sugarcane farming (9%); together these make up 80% of the total WTW GHG emissions of sugarcane ethanol.

Sensitivity cases of sugarcane ethanol

We developed four sugarcane ethanol cases in this study to show variations in energy and GHG emission effects of sugarcane ethanol. The difference between Cases 1 and 2 shows the contribution of energy embedded in farming equipment production and sugarcane mill construction; that between Cases 1 and 3 shows the contribution of energy embedded in farming equipment production; and that between Cases 1 and 4 shows the contribution of transporting ethanol from Brazil to the United States.

Figures 9 and 10 show the effects of these factors. In particular, inclusion of energy embedded in farming equipment and sugarcane mill construction lowers fossil energy reductions by sugarcane ethanol by 2.6 percentage points and GHG emission reductions by 2.9 percentage points. Inclusion of energy embedded only in farming equipment lowers fossil energy reductions by 1.3 percentage points and GHG reductions by 1.3 percentage points. These results imply that energy embedded in farming equipment and sugar cane mills contributes in equal proportion to total sugarcane ethanol results.

The difference between Cases 1 and 4 indicates that transportation of sugarcane ethanol from Brazil to the United States contributes to a 1.5-percentage-point difference in fossil energy use and a 1.7-percentage-point difference in GHG emissions for sugarcane ethanol.

We also analyzed two cases for open-field burning - one with 100% burning and the other with 0% burning (this is compared with the assumed 80% open-field burning for all four sugarcane ethanol cases examined in this study). The results of the two cases showed a difference in GHG emission reductions of 9 percentage points. Brazil is going to phase out open-field burning in the future, which will certainly help further reduce GHG emissions of sugarcane farming, together with reductions in emissions of criteria pollutants such as NO_x and PM_{10}.

CH_4 emissions from open-field burning are subject to great uncertainty (Table 3). Use of a CH_4 emission factor of 0.15 g/kg of biomass instead of 2.7 g/kg helps increase GHG emission reductions of sugarcane ethanol by 5.2 percentage points.

We assumed in our analysis that the exported electricity from sugarcane ethanol plants will displace electricity generated in natural-gas electric power plants, which are believed to be the marginal electric power mix in Brazil. On the other hand, if the exported electricity displaces the average electricity in Brazil (83% of which is from hydro power), the GHG emission benefits of sugarcane ethanol would be reduced by up to 8 percentage points.

Conclusions

By using the GREET model to conduct a WTW analysis of the pathway of producing ethanol from sugarcane in Brazil and using it in the United States, we reached the following conclusions. Sugarcane ethanol could achieve fossil energy reduction as much as 97% relative to petroleum gasoline. The large reduction is a result of use of bagasse in sugarcane mills in place of coal or natural gas to generate the heat and power needed for plant operation. This and other factors such as low use of energy and fertilizer for sugarcane farming contribute to a positive net energy balance of 0.96 MJ per MJ of ethanol produced.

Sugarcane ethanol could achieve a reduction of 78% in GHG emissions relative to those of petroleum gasoline. This reduction is similar to that of cellulosic ethanol. Even when energy embedded in farming equipment and sugarcane mills is included, GHG emission reductions by sugarcane ethanol are still more than 75%. The large reductions can be attributed to the use of bagasse in sugarcane mills, among other factors. Of the total GHG emissions associated with sugarcane ethanol, the five major contributors are open-field burning of sugarcane tops and leaves, N_2O emissions from sugarcane fields, fertilizer production, sugarcane mill operation, and sugarcane farming.

Acknowledgments

This work was sponsored by the Office of FreedomCAR and Vehicle Technologies under the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy. Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC, under contract No. DE-AC02-06CH11357.

We thank the following individuals for providing helpful comments on an earlier manuscript: Dr. Issais Macedo of Brazil, Mr. Robert Edwards of the Joint Research Center of the European Commission, and Mr. Vincent Camobreco of the United States Environmental Protection Agency. We also thank the reviewers of this journal for their helpful comments on our draft manuscript.

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APPENDIX F

Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Brazilian Sugarcane Ethanol Production Simulated by Using the GREET Model

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Date of submission: July 23, 2007
Number of pages: 28
Number of figures: 11
Number of tables: 11
Number of equations and formulas: 0

(Paper to be submitted to the *International Journal of Life Cycle Assessment*)

July 20, 2007

Abstract

By using data available in the open literature, we expanded the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory to include Brazil-grown sugarcane ethanol. With the sugarcane ethanol pathway added to the GREET model, we examined the well-to-wheels (WTW) energy use and greenhouse gas (GHG) emissions of sugarcane-derived ethanol produced in Brazil and used to fuel light-duty vehicles in the United States. Results for sugarcane ethanol were compared with those for petroleum gasoline. This paper documents the development of the sugarcane-to-ethanol pathway in the GREET model. The pathway comprises fertilizer production, sugarcane farming, sugarcane transportation, and sugarcane ethanol production in Brazil; ethanol transportation to U.S. ports and then to U.S. refueling stations; and ethanol use in vehicles. We developed and examined several sensitivity cases to test the effect of key parameters on WTW results for sugarcane ethanol. Our analysis revealed that sugarcane ethanol can reduce GHG emissions by 78% and fossil energy use by 97%, relative to petroleum gasoline.

1. Introduction

Brazil began its sugarcane fuel ethanol program in 1975 after the first oil crisis and has since expanded it significantly. Brazil is now the number 2 fuel ethanol producer and consumer after the United States. Ethanol has become a mainstream motor fuel in Brazil, accounting for 40% of its gasoline market. More than 80% of new cars sold in 2006 were ethanol flexible-fuel vehicles (FFVs).

Brazil has vast land available for sugarcane farming. About five million hectares of land are currently used for sugarcane farming in Brazil (Macedo 2005), and some in Brazil maintain that an additional five million hectares can be made available for sugarcane farming. Brazil expects that its sugarcane ethanol industry will continue to expand. In fact, companies from other countries are beginning to invest in the sugarcane ethanol industry in Brazil. In addition to its own consumption, Brazil seeks to export fuel ethanol to other countries, including the United States, the European Union, and Japan.

With the support of the U.S. Department of Energy (DOE), Argonne National Laboratory has been developing and applying the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to examine energy and emission benefits of advanced vehicle technologies and new transportation fuels (see Brinkman et al. 2005 for the GREET model and its applications). The GREET model features many fuel ethanol production pathways from feedstocks such as corn, fast-growing trees, switchgrass, crop residues, and forest residues. As part of this effort, we added the production of sugarcane ethanol in Brazil and use of it in the United States to the GREET model.

2. System Boundary and Analysis Cases for the Sugarcane-to-Ethanol Pathway

We conducted a well-to-wheels (WTW) analysis of Brazilian sugarcane-derived ethanol based on the system boundary depicted in figure 1. The sugarcane-to-ethanol pathway simulated in this study comprises the following stages:

- Fertilizer production
- Sugarcane farming and harvesting
- Sugarcane transportation
- Ethanol production
- Ethanol transportation from sugarcane mills in Brazil to U.S. ports
- Ethanol transportation and distribution from ports to refueling stations within the United States
- Ethanol use in U.S. vehicles

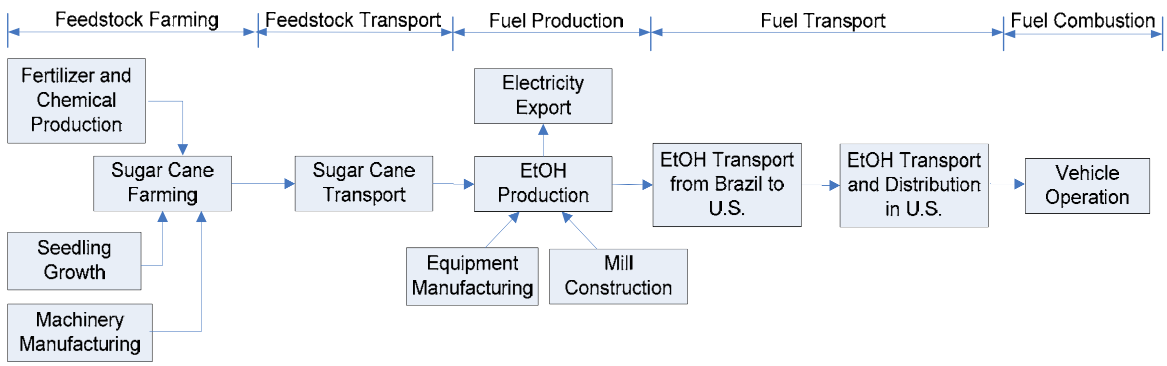


Figure 1. Stages of the Sugarcane-to-Ethanol Pathway

The life cycle of sugarcane-derived ethanol begins with the manufacture of fertilizer and farming machinery and the preparation of cane seedlings. Farming operations include chemical application, irrigation, tillage, and harvest. The current sugarcane farming practice involves open-field burning of sugarcane leaves and straws before and after harvest to facilitate the manual harvest and to control disease. Harvested sugarcane is transported via trucks to sugarcane mills, where it undergoes sugar juice extraction, followed by fermentation of juice for ethanol production (and/or sugar production).

The residues from juice extraction — called "bagasse" — are combusted in sugarcane mills to generate steam and electricity to meet the demand for heat and power. Since 2000, sugarcane mills have made major efforts to export their excess electricity to the electric grid. In addition to the manufacture of farming machinery and sugarcane mill equipment, construction of sugarcane mills was included in this analysis.

Ethanol is transported from sugarcane mills to Brazilian ports via rails and pipelines, to U.S. ports by ocean tankers, and then to U.S. refueling stations via trucks. Ethanol is used either in low-level blends such as E10 (mixture of 10% ethanol and 90% gasoline by volume) in regular gasoline vehicles or high-level blends such as E85 (mixture of 85% ethanol and 15% gasoline by volume) in FFVs.

The gasoline life cycle, on the other hand, begins with crude oil recovery in oil fields and ends in gasoline combustion in gasoline vehicles, a pathway that is already in the GREET model.

In this near-term (2006–2010) analysis of the sugarcane ethanol life cycle, many factors play a key role in determining the overall energy use and greenhouse gas (GHG) emissions of sugarcane ethanol. We examined these factors by developing several sugarcane ethanol cases, all of which produce ethanol and export electricity to the electric grid. In addition, we included petroleum gasoline, corn ethanol, and switchgrass ethanol for comparison.

The base case established for sugarcane ethanol was production in Brazil and use in the United States. Other cases were developed to test the importance of the following parameters: (1) whether sugarcane ethanol is used in the United States or Brazil (to assess the contribution of ocean tanker transportation of ethanol), and (2) whether energy embedded in farming equipment manufacturing and sugarcane mill construction makes a significant contribution to the WTW results of sugarcane ethanol. The sugarcane (SC) cases and the petroleum gasoline, corn ethanol, and switchgrass ethanol cases were as follows:

- SC Case 1 (the base case for sugarcane ethanol): sugarcane ethanol is produced in Brazil and used in the United States; energy embedded in farming equipment manufacturing and sugarcane mill construction is not included (This case is consistent with the petroleum gasoline pathway.)

- SC Case 2: same as SC Case 1 except that energy embedded in farming equipment manufacturing and sugarcane mill construction is included

- SC Case 3: same as SC Case 1 except that energy embedded in farming equipment manufacturing is included

- SC Case 4: same as SC Case 3 except that sugarcane ethanol is used in Brazil (This case shows the contribution of ocean tanker transportation of ethanol.)

- Petroleum gasoline production and use in the United States excluding energy embedded in all infrastructure-related activities

- Corn ethanol production and use in the United States, including energy embedded in farming machinery

- Cellulosic ethanol production and use in the United States with switchgrass as the feedstock and including energy embedded in farming machinery manufacture

3. Data Sources and GREET Assumptions

To develop the sugarcane ethanol pathway in GREET, we collected data for the activities associated with the sugarcane ethanol pathway from the open literature. The data were processed to derive input parameters for GREET.

Previous studies have been conducted to evaluate the GHG emission effects of sugarcane ethanol. Macedo et al. (2004) conducted a detailed analysis of the energy and emission effects associated with the production and use of sugarcane ethanol in Brazil. A study by Concawe et al. (2007) included sugar cane ethanol among many other transportation fuels; it relied on data developed by Macedo et al. and other studies.

3.1. Sugarcane Farming

We analyzed energy use and emissions for activities involved in sugarcane farming, including fertilizer, lime, and chemical production; sugarcane seedling preparation; farming operations; farming equipment manufacturing; and open-field burning of sugarcane leaves and straws.

3.1.1. Chemical and Energy Inputs for Sugarcane Farming

Once sugarcane seedlings have been planted on sugarcane farms, the sugarcane can be harvested for five to seven seasons. After that, sugarcane farms are replanted. Table 1 presents the typical composition of sugarcane. Traditionally, sugarcane is harvested by laborers (“sugarcane cutters”); this harvest is often referred as to the manual harvest. To ease cutters’ efforts, sugarcane fields are burned before harvest. After harvest, the remaining stalks are often burned to control disease and promote seedling growth in the next season. Primarily because of concerns about air pollution caused by open-field burning, the state of Sao Paulo will phase out open burning completely by 2018. As a result, mechanical harvesting will replace manual harvesting. As of 2005, 65% of the sugarcane harvest in Brazil was manual and 35% was mechanical (Macedo 2005).

Table 1. Sugarcane Composition

Parameter	Value (%)
Sucrose content	14.5
Fiber content	13.5
H_2O content	72.0

Source: Macedo et al. 2004.

Table 2 summarizes the application rates of nitrogen (N) and phosphate (P_2O_5) fertilizer, potash (K_2O), lime ($CaCO_3$), herbicide, and pesticide on Brazilian sugarcane farms. Fertilizer and chemical use are usually reported in kilograms per hectare per year (kg/ha/yr); however, for GREET simulations, we need to use kilograms or grams of per metric ton (kg/MT) of sugarcane harvested. We converted the value by using a sugarcane yield of 68.6 MT/ha (Macedo et al. 2004). The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007).

Table 2. Fertilizer and Chemical Inputs for Sugarcane Farming in Brazil

Input	Assuncao (2000)[a]	Macedo et al. (2004)[b]	GREET[e]
N fertilizer			
kg/ha/yr	77.2	71.6[c]/75[d]	
g/MT of sugarcane	1,152.2	1,042.2[c]/1,091.7[d]	1,091.7
P_2O_5			
kg/ha/yr		40.8[c]/8.3[d]	
g/MT of sugarcane		593.9[c]/120.8[d]	120.8
K_2O			
kg/ha/yr		120[c]/13.3[d]	
g/MT of sugarcane		1,746.7[c]/193.6[d]	193.6
Lime ($CaCO_3$)			
kg/ha/yr		366.7	
g/MT of sugarcane		5,337.7	5,337.7
Herbicide use			
g/MT of sugarcane		26.9	26.9
Pesticide use			
g/MT of sugarcane		2.21	2.21

[a] Assuncao assumed a nitrogen application of 28 kg/ha for planting of sugarcane and 87 kg/ha for each harvest season. We assumed a cycle of 6 years with five cuts. He further assumed a sugarcane yield of 80.4 MT/ha/cut, resulting in 67 MT/ha over the 6-year period. These values were used to derive nitrogen application per hectare per year and per metric ton of sugarcane harvested.
[b] Macedo et al. (2004) used a sugarcane yield of 68.7 MT/ha over a 6-year sugarcane cycle. We used this value to derive nitrogen application rates per metric ton.
[c] For farms that do not use filter mud cake and vinasse (the residues left in a still following distillation).
[d] For farms that use filter mud cake and vinasse.
[e] For GREET simulations, weighted average values between sugarcane fields without and with use of filter mud and vinasse would be ideal. Because of the lack of data regarding breakdown of the two types of sugarcane plantations, we adopted the values for the fields with use of filter mud and vinasse.

For sugarcane farming, energy use includes diesel fuels used to power farming equipment, energy spent preparing sugarcane seedlings, and energy embedded in farming equipment manufacturing (Table 3). Although GREET WTW analyses generally do not include energy embedded in equipment, we included it to be consistent with the pathways for ethanol production from different feedstocks, which include this energy. Nonetheless, we designed an option in GREET for including or excluding the energy embedded in farming equipment manufacturing and associated emissions.

Table 3. Inputs of Energy Use for Farming Operation, Seedling Preparation, and Farming Machinery Manufacturing for Sugarcane Farming

Input	Assuncao (2000)	GTZ (2005)	Macedo et al. (2004)	GREET
Farming operation[a]				
MJ[b]/MT of sugarcane	30.1	38	38	
Btu[b]/MT of sugarcane	28,531	36,019	36,019	36,019
Sugar cane seedling preparation				
MJ/MT of sugarcane	5.76	6	5.88	
Btu/MT of sugarcane	5,460	5,687	5,573	5,573
Energy embedded in farming machinery				
MJ/MT of sugarcane	33.1		29.1	
Btu/MT of sugarcane	31,346		27,583	27,583

[a] The farming energy data include energy use for sugarcane harvesting, as well as for other farming activities. Data from the three cited sources are for combinations of manual and mechanical harvest. Although manual harvest now accounts for more of the total harvest than mechanical harvest, in the long term, mechanical harvest will account for more. Energy use between the two harvest methods could be different, but no data showing the difference are available. The difference in harvest energy use may be small, because manual harvest collection and loading activities are still performed by machines to a large extent.

[b] MJ = millijoules; Btu = British thermal unit.

3.1.2. Open-Field Burning of Sugarcane Leaves and Tops

Sugarcane leaves and tops are typically burned in the field before and after harvest. Macedo et al. (2004) reported a yield of 280 kg of leaves and tops (with 50% moisture content, or 140 kg of dry leaves and tops) per metric ton of sugarcane harvest. At present, 80% of sugarcane farms in Brazil practice open-field burning. Because open-field burning will be gradually phased out, in developing the sugarcane ethanol pathway in GREET, we assumed burning of 80% of leaves and tops at present and 0% in 2020.

For the GREET simulation, we took into account emissions from open-field burning — in particular, emissions of two pollutants: methane (CH_4) and nitrous oxide (N_2O). Emissions of carbon dioxide (CO_2) from open-field burning were not taken into account, because the CO_2 is uptaken during sugarcane growth. Emissions from open-field burning of sugarcane leaves and tops were estimated by assuming a leaf and top moisture content of 15%, which is similar to that of corn stover and switchgrass. The carbon content of leaves and tops is 50% on a dry-matter basis (Macedo et al. 2004).

Table 4 lists our estimates of emissions generated from open-field burning. These were based on three sources: summaries of Macedo et al. (2004) and Assuncao (2000); results in Andreae and Merlet (2001); and data included in the Intergovernmental Panel on Climate Change guidelines (IPCC 2006a). Average emissions values from open-field burning of agricultural residues listed in the IPCC guidelines appear higher than those from other sources. We used IPCC data as our base case for emission factors of CH_4, N_2O, carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter measuring

2.5 micrometers or less ($PM_{2.5}$). For PM_{10} (particulate matter measuring 10 micrometers or less), we estimated emission factors on the basis of a ratio of 2:1 between PM_{10} and $PM_{2.5}$, which was derived from coal combustion emission factors in GREET. Therefore, we used a value of 7.8 g/kg of leaves and tops burned for PM_{10}. For volatile organic compound (VOC) and sulfur oxides (SO_x) emission factors, we used values estimated by Andreae and Merlet (2001).

Table 4. Emission Factors of Open-Field Burning of Sugarcane Leaves and Tops

	Emission Factors (g/kg of dry leaves and tops burned)					
		Macedo et al. (2004)				
Pollutant	Andreae and Merlet (2001)	Low Value[a,b]	High Value[a,b]	Assuncao (2000)[a]	IPCC (2006a)	GREET
CO_2	1515 ($\pm$177)				1515 ($\pm$177)	NN[c]
CO	92 ($\pm$84)				92 ($\pm$84)	92
CH_4	2.7	0.1464	1.0214	0.2886	2.7	2.7
NO_x	2.5($\pm$1)				2.5 ($\pm$1)	2.5
N_2O	0.07				0.07	0.07
$PM_{2.5}$	3.9					3.9
PM_{10}						7.8 [d]
VOC	7.0					7.0
SO_x	0.4					0.4

[a] These sources reported CH_4 emissions in kg/MT of sugarcane harvested. We used the yield of 280 kg of sugar cane leaves and tops with 50% moisture content per MT of sugarcane harvested to convert the original values into values in g/kg of leaves and tops burned.
[b] Macedo et al. (2004) maintained that the low values represented the average Brazilian emission rates, and the high values were adopted from the IPCC guidelines.
[c] Data are not needed here. CO_2 emissions are calculated in GREET by using the carbon balance of sugar cane leaves and tops; see Section 4.1.
[d] Data were not available. This value was estimated on the basis of the ratio of PM_{10} versus $PM_{2.5}$ for coal combustion.

3.1.3. N_2O Emissions from Sugarcane Fields

A major source of N_2O emissions from sugarcane farming is nitrification and denitrification of nitrogen fertilizer applications. In Brazil, the most frequently used type of nitrogen fertilizers is urea (Macedo 2007), from which N_2O is emitted directly and indirectly. When applied to soil, nitrogen fertilizer is volatilized and converted to N_2O; when oxidized, some of it is emitted directly to the air as N_2O. A large amount of nitrogen fertilizer leaches to groundwater or rivers through surface runoff, during which some of it is converted to N_2O via microbial nitrification and denitrification. Macedo et al. (2004) estimated that on an annual basis, 75 kg of nitrogen in nitrogen fertilizer applied to a 1-ha sugarcane field resulted in 1.76 kg of N_2O emissions in the Central-South region of Brazil, which resulted in 1.5% in weight (wt%) of nitrogen in N_2O per weight unit of nitrogen in nitrogen fertilizer applied.

N_2O emissions from soil are highly uncertain; they depend on various conditions such as the amount of nitrogen fertilizer applied, soil type, soil moisture content, and temperature. According to the IPCC guidelines (2006b), the following are the N_2O emission factors for nitrogen in N_2O generated from the nitrogen in nitrogen fertilizer for generic applications: 1% for direct N_2O-N emissions, with a range of 0.3–3%; 1% for N_2O emissions from volatilization, with a range of 0.2–5% and a volatilization rate for nitrogen input of 10%, with a range of 3–30%; and 0.75% N_2O emissions from leaching and runoff, with a range of 0.05–2.5% and a leaching and runoff rate for nitrogen input of 30%, with a range of 10–80%. Using the average values in the IPCC guidelines (2006b), we derived a total N_2O-N rate of 1.325% (1% + 1% × 10% + 0.75% × 30%), which is close to the value of 1.5% derived from Macedo et al. (2004). We used the rate of 1.5% in our analysis.

The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007). A gram of urea (NH_2CONH_2) contains 0.2 g of carbon, resulting in 0.43 g of carbon per gram of nitrogen in urea. This results in 1.577 g of CO_2 per gram of nitrogen in urea. We included this CO_2 emission source in the GREET simulation.

3.1.4. Sugarcane Transportation from Farms to Sugarcane Mills

Harvested sugarcane contains about 70% water. Because sugarcane is bulky and heavy, sugarcane mills are built in the midst of sugarcane farms to minimize transportation distance. Sugarcane is transported via trucks (see figure 2) an average one-way distance of 20 km (Macedo et al. 2004). The payload of a truck is 40–50 MT (Moreira and Goldemberg 1999). With these inputs, past studies in Brazil concluded that energy use for transporting sugarcane from farms to mills is 31–43 MJ/MT of sugarcane (Assuncao 2000; GTZ 2005; Macedo et al. 2004).

Figure 2. A Truck Carrying Sugarcane to Sugarcane Mill

For GREET simulations, we assumed that sugarcane is transported by a diesel truck with a payload of 40 MT for a 20-km one-way trip from field to mill. Furthermore, we assumed a fuel economy of 4 miles per gallon of diesel fuels for trucks transporting sugarcane. On the basis of these assumptions, the GREET model estimated an energy consumption of 24.4 MJ/MT of sugarcane transported. This value is lower than the values in the cited studies; those studies may have included direct energy use (as was the case in our estimate) and energy embedded in manufacturing the trucks.

3.2. Ethanol Production in Sugarcane Mills

In sugarcane mills, sugarcane is washed and crushed, and cane juice is extracted. The juice is then treated to produce ethanol and/or sugar. The split between the two products is based on market demand. The stream for ethanol production is then fermented, and the fermentation broth is subject to distillation, yielding product ethanol. CO_2 is emitted during fermentation. Figure 3 is a schematic of the sugarcane ethanol production process. To simplify this analysis, we assumed that a sugarcane ethanol mill is operated with 100% feed for ethanol production. The primary source of process fuel is bagasse with additional lubricant oil to support machinery operation.

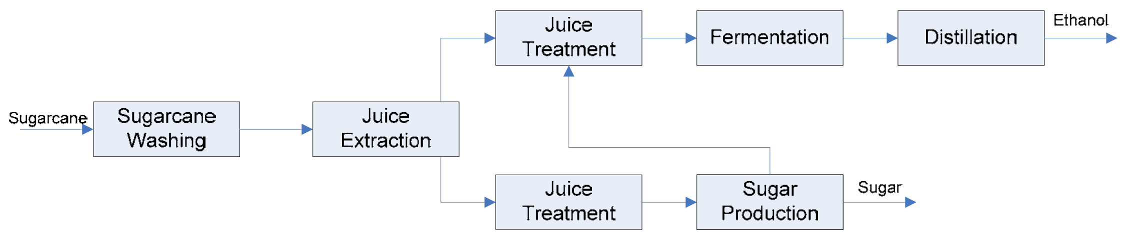


Figure 3. Schematic Representation of the Sugarcane Ethanol Production Process

3.2.1. Ethanol Yield

Table 5 presents a summary of ethanol yield from several studies. We used a yield of 91 L of ethanol/MT of sugarcane, based on the best value reported in Macedo et al. (2004).

Table 5. Summary of Ethanol Yield in Sugarcane Mills[a]

Source	Ethanol Yield (L/MT)	Notes	GREET Input (L/MT)/(gal/MT)[b]
Moreira and Goldemberg (1999)	79.5	1996/97 season yield	
Assuncao (2000)	73 85.4	1985 season yield 2000 season yield	
GTZ (2005)	80		
Macedo et al. (2004)	86 91	Average value Best value	 91/24

[a] Assuming that all sugarcane goes to ethanol production.
[b] Based on wet metric ton of sugarcane.

3.2.2. Energy Requirements in Sugarcane Mills

Table 6 shows the amounts of electric, thermal, mechanical, and chemical energy required for production of ethanol in sugarcane mills. Sugarcane mills are self-sufficient in terms of thermal energy and electricity use. Heat demand represents the majority of energy use and is met through bagasse combustion. Most sugarcane mills generate their own electricity for internal use. The use of bagasse as the process fuel is discussed in Section 3.2.4. We selected values for GREET input parameters on the basis of the latest data from the open literature. We estimated total electricity use by the sugarcane mill to be 28.85 kWh/MT of sugarcane processed. Of this total, 16.84 kWh/MT is used to drive mechanical work with a conversion efficiency of 95% (Table 7).

Table 6. Energy Consumption in Ethanol Production Process

Parameter	MJ/MT of Sugarcane	Data Source	GREET Input (MJ/MT of Sugarcane)
Energy Use			
Electricity	43.20	Macedo 2005	43.20
Mechanical energy	57.60	Macedo 2005	57.60
Thermal energy	1,188.00	Macedo 2005	1,188.00
Chemical and Lubricant Use			
	7.34	Assuncao 2000	
	6.00	GTZ 2005	
	6.36	Macedo et al. 2004	6.36
Energy Embedded in Sugar Mill Construction			
Average value	10.78	Assuncao 2000	
Average value	12.00	GTZ 2005	
Best value	8.07	Assuncao 2000	
Best value	9.00	GTZ 2005	
Average value	11.97	Macedo et al. 2004	
Best value	9.29	Macedo, 2004	9.29
Energy Embedded in Sugar Mill Equipment			
Average value	27.96	Assuncao 2000	
Average value	31.00	GTZ 2005	
Best value	20.98	Assuncao 2000	
Best value	24.00	GTZ 2005	
Average value	31.07	Macedo et al. 2004	
Best value	24.16	Macedo et al. 2004	24.16

We assumed that the thermal energy (1,188 MJ, or 1.126 million Btu, per MT of sugarcane) is supplied by bagasse combustion in a biomass boiler to produce steam with an efficiency of 80%. There is 1.408 million Btu of bagasse per MT of sugarcane, or 58,546 Btu/gal of ethanol produced (Table 7). A small amount of lubricants (6.36 MJ/MT of sugarcane) is used in sugarcane mills, which we assumed to be similar to residual oil in terms of energy and emission profiles. Therefore, we approximated the energy use of lubricant oil to that of residual oil.

Table 7. Process Energy Use in Sugarcane Mills for Ethanol Production

	MJ/MT of Sugar cane	KWh/MT of Sugarcane	KWh/gal of EtOH[a]	Btu/MT of Sugarcane	Btu/gal of EtOH[a]
Electricity	43.2[b]	12.00	0.50		
Mechanical	57.6[b]	16.84[c]	0.70		
Thermal	1,188[b]			1,407,583	58,546
Lubricant oil	6.36[b]			6,028	251
Mill construction	9.29[b]				366
Equipment manufacturing	24.16[b]				953
Total		28.85	1.20		

[a] The conversion from sugarcane processed to ethanol produced is based on the ethanol yield of 91 L/MT of wet sugarcane.
[b] Data source: see Table 6.
[c] We assumed a conversion efficiency of 95% from electric energy to mechanical energy.

Macedo et al. (2004) estimated a life-cycle energy use of 9.29 MJ/MT of sugarcane processed in construction of sugarcane mills and 24.16 MJ/MT in manufacture of sugarcane mill equipment (that is, embedded energy in mill equipment). We included these values in the GREET model. The equipment used was assumed to be 100% steel. Emissions from equipment manufacturing were estimated on the basis of process fuel shares for steel production as presented in GREET 2.7.

3.2.3. Bagasse as the Process Fuel in Sugarcane Mills

Bagasse is the residue of sugarcane after the juice has been extracted. Because of its high carbon content (46.3 wt% on a dry matter basis), it serves as an excellent source of process fuel in sugarcane mills. We assumed that bagasse is combusted in a biomass boiler to produce steam to meet the plant demand for steam and to generate electricity with a steam turbine to meet the plant requirement for electricity and for electricity export.

We used a bagasse yield of 280 kg (50% moisture content) per MT of sugarcane, which was reported by Macedo et al. (2004). The lower heating value (LHV) of bagasse in references ranged from 7.530 to 7.736 MJ/kg (with 50% moisture content, Macedo et al. 2004; Garcia 2007). One heating value reported by Assuncao (2000), 9.449 MJ/kg, was 2 MJ higher and was not specified as either high heating value (HHV) or LHV. We compared the data with Perry's *Chemical Engineers' Handbook* (Perry and Green 1997) which listed an HHV of 8.37–11.63 MJ/kg for bagasse, suggesting that the value of 9.448 MJ/kg is most likely the HHV. For sugarcane ethanol simulations in GREET, we used a LHV of 7.53 MJ/kg (with 50% moisture) for bagasse. On a dry-matter basis, the LHV for bagasse is 15.06 MJ/kg, or 12,947,320 Btu/ton.

The steam and electricity balance for sugarcane ethanol processing is presented in Table 8. The total energy provided by bagasse, 83,124 Btu/gal of ethanol produced, was determined by using a bagasse energy yield of 280 kg/MT sugarcane × 7.53 MJ/kg at an ethanol yield of 0.024 gal/kg of sugarcane (91 L/MT). The steam needed for plant operation is 58,546 Btu/gal of ethanol, which is based on a boiler efficiency of 80% (Table 7).

We assumed the surplus steam, 24,578 Btu/gal of ethanol, is used to generate electricity. With an electricity generation efficiency of 30% (the current Brazil industrial average), a total of 2.16 kWh of electricity can be generated for each gallon of ethanol produced. After 1.20 kWh (Tables 7 and 8) has been consumed in the process, an excess of 0.96 kWh/gal of ethanol is available for export.

Table 8. Ethanol Plant Steam and Electricity Energy Balance (per gallon of ethanol)

Bagasse Energy Yield (Btu)	Internal Steam Needs (Btu)	Extra Btu for Electricity Generation (Btu)
83,124[a]	58,546	24,578
Electricity Generated from Extra Bagasse Energy (KWh)	Internal Electricity Needs (kWh)	Extra Electricity for Export (kWh)
2.16[b]	1.20	0.96

[a] This value is calculated as follows. One MT of sugarcane results in 280 kg of bagasse with 50% moisture content and 91 L of ethanol. Thus, a gallon of ethanol is associated with 11.66 kg of bagasse, which contains 87.70 MJ of energy, or 83,124 Btu of energy.
[b] Based on a power generation efficiency of 30%.

3.2.4. Bagasse Combustion Emissions

The IPCC guidelines (2006b) specify emission factors of CH_4 and N_2O from biomass combustion; see Table 9. Because of the large variations in the CH_4 and N_2O emission factors, we adopted the IPCC average values for GREET simulations.

Table 9. Emission Factors of Bagasse Combustion

Pollutant	Emission Factors (g/mm Btu of bagasse)			
	From IPCC Guidelines (2006b)			GREET Inputs
	Low	Average	High	
CH_4	11.00	31.65	105.50	31.65
N_2O	1,58	4.22	15.83	4.22

3.3. Ethanol Transportation from Sugarcane Mills to Refueling Stations

While some Brazilian sugarcane ethanol is exported to Japan, the European Union, and the United States, the majority of the sugarcane ethanol produced in Brazil is used in the Brazilian domestic market. For a U.S. perspective of Brazilian sugarcane ethanol, we examined the case in which sugarcane ethanol is produced in Brazil and used in the United States market so that we could compare its effects directly with those of ethanol production pathways already examined for the United States.

For the case of the domestic use of ethanol in Brazil, we assumed that ethanol is transported via pipeline and rail for 350 miles (in each mode) from sugarcane mills to bulk terminals and then via truck for 50 miles to refueling stations, where it is used either in its pure form or blended with gasoline.

For the case of ethanol exported to the United States, we accounted for ethanol transportation in both Brazil and the United States. Ethanol is first transported from mills to Brazilian ports in Southern Brazil. For this analysis we selected a representative port, Santos, a major port in Brazil. Most sugarcane mills are located in the two southern states near the Santos port that provide about 50% of the nation’s ethanol. In particular, we assumed that ethanol is transported via pipeline and rail on an average of 500 miles (in each mode) from sugarcane mills to the Santos port, where it is loaded onto ocean tankers for transporting to the United States. We chose two U.S. ports, New York and Los Angeles, as entry points for Brazilian ethanol to the U.S. market. We used the average distance of 6,449 nautical miles from Santos to New York and from Santos to Los Angeles (see www.distance.com). Inside the United States, we assumed that ethanol is distributed regionally on the East and West Coasts, while the rest of the country receives domestic corn ethanol from the U.S. Midwest. In particular, we assumed that the imported ethanol is transported 100 miles by truck to blending and storage facilities and further distributed to refueling stations.

3.4. Extraction and Production of Process Fuels and Electricity Generation Mix

For individual stages of the sugarcane ethanol pathway in Brazil, such as sugarcane farming, cane transportation, ethanol production, and ethanol transportation to U.S. ports, the energy use and emissions of primary energy recovery and processing, including coal, natural gas, and oil, were not available at the time of this study. We used GREET default values, which are based on U.S. industry averages. These values may be updated once Brazilian data become available.

To estimate energy and emission credits of the exported electricity generated at sugarcane mills in Brazil, energy and emissions associated with electricity use in Brazil were estimated by assuming the electricity exported from sugarcane mills would replace electricity generation in natural gas plants. It is believed that natural gas power plants are marginal power plants in Brazil. In comparison, Table 10 shows the average power generation mix in Brazil.

Table 10. Average Electricity Generation Mix in 2004 in Brazil

Plant Fuel	Average Electricity Generation Mix in Brazil (%)
Petroleum	1.2
Natural gas	5.0
Coal	1.7
Biomass	4.2
Nuclear	3.0
Hydro	82.9
Others	2.0

Source: Ministry of Mine and Energy of Brazil (2005).

4. Key Issues in WTW Analysis of Sugarcane Ethanol

4.1. CO_2 Credits

During their growth, sugarcane plants take CO_2 from the air for the photosynthesis process. The carbon taken in by sugarcane plants resides in them and is further converted to carbon in CO_2, CO, VOC, and CH_4, which are generated through various chemical and biological routes (fermentation, combustion, and the like) when sugarcane is processed to produce ethanol. The CO_2 from sugarcane that is emitted through a combustion process or through ethanol combustion on vehicles is considered zero CO_2 emissions to the air, since this is the carbon from the air during sugarcane plant growth. In this case, the renewable carbon from sugarcane, rather than fossil fuel carbon, is used for combustion. Similarly, direct CO_2 emissions from sugar fermentation to ethanol are considered to be zero CO_2 emissions to the air.

We examined the fate of the renewable carbon in sugarcane beginning with harvested sugarcane by making several assumptions:

- All carbon in sugarcane plants is from atmospheric CO_2.
- Emissions from carbon in sugarcane plants end in four sources: CO_2, CO, VOC, and CH_4.
- CO and VOC, which are emitted to the air during combustion of sugarcane tops and leaves in sugarcane fields and combustion of bagasse in ethanol plants, are

converted to CO_2 in the air in a short time; these CO_2 sources, together with direct CO_2 emissions from these combustion processes, are not included in CO_2 emission calculations for sugar cane ethanol, since they are ultimately from the air.

- CH_4 from these combustion processes remains in the air for a long time, and these CH_4 emissions are accounted for as a GHG emission source for sugarcane ethanol.

- The organic carbon content of soil in sugarcane farms remains constant; however, this may not be the case if sugarcane ethanol production is expanded significantly and certain land uses are changed to accommodate such expansion.

Figure 4 is a schematic diagram of the fate of atmospheric carbon in the sugarcane ethanol pathway. The renewable carbon in sugarcane is utilized (combusted) in the sugarcane-to-ethanol pathway via three major routes: open-field burning of sugarcane leaves and tops, bagasse combustion in ethanol plants, and ethanol combustion during vehicle operation. All four forms of carbon emissions from these sources — CO_2, CO, VOC, and CH_4 — originate in carbon uptake from the air by sugarcane plants during growth. Among them, CO and VOC typically are oxidized to CO_2 within a few days after being released to the air. The amount of CO_2 generated is basically the carbon transformed from atmospheric CO_2; that is, the CO_2 emission sources shown in figure 4 are actually CO_2 from the air during sugarcane growth.

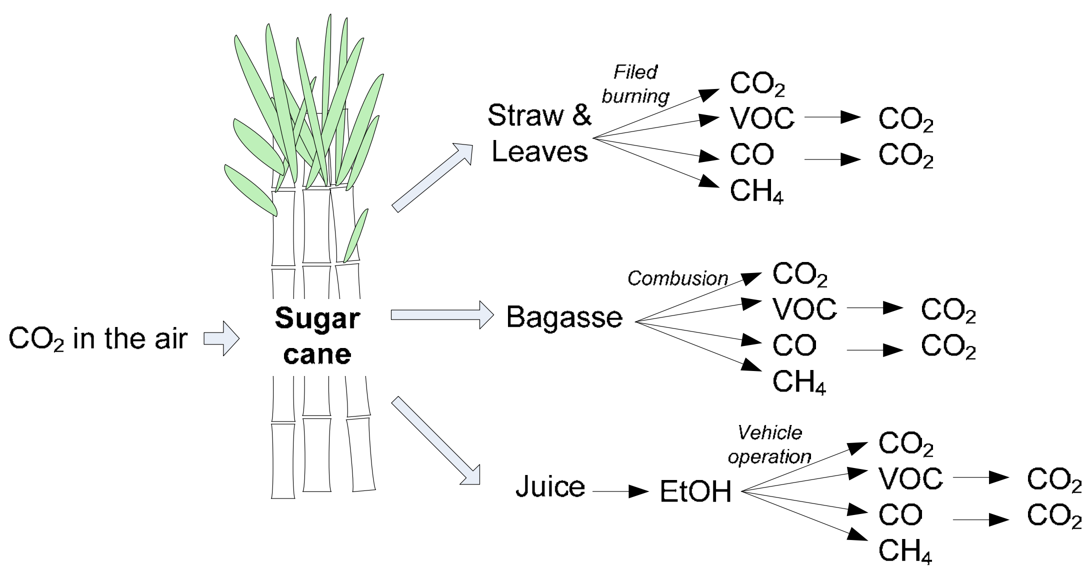


Figure 4. Fate of Renewable Carbon in the Sugarcane Ethanol Pathway

4.2. Energy and Emission Credits of Exported Electricity

Bagasse is combusted to provide steam for meeting process heat requirements at sugarcane mills, and excess steam generates electricity to satisfy plant internal power demand. Excess power could be exported to the electric grid. In some cases, mills may not be connected to the electric grid; thus, power export may not be an option. In the

GREET model, we designed two options for the sugarcane ethanol pathway: (1) ethanol production with no electricity export; and (2) ethanol production with excess electricity exported to the electric grid.

In the case in which excess electricity is exported to the electric grid (the case we considered in our simulations), electricity generated from sugarcane mills is assumed to displace electricity generated with natural gas electric power plants. On the other hand, if the exported electricity is assumed to displace the electricity with the Brazilian average electric generation mix, which is largely hydropower (82.9%, see table 10), the energy and emission credits of the exported power would be smaller. In other words, the fact that the renewable power generated from bagasse displaces another primary renewable power reduces the benefit of the exported electricity from sugarcane ethanol plants.

5. Results and Discussions

As indicated in Section 2, we established a base case for production of sugarcane ethanol in Brazil and use of it in the United States (SC Case 1). Three sensitivity cases were developed from the base case. For comparison, we selected the base case to compare sugarcane ethanol with corn ethanol, switchgrass-based cellulosic ethanol, and petroleum gasoline, since evaluation of these three cases does not include energy embedded in corn ethanol plants and petroleum refineries. WTW results of energy use and GHG emissions are presented in figures 5–11 and in Table 11. Energy and GHG emission results are expressed for each million Btu of fuel produced and used.

Energy use results for sugarcane ethanol, corn ethanol, and cellulosic ethanol are presented together in this section. While results for sugarcane and corn ethanol are based on operational data of many plants, results for cellulosic ethanol from switchgrass are based on projections and engineering simulations of switchgrass growth and cellulosic ethanol production. Note that in terms of commercial readiness, cellulosic ethanol is not at the same stage of development as sugarcane and corn ethanol.

5.1 Fossil and Petroleum Energy Use Results

Ethanol produced from Brazilian sugarcane achieves substantial reductions in fossil energy use (97%) relative to petroleum gasoline (Figure 5). The reductions are 2.6 times as much as those by corn ethanol. Fossil energy includes petroleum, natural gas, and coal energy; thus petroleum energy use presented here is a subset of fossil energy use.

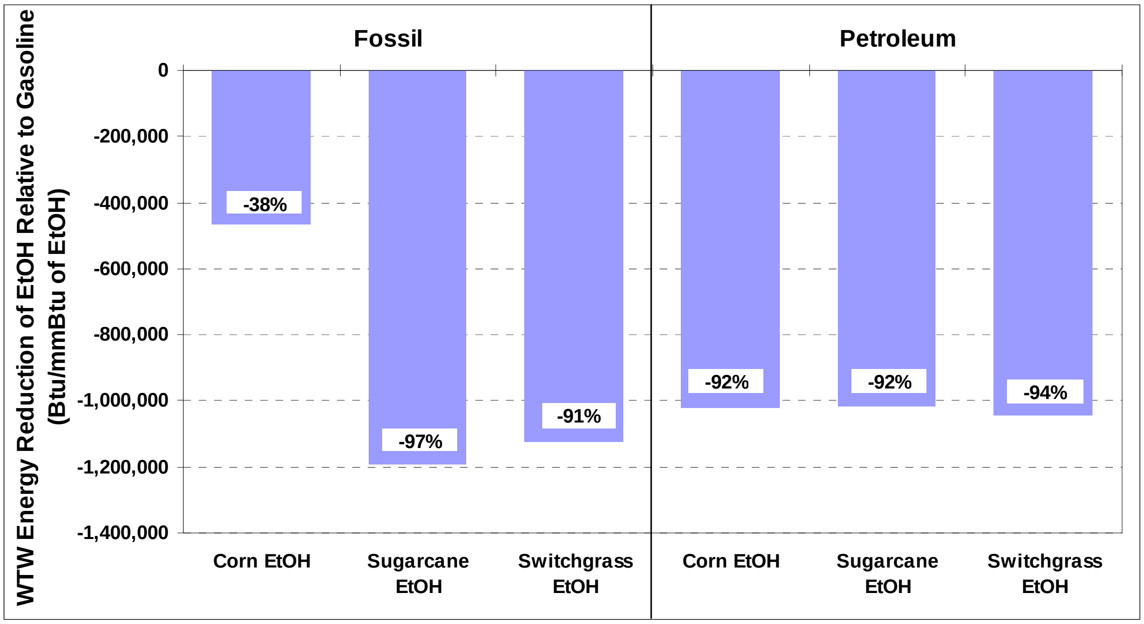
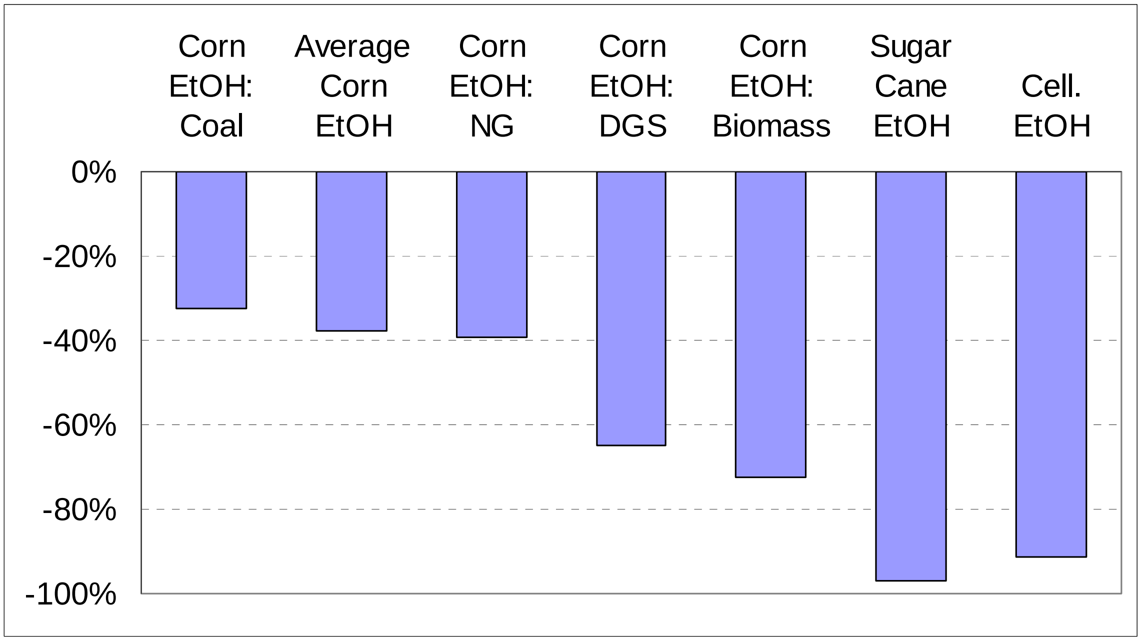


Figure 5. WTW Fossil Energy and Petroleum Reductions by Ethanol Relative to Petroleum Gasoline

Figure 5 shows that ethanol can provide reductions of more than 90% in petroleum energy compared to gasoline, regardless of the feedstocks for ethanol production (corn, sugarcane, or switchgrass). Figure 6 compares sugarcane ethanol with various ethanol production and feedstock options. Among the ethanol production and feedstock options evaluated, fossil energy reduction by sugarcane ethanol is similar to that by cellulosic ethanol. Figure 7 presents the net energy balance values of various ethanol production options and petroleum gasoline per million Btu of fuel produced. The net energy balance (NEB) is the difference between the Btu content of a fuel and the fossil Btu input to the fuel production pathway. A positive value of NEB represents an energy surplus for a fuel, while a negative value shows an energy deficiency. All the ethanol options show positive NEB values. For each million Btu of ethanol produced from sugarcane grown in Brazil and utilized in the United States, there is a net gain of 0.96 million Btu, in contrast to a net gain of 0.23 million Btu for corn ethanol and 0.89 million Btu for switchgrass-derived ethanol.



(Corn ethanol and cellulosic ethanol results are from Wang et al. (2007); each corn ethanol type represents the corn ethanol plants fueled with a given process fuel.)

Figure 6. WTW Fossil Energy Reductions of Various Ethanol Production Options Relative to Petroleum Gasoline

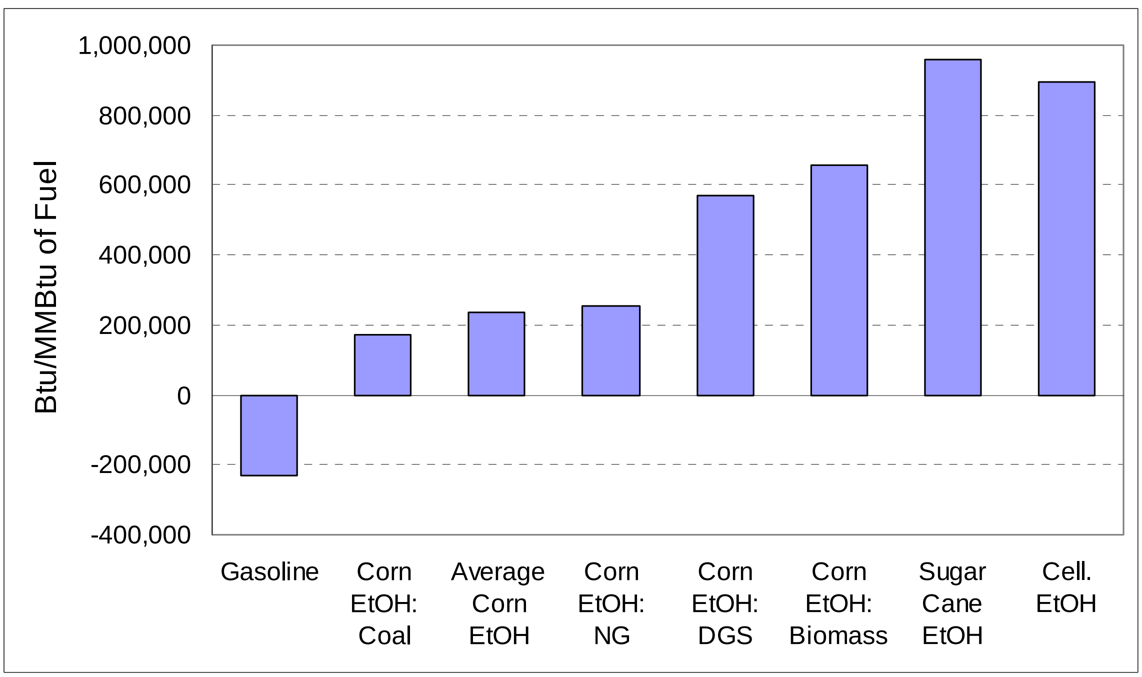


Figure 7. Net Energy Balance of Ethanol and Petroleum Gasoline:

The unique advantage of the sugarcane ethanol pathway is that ethanol production in sugarcane mills is self-sustaining in terms of energy need: the juice is used for ethanol production and bagasse is used for heat and power generation. As a result, ethanol production requires 58,546 Btu of heat demand and 1.20 kWh of electricity per gallon of ethanol. In addition, renewable power at the rate of 0.96 kWh can be exported to the electric grid. This reduction in fossil energy use is the main cause of the marked difference in WTW results between sugarcane ethanol and corn ethanol. Table 11 illustrates that approximately 100,785 Btu of natural gas and 163,609 Btu of coal per million Btu of ethanol are saved by sugarcane ethanol production compared to corn ethanol. Recently, designers and operators started to address the issue of process fuel demand in corn ethanol plants by considering renewable sources such as wood chips or distiller's grains and solubles (DGS). With these renewable energy sources, corn ethanol could reduce an additional 27% (DGS as the process fuel) or 34% (wood chips as the process fuel) of fossil energy use (Figure 6).

Table 11. WTW Fossil Energy Use for Ethanol (Btu/Million Btu of Ethanol)

Fossil Energy	Corn EtOH	Sugarcane EtOH
Natural Gas	468,709	–96,097[a]
Coal	206,284	42,675
Petroleum	90,398	92,596
Total	765,391	39,174

[a] The negative value represents the reduction of natural gas-based electricity generation that is displaced with the electricity exported from sugar cane mill.

Sensitivity analysis of sugarcane ethanol with the four sugarcane ethanol production options (as presented in Figure 10) indicates that (1) energy embedded in sugarcane mills contributes 0.3% of total fossil energy use; (2) energy embedded in farming equipment contributes 2.3%; and (3) transportation of ethanol from Brazil to the United States contributes 3.0%.

5.2. GHG Emissions Results

Figure 8 shows WTW GHG emission reductions by sugarcane ethanol and several other ethanol production options, compared to petroleum gasoline. The GHG emission reductions by sugarcane ethanol are 3.8 times as much as those by corn ethanol and rank second only to those by cellulosic ethanol.

For the five corn ethanol production options, GHG emission changes range from a 3% increase to a 52% reduction, depending on the process fuel used.

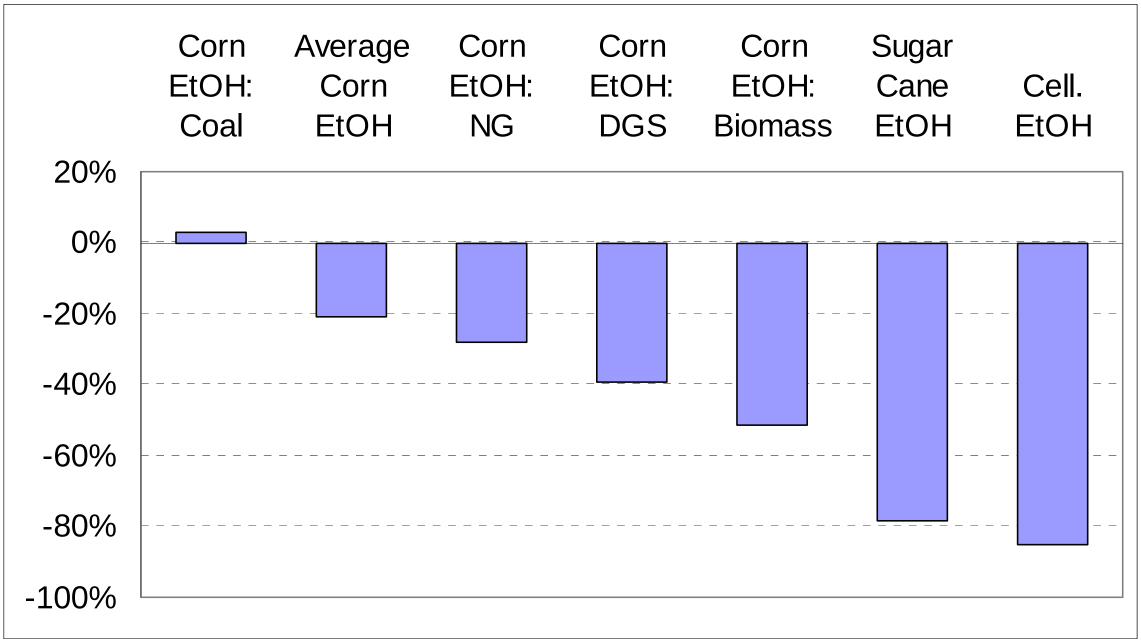


Figure 8. WTW GHG Emission Reductions by Various Ethanol Production Options Relative to Petroleum Gasoline

We examined key stages of the sugarcane ethanol pathway for their contributions to total GHG emissions. Similar to that for cellulosic ethanol, the sugarcane ethanol pathway generates heat and power from bagasse in sugarcane mills to displace natural gas or coal use. However, sugarcane farming differs considerably from cellulosic biomass farming. For example, sugarcane farming is associated with open-field burning of sugarcane tops and leaves, a practice not used in either corn farming or cellulosic biomass farming. CH_4 and N_2O emissions from open-field burning alone are responsible for 24% of total GHG emissions for sugarcane ethanol (Figure 9). In particular, the five major contributors to sugarcane ethanol GHG emissions are open-field burning (24%), N_2O emissions from sugarcane fields (14%), fertilizer production (16%), GHG emissions from sugarcane mills (17%), and sugarcane farming (9%); together these make up 80% of the total WTW GHG emissions of sugarcane ethanol.

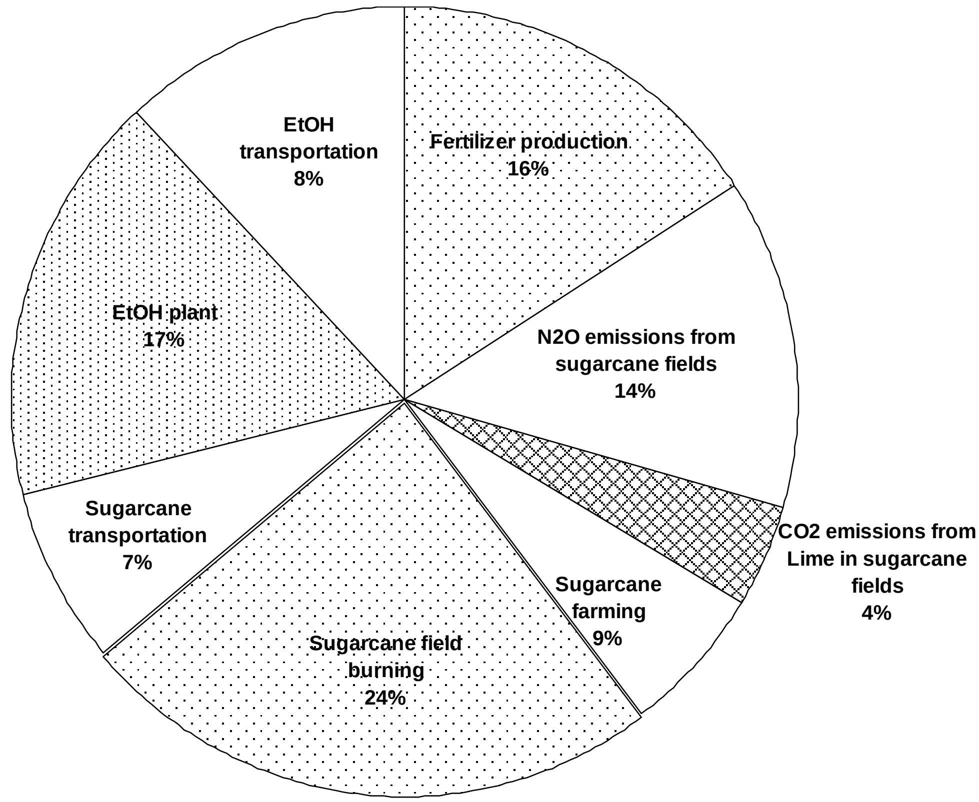


Figure 9. Shares of GHG Emissions of Sugarcane Ethanol Pathway Activities

5.3. Sensitivity Cases of Sugarcane Ethanol

We developed four sugarcane ethanol cases in this study to show variations in energy and GHG emission effects of sugarcane ethanol. The difference between Cases 1 and 2 shows the contribution of energy embedded in farming equipment production and sugarcane mill construction; that between Cases 1 and 3 shows the contribution of energy embedded in farming equipment production; and that between Cases 1 and 4 shows the contribution of transporting ethanol from Brazil to the United States.

Figures 10 and 11 show the effects of these factors. In particular, inclusion of energy embedded in farming equipment and sugarcane mill construction lowers fossil energy reductions by sugarcane ethanol by 2.6 percentage points and GHG emission reductions by 2.8 percentage points. Inclusion of energy embedded only in farming equipment lowers fossil energy reductions by1.3 percentage points and GHG reductions by 1.2 percentage points. These results imply that energy embedded in farming equipment and sugarcane mills contributes in equal proportion to total sugarcane ethanol results.

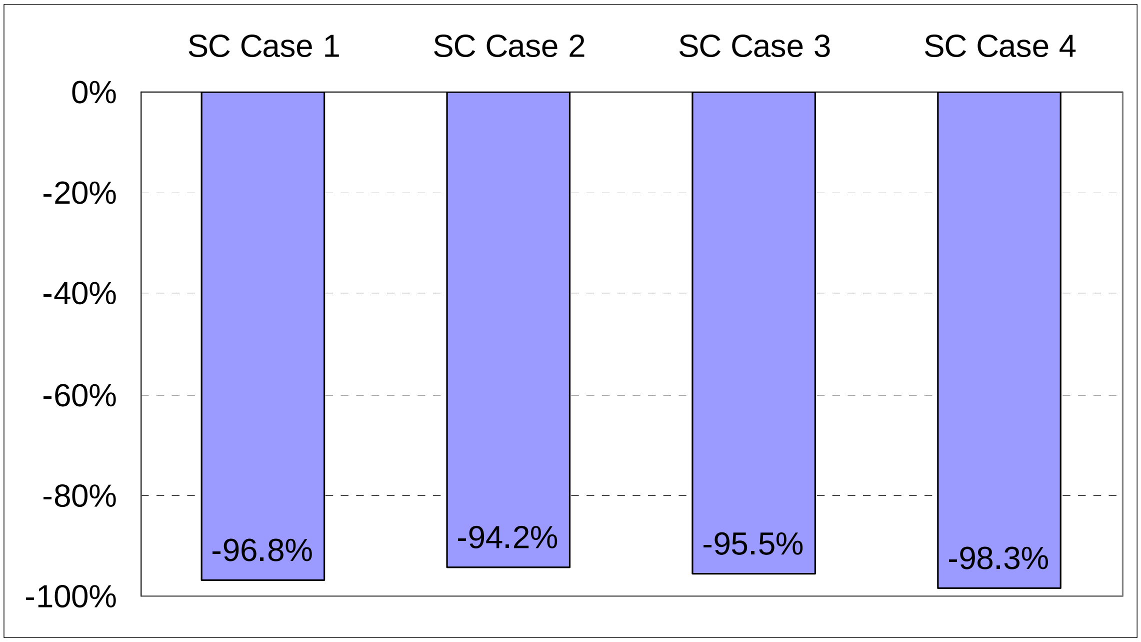


Figure 10. Fossil Energy Reductions by Four Sugarcane Ethanol Cases Relative to Petroleum Gasoline

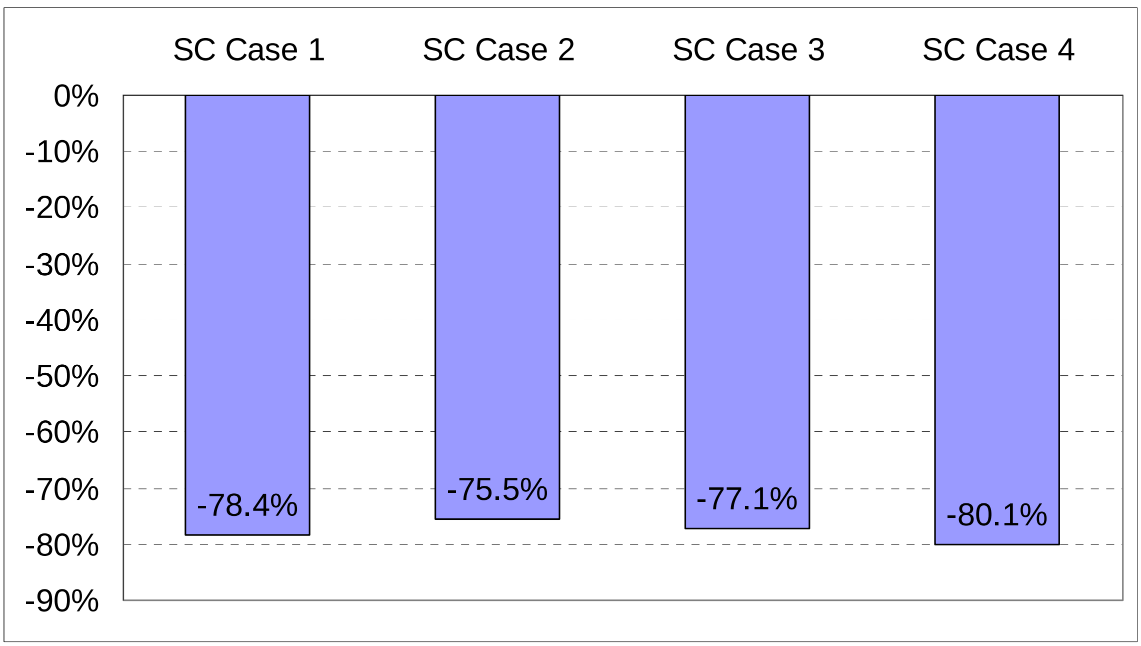


Figure 11. GHG Emission Reductions by Four Sugarcane Ethanol Cases Relative to Petroleum Gasoline

The difference between Cases 1 and 4 indicates that transportation of sugarcane ethanol from Brazil to the United States contributes to a 1.5-percentage-point difference in fossil energy use and a 1.7-percentage-point difference in GHG emissions for sugarcane ethanol.

We also developed two cases for open-field burning — one with 100% burning and the other with 0% burning (this is compared with the assumed 80% open-field burning for all four sugarcane ethanol cases examined in this study). The results of the two cases showed a difference in GHG emission reductions of 9 percentage points. Because Brazil is going to phase out open-field burning in the future, this will certainly help further reduce GHG emissions of sugarcane farming, together with reductions in emissions of criteria pollutants such as NO_x and PM_{10}.

CH_4 emissions from open-field burning are subject to great uncertainty (Table 4). Use of a CH_4 emission factor of 0.15 g/kg of biomass instead of 2.7 g/kg helps increase GHG emission reductions of sugarcane ethanol by 5.2 percentage points.

We assumed in our analysis that the exported electricity from sugarcane ethanol plants will displace electricity generated in natural gas electric power plants, which are believed to be the marginal electric power plants in Brazil. On the other hand, if the exported electricity displaces the average electricity in Brazil (83% of which is from hydro-power), GHG emission benefits of sugarcane ethanol are reduced by up to 8 percentage points.

6 Conclusions

By using the GREET model, our WTW analysis of the pathway of producing ethanol from sugarcane in Brazil and using it in the United States reached the following conclusions. Sugarcane ethanol could achieve fossil energy reduction as much as 97% relative to petroleum gasoline. The large reduction is a result of use of bagasse in sugarcane mills in place of coal or natural gas to generate the heat and power needed for plant operation. This and other factors such as low sugarcane farming energy and fertilizer use contribute to a positive net energy balance of 0.96 million Btu per million Btu of ethanol produced.

Sugarcane ethanol could achieve a reduction of 78% in GHG emissions relative to those of petroleum gasoline. This reduction is similar to that of cellulosic ethanol. Even when energy embedded in farming equipment and sugarcane mills is included, GHG emission reductions by sugarcane ethanol are still more than 75%. The large reductions can be attributed to the use of bagasse in sugarcane mills. Of the total GHG emissions associated with sugarcane ethanol, the five major contributors are open-field burning of sugarcane tops and leaves, N_2O emissions from sugarcane fields, fertilizer production, sugarcane mill operation, and sugarcane farming.

7. Acknowledgments

This work was sponsored by the Office of FreedomCAR and Vehicle Technologies under the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy. Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC, under contract No. DE-AC02-06CH11357.

We thank the following individuals for providing helpful comments on an earlier manuscript: Dr. Issais Macedo of Brazil, Mr. Robert Edwards of the Joint Research Center of the European Commission, and Mr. Vincent Camobreco of the United States Environmental Protection Agency.

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APPENDIX G

Rabobank

Power struggle

The future contribution of the cane sector to Brazil's electricity supply

Title Power struggle
The future contribution of the cane sector to Brazil's electricity supply

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Executive summary

Projections from Brazil's Ministry of Mines and Energy suggest that the consumption of electricity in Brazil between now and 2030 can be expected to grow at an average annual rate of between 3.5% and 5.1%. The country's strategy for meeting demand for electricity in the medium term (5 years) is largely based on new hydro projects and one large nuclear energy project. Given the vulnerability of large projects to time overruns, there is concern both within and outside the electricity business that the threat of power shortages or power rationing at some point in the next five years is growing. Thus there seems to be a compelling case to harness other sources of electricity generation which may be relatively quick to establish.

Cane-based cogeneration projects are relatively quick to establish and produce electricity from a renewable resource. The cane industry in Brazil is currently expanding rapidly – Rabobank currently forecasts that cane production in Brazil will rise from 428 million tonnes in 2006/07 to close to 700 million tonnes by 2012/13, and this expansion is taking place reasonably close to the areas of Brazil where energy demand is greatest. But while electricity sales by the sector have been increasing, the growth in cane sector electricity generation remains a long way short of its potential. Can reasons for this be identified?

Cogeneration projects require substantial initial investment and have relatively long pay-back periods. Therefore, investors need to feel confident about the stability of the business environment, especially with regard to pricing. In this respect, problems regarding the calculation of a bonus payment (linked to the industry's ability to supply electricity during the dry season) in regulated market contracts may have undermined the confidence of some cane industry players in the electricity business.

Despite this, there is a general view both in the industry and beyond that electricity prices (contract and spot market) are on a rising trend. Expectations of rising prices in the future will encourage more cane sector players to consider cogeneration projects.

Without doubt a key factor inhibiting greater involvement by the cane sector in electricity generation at present seems to be the requirement for mills to provide and administer the connection to the grid. This is expensive, time-consuming and in regions where there is a concentration of mills, it could lead to unnecessary expenditure and a sub-optimal transmission structure. If negotiations with other industry stakeholders can produce changes in these arrangements, effectively permitting mills to sell electricity 'from the factory gate', there is likely to be a surge of new interest in cogeneration projects.

Introduction

Brazil has the largest sugar cane milling industry in the world. It is also one of the world's fastest growing cane industries, thanks to a combination of competitive sugar and ethanol production costs, abundant land resources, the recent boom in the domestic markets for fuel ethanol, and the promise of a growing export market for ethanol in years to come. Rabobank currently forecasts that cane production in Brazil will rise from 428 million tonnes in 2006/07 to close to 700 million tonnes by 2012/13.

As a result of this growth, the cane industry's potential to contribute to the country's electricity supply is also growing in significance. All cane mills use bagasse (the fibrous residue from cane milling) to produce steam and electricity. This simultaneous production of electricity and thermal energy is known as cogeneration. This term tends to be used in cases where mills opt to produce more electricity than they need for their own operations, and sell the surplus electricity to the national grid; this is what is typically referred to as a cogeneration project.

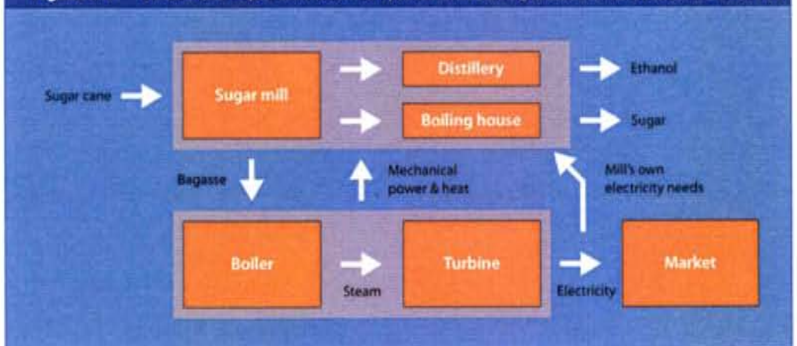
There appears to be no better time than now for mills to consider such projects – the cane industry's expansion coincides with a period of robust economic growth in Brazil, which in turn is causing demand for energy to grow strongly. At the same time, progress in commencing major new hydroelectric energy projects appears susceptible to delay, creating fears of a possible energy crisis if the current rate of economic growth is sustained over the medium term. However, even if the threat of a structural energy crisis fades away, the cane sector can contribute significantly to the overall security of national energy supply. This is because the availability of bagasse-based energy peaks in the dry season, at the very time of the year when the country's main energy source – hydroelectricity – is most vulnerable.

With so many points in its favour, it might be expected that electricity would rapidly become the third standard product (after sugar and ethanol) of the Brazilian cane industry. But while electricity sales by the sector have indeed been increasing, the growth in electricity generation remains far short of its potential. This report investigates why this should be so, and examines the economic and institutional factors that will influence the further development of electricity as a third pillar of business for Brazil's millers.

Cogeneration basics

The dictionary definition of cogeneration is the simultaneous production of electricity and useful thermal energy from a common fuel source. Cogeneration is nothing new to the cane sugar industry – in fact, all of the world's sugar mills generate electricity, fuelled by the burning of bagasse, the fibrous residue from cane milling, in the mill's boiler. The steam produced in the mill's boiler is used for two purposes: to provide mechanical power and heat required to mill cane and for the various processes involved in sugar and ethanol production from cane juice, and to drive a turbo generator, which generates electricity. In the first instance, this electricity is generated to satisfy the mill's own energy needs. However, energy-efficient mills can opt to install a combination of boiler and generation equipment that enables them to produce surplus electricity, from a renewable resource, which can be sold to the grid (Figure 0.1).

Figure 0.1 Schematic representation of typical mill configuration and operation in Brazil



Source: Rabobank, 2007

Box 1 The standard means of expressing electrical energy capacity and supply

Megawatts (MW). Units most commonly used to express the capacity of a generation system; a megawatt is 10^6 watts, with one watt representing the delivery of one joule of energy per second.

Megawatt hours (MWh). Units of power supplied or required (i.e., the delivery of one megawatt for a period of one hour); a megawatt hour is 10^6 watts per hour.

Terawatt hour (TWh). 10^{12} watts per hour; this unit is generally used in describing national energy requirements or supplies.

This report has been published in line with Rabobank's long-term commitment to the international food and agribusiness. It is one of a series of publications undertaken by the global department of Food & Agribusiness Research and Advisory.

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APPENDIX H

Energy Information Administration www.eia.doe.gov

COUNTRY ANALYSIS BRIEFS

Brazil

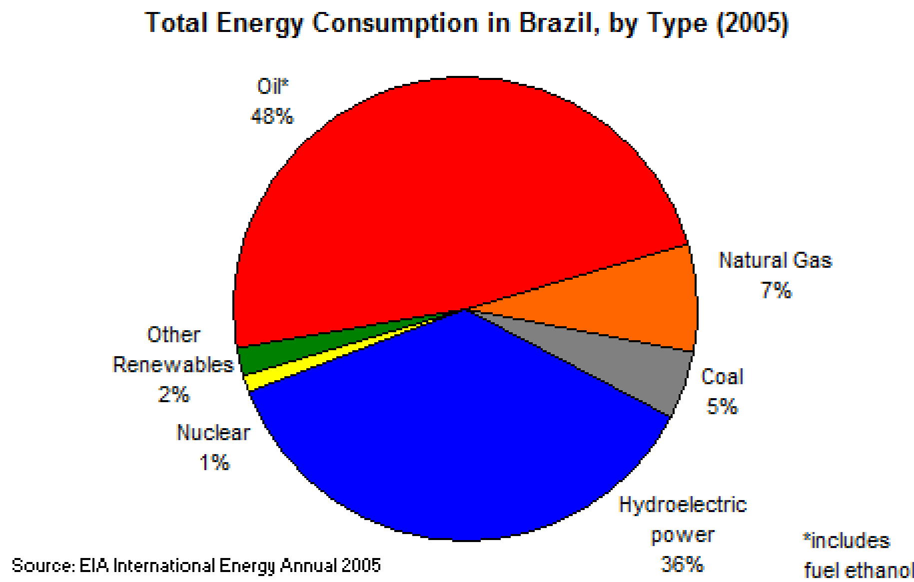
Last Updated: October 2008

Background

Brazil has experienced rapidly expanding oil, natural gas, and electricity consumption in recent years.

Brazil is the 10th largest energy consumer in the world and the third largest in the Western Hemisphere, behind the United States and Canada. Total primary energy consumption in Brazil has increased significantly in recent years. In addition, Brazil has made great strides in increasing its total energy production, particularly oil, over the past decade. Increasing domestic oil production has been a long-term goal of the Brazilian government.

The largest share of Brazil's total energy consumption comes from oil (48 percent, including ethanol), followed by hydroelectricity (35 percent) and natural gas (7 percent). The large share of hydroelectricity in Brazil's energy mix represents the dependence of electricity generation on hydroelectric dams. Natural gas is currently a small share of total energy consumption, but attempts to diversify electricity generation from hydropower to gas-fired power plants should cause natural gas consumption to grow in coming years.

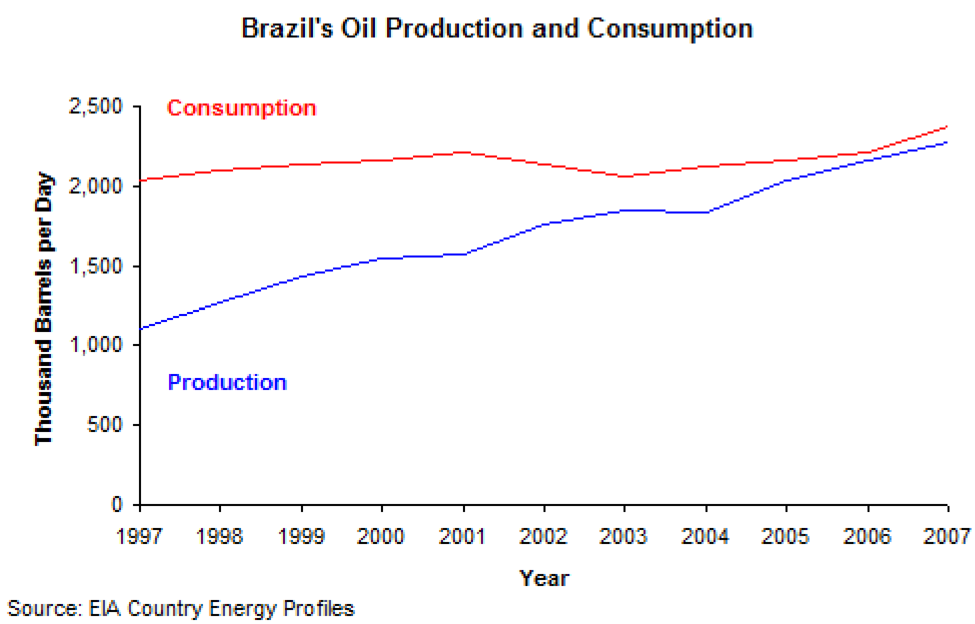


Oil

Brazil has the second-largest crude oil reserves in South America, and is one of the fastest growing oil producers in the world.

Overview

According to *Oil and Gas Journal (OGJ)*, Brazil had 12.2 billion barrels of proven oil reserves in 2008, second-largest in South America after Venezuela. The offshore Campos and Santos Basins, located on the country's southeast coast, contain the vast majority of Brazil's proven reserves. In 2007, Brazil produced 2.28 million barrels per day (bbl/d) of oil, of which 77 percent was crude oil. Brazil's oil production has risen steadily in recent years, with the country's oil production in 2007 about 5 percent (or 110,000 bbl/d) higher than 2006. EIA estimates that Brazil's oil consumption in 2007 averaged 2.37 million bbl/d. Based on its September 2008 *Short Term Energy Outlook*, EIA forecasts Brazilian oil production to reach 2.41 million bbl/d in 2008 and 2.72 million bbl/d in 2009. As a result of this rising oil production, EIA estimates that Brazil will become a net oil exporter by 2009.



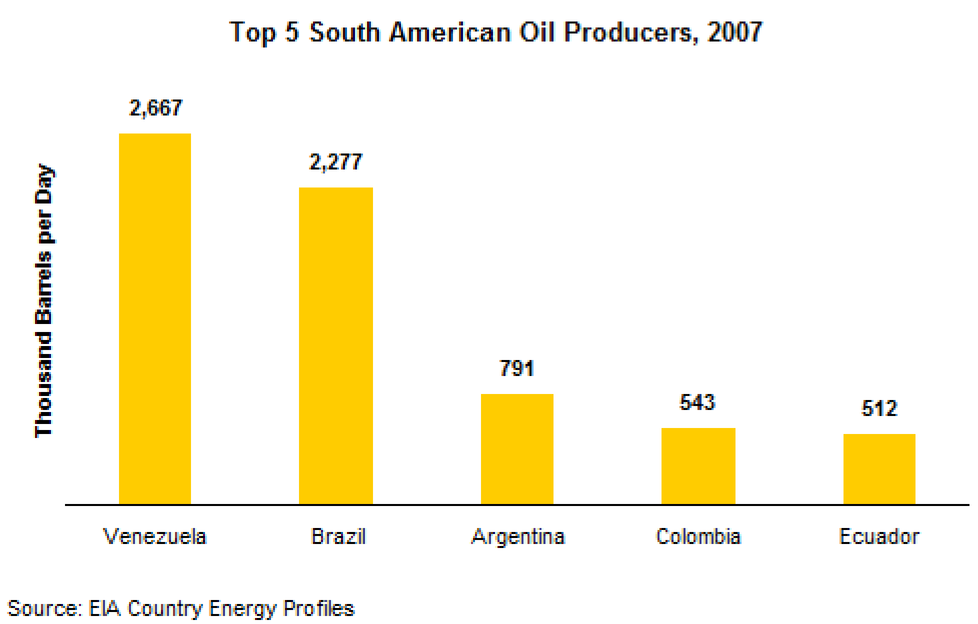
Sector Organization

State-controlled Petrobras is the dominant player in Brazil's oil sector, holding important positions in up-, mid-, and downstream activities. The company held a monopoly on oil-related activities in the country until 1997, when the government opened the sector to competition and freed oil prices from state control. The principal government agency charged with monitoring the oil sector is the National Petroleum Agency (ANP), which is responsible for issuing exploration and production licenses and ensuring compliance with relevant regulations.

Despite the opening of the sector to private actors in the late 1990s, foreign-operated oil projects are rare in Brazil. Royal Dutch Shell was the first foreign operator of crude oil production in the country, operating a single, relatively small field in the Campos Basin. In mid-2007, Devon brought its Polvo field on-stream, representing the first oil project without any Petrobras participation. Private competition in the sector is not just from foreign companies: in 2008, Brazilian oil company OGX raised $4 billion in an IPO, and the company secured interests in 21 blocks in Brazil's ninth licensing round.

Exploration and Production

Petrobras controls over 95 percent of the crude oil production in Brazil. The largest oil-production region of the country is Rio de Janeiro state, which contains about 80 percent of Brazil's total production. Most of Brazil's crude oil production is offshore in very deep water and consists of mostly-heavy grades. One of Brazil's principle marketed crude streams is Marlim, which has an API of 19.6º and a sulfur content of 0.67 percent.



Petrobras has brought numerous projects onstream in recent years, with many more planned for the near future (see table below). In 2007, the company brought online Piranema (20,000 bbl/d nameplate production capacity), Espadarte (100,000 bbl/d), the second phase of the Golfinho (100,000 bbl/d), and two floating production, storage, and offloading (FPSO) units in the Roncador field (380,000 bbl/d). In September 2008, construction of the P-53 FPSO was completed, and the vessel is scheduled for installation in the Marlin field by the end of the year. In 2009, Petrobras plans to install another FPSO in the Marlim field, P-51, with a nameplate production capacity of 180,000 bbl/d.

Shell's Bijupira-Salema project in the Campos Basin was the first field in Brazil not operated by Petrobras. The project came on-stream in 2003 and produces about 50,000 bbl/d. Shell is also developing its BC-10 project (100,000 bbl/d), which will utilize an oil tanker currently being converted into an FPSO in Singapore. Devon brought its Polvo project (50,000 bbl/d) online in August 2007, representing the only upstream oil project without any Petrobras participation. Chevron is developing the Frade project (100,000 bbl/d), with first production expected in 2009. Finally, StatoilHydro is developing the Peregrino field in Brazil, with expected production capacity of 100,000 bbl/d.

In large part due to this sizable slate of new projects, EIA expects that Brazil's total oil production could reach 2.72 million bbl/d in 2009. This forecast takes into account the above-mentioned projects and an estimate for decline rates at Brazil's older, mature fields. This could make Brazil one of the largest sources of new, non-OPEC oil supply growth. However, recent experience has shown that non-OPEC supply growth has been overestimated in recent years, so there is considerable downside risk to this forecast. Such risks include larger decline rates at mature fields and delays to project schedules. In total, industry analysts estimate that spending on investments in oil and natural gas exploration and production in Brazil could amount to $72 billion by 2012.

Subsalt Reserves: Tupi and Beyond

Petrobras announced that it had discovered an estimated 5-8 billion barrels of recoverable reserves (including both oil and natural gas) in the Tupi field, located in the Santos Basin. The reserves occur in a subsalt zone that is an average of 18,000 feet total below the ocean surface. The Tupi find is the largest oil discovery since the supergiant Kashagan field in Kazakhstan. In addition, oil encountered in the subsalt zones appears to be lighter and sweeter than most of Brazil's existing production. Following Tupi, numerous additional subsalt discoveries were announced, including Carioca, Iara, and Guara. Preliminary estimates by industry analysts of the total extent of recoverable oil and natural gas reserves in the entire subsalt reserve have approached 56 billion barrels of oil equivalent.

Tupi and the subsequent subsalt announcements immediately transformed the nature and focus of Brazil's oil sector, and the potential impact of the subsalt discoveries upon world oil markets is vast. However, considerable challenges must still be overcome in order to bring these reserves to fruition. The full scope and nature of development of the subsalt resources is still pending the establishment of the formal contractual framework that will guide exploitation of the reserves. In addition, the difficulty of access to the reserves, considering both the large depths and pressures involved with subsalt oil production, mean that there are many technical hurdles that must be overcome. Finally, the subsalt reserves contain a high concentration of natural gas, along with oil, and proper handling this gas will require additional infrastructure and consideration. As a result, production from small pilot projects is possible in the next several years, but large-scale development of the subsalt reserves will likely not occur until well into the next decade.

Pipelines

Transpetro, a wholly owned subsidiary of Petrobras, operates Brazil's crude oil transport network. The system consists of 4,000 miles of crude oil pipelines, coastal import terminals, and inland storage facilities. The overall structure of the network enables the movement of crude oil from coastal production facilities and import terminals to inland refineries and consumption centers.

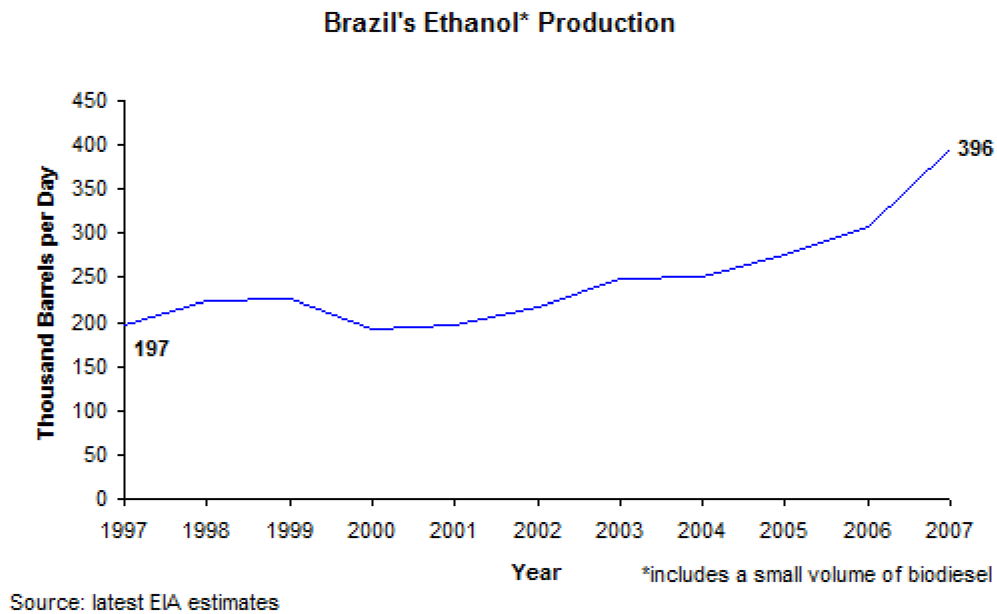
Downstream

According to *OGJ*, Brazil has 1.9 million bbl/d of crude oil refining capacity spread amongst 13 refineries. Petrobras operates 11 facilities, the largest being the 360,000-bbl/d Paulinia refinery in Sao Paulo. Petrobras also controls a dominant stake in the retail products market. According to the International Energy Agency (IEA), regular unleaded gasoline prices averaged $1.17 per liter in 2006 ($4.43 per gallon), versus $2.58 per gallon in the United States.

In February 2005, Petrobras signed an agreement with Venezuela's state-owned Petroleos de Venezuela S.A. (PdVSA) to build a new, 200,000-bbl/d refinery in the northeastern Brazil at a cost of $5 billion. The companies expect to complete the facility, dubbed Abreu e Lima, by 2010, with each country providing half of the crude oil processed there. The facility has reportedly suffered delays due to disagreements between the two countries, but media accounts indicate that Petrobras broke ground on the facility in late 2007. Petrobras announced in 2008 that it plans to spend $40 billion over the next 5-10 years to increase Brazil's refining capacity by 1.3 million bbl/d.

Ethanol

Brazil is one of the largest producers of ethanol in the world and is the largest exporter of the fuel. In 2007, Brazil produced 390,000 bbl/d of ethanol, up from 306,000 in 2006. Based on the September 2008 *Short Term Energy Outlook*, EIA forecasts that Brazil's ethanol production will reach 440,000 bbl/d in 2008 and 530,000 bbl/d in 2009. Over half of all cars in the country are of the flex-fuel variety, meaning that they can run on 100 percent ethanol or an ethanol-gasoline mixture. Eight in ten new cars sold in Brazil are flex-fuel vehicles. All gasoline in Brazil contains ethanol, with blending levels varying from 20-25 percent. Ethanol in Brazil comes from sugar cane, which prospers in the country's tropical climate.



In 2008, BP announced that it was taking a stake in an ethanol project in Edia, Goias state that would produce 115 million gallons per year (7,500 bbl/d), making it one of the largest ethanol plants in Brazil. Petrobras has also launched numerous ethanol pipeline projects, including one linking Goias with Sao Paulo.

In recent years, Brazil has sought to increase ethanol exports, especially to the United States. Media reports indicated that Brazilian ethanol exports could total 5 billion liters in 2008 (86,000 bbl/d). In 2007, Brazil exported 12,600 bbl/d of ethanol to the United States, down from 30,000 bbl/d in 2006 but well above levels seen prior to 2005. The increase in exports to the U.S. has been driven by the phase-out of methyl tertiary butyl ether (MTBE) in the United State, which effectively replaced MTBE with ethanol as an additive to gasoline. However, surging domestic demand and high domestic prices may limit export growth. In addition, Brazil's ethanol exports face high tariffs in some markets, such as the 54 cent per gallon tariff in the United States. Besides the United States, Brazil exports ethanol to Europe, and it began exports to industrial customers in Japan in 2008.

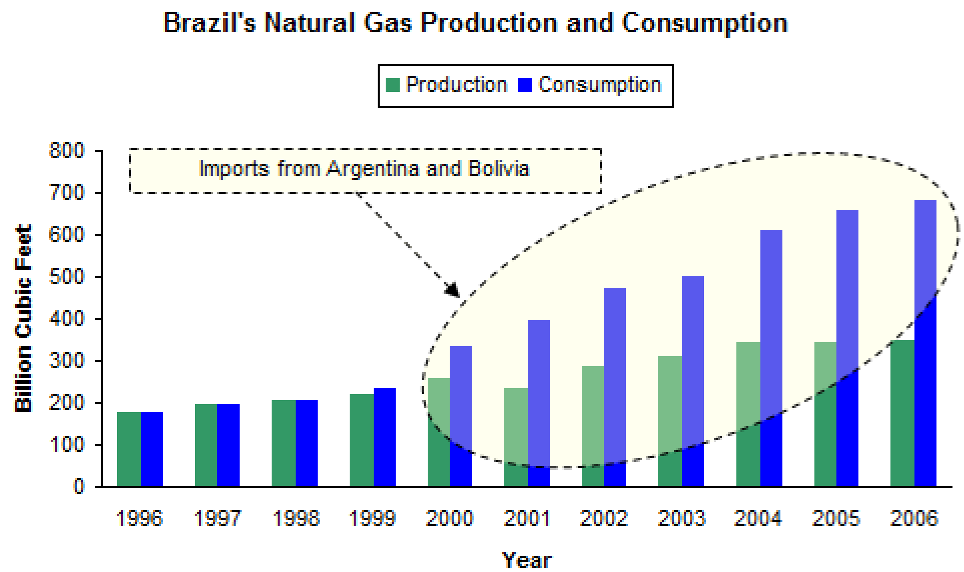
Brazil is also reportedly looking towards growing production of biodiesel. In 2008, Petrobras announced that it planned to build three biodiesel plants in the country, with at least one plant oriented towards the export market. ANP announced a 3 percent blending requirement for domestic diesel sales in July 2008, with plans to reportedly increase this to 5 percent by 2013.

Natural Gas

Natural gas constitutes only a small portion of Brazil's total energy consumption.

OGJ reported that Brazil had 12.3 trillion cubic feet (Tcf) of proven natural gas reserves in 2008. The Campos and Santos Basins hold the majority of reserves, but there are also sizable reserves in the interior stretches of the country. Despite Brazil's sizable natural gas reserves, natural gas production has grown slowly in recent years, mainly due to a lack of domestic transportation capacity and low domestic prices. In 2006, Brazil produced 349 billion cubic feet (Bcf) of natural gas, up slightly from 2005.

Natural gas consumption is a small part of the country's overall energy mix, constituting only 7 percent of total energy consumption in 2005. However, natural gas demand is rising: in 2006, Brazil consumed 683 Bcf of natural gas, up from 657 Bcf in 2005. High oil prices have helped spur natural gas demand in Brazil: natural gas is mostly used as a substitute for fuel oil in industrial and power-generating applications, and domestic prices for natural gas are much lower than international fuel oil prices. Further, the introduction of natural gas imports has lead to growth in domestic consumption.



Source: EIA *International Energy Annual*

Sector Organization

Petrobras is the largest producer of natural gas in Brazil. The company reportedly controls over 90 percent of Brazil's natural gas reserves. Other important participants in the sector include Sulgas and Britain's BG. ANP has sought to attract international investment to the sector, with recent exploration licensing rounds including many gas-prone areas. Petrobras is also the largest wholesale supplier of natural gas. The industrial sector is the largest consumer of natural gas in Brazil, representing about 80 percent of total domestic consumption. However, the two fastest growing sectors are thermal electricity generation and vehicular compressed natural gas (CNG).

Exploration and Production

The largest share of Brazil's natural gas production occurs from offshore fields in the Campos Basin in Rio de Janeiro state. Most onshore production occurs in Amazonas and Bahia states and is mostly for local consumption due to the lack of transportation infrastructure.

In order to meet rising demand, Petrobas plans to bring several new natural gas projects online over the coming years. The largest is the Mexilhao project, which contains estimated total reserves of 14 Tcf. Current plans call for production to come online in 2009 at 100 Bcf per year, eventually rising to 180 Bcf per year.

As discussed in the Oil section of this report, recent announcements about discoveries in Brazil's offshore subsalt have generated considerable excitement. Along with their potential to significantly increase oil production in the country, the subsalt areas are estimated to contain sizable natural gas reserves as well. According to Petrobras, Tupi alone could contain 5-7 Tcf of recoverable natural gas, which if proven, could increase Brazil's total natural gas reserves by 50 percent.

Pipelines

Petrobras operates Brazil's domestic natural gas transport system. The network has over 1,550 miles of natural gas pipelines, mostly in the southeast and northeast parts of the country. The network consists of main systems in the southeast, northeast, and the state of Espirito Santo; these systems are not currently interconnected, which has hindered development of domestic production and consumption. In June 2006, China's Sinopec began construction on the 730-mile Gasene pipeline linking the northeast and southeast networks. According to media reports, construction of the third and final stage of the Gasene system began in 2008, with completion fo the project expected by the end of 2009. In 2005, construction began on the Gas Unificacao, or Gasun; the 1,400-mile Gasun will link Mato Grosso dul Sul, in southwest Brazil, to Maranhao, in the northeast.

A lack of natural gas transportation infrastructure in the interior regions of the country has hindered exploration and production. In particular, Amazonas state contains considerable reserves that remain unexploited, especially the Urucu field, which contains Brazil's largest onshore natural gas reserves. In 2005, Petrobras began construction of the Urucu pipeline that will link Urucu to Manaus, the capital of Amazonas state. The project includes construction of a 240-mile pipeline from Manaus to Coari, where it will interface with an existing liquefied petroleum gas (LPG) pipeline that Petrobras will convert to transport natural gas. The Urucu pipeline will parallel an existing oil pipeline and carry natural gas that is currently re-injected or flared during oil production.

In order to exploit the gas potential of the offshore subsalt reserves, Brazil will need to construct additional pipeline infrastructure in the area. In 2008, Petrobras announced that it would construct a 150-mile natural gas pipeline linking the Tupi field to its Mexilhao development. From there, a pipeline would link Mexilhao to shore, allowing any gas production from Tupi to flow to the domestic market.

Import Pipelines

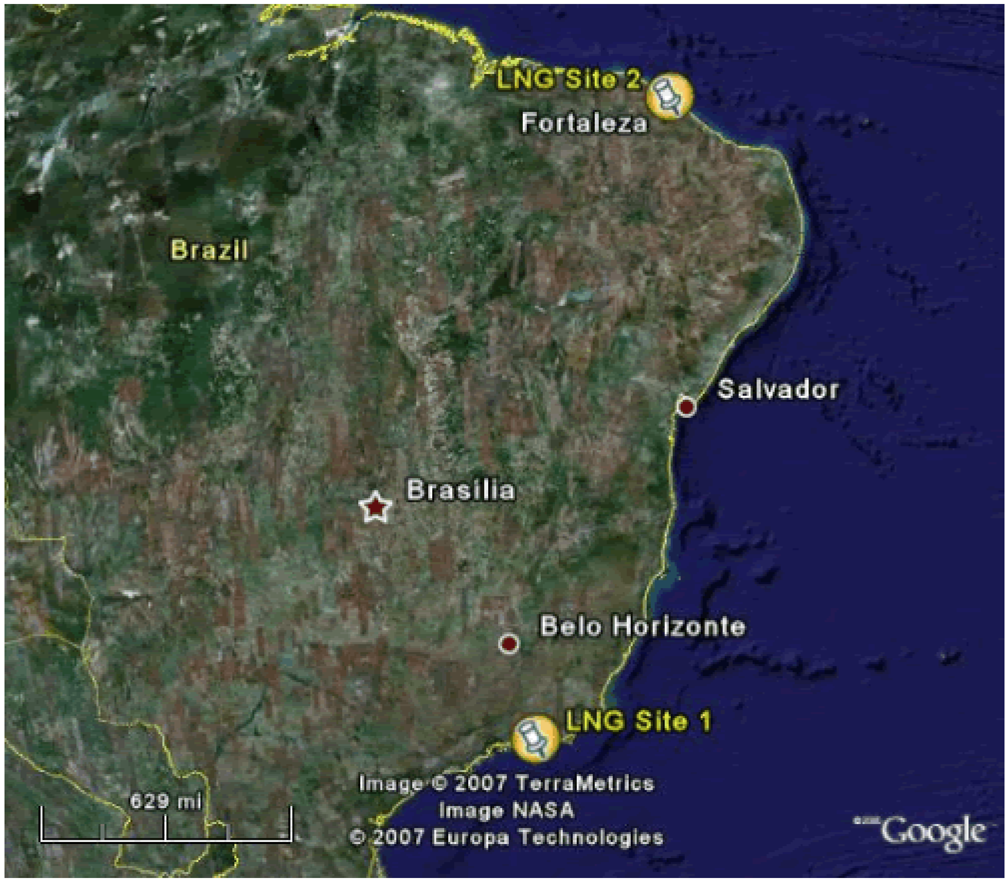
Brazil imports natural gas from Bolivia via the Gasbol pipeline linking Santa Cruz, Bolivia to Porto Alegre, Brazil, via Sao Paulo. The 2,000-mile Gasbol has a maximum capacity of 1 Bcf per day (Bcf/d). Gasbol also has a 170-mile, extension that connects to a natural gas-fired power plant in Cuibana, supplying 100 million cubic feet per day (MMcf/d). According to ANP, Brazil imported about 360 Bcf of natural gas from Bolivia in 2007

Brazil also receives natural gas from Argentina via the Parana-Uruguayana pipeline. The 275-mile, 100-MMcf/d pipeline connects to a gas-fired power plant operated by AES. According to ANP, Brazil imported 5.9 Bcf of natural gas from Argentina in 2007.

Liquefied Natural Gas

The construction of liquefied natural gas (LNG) terminals in Brazil could allow for larger natural gas imports and a reduced dependency upon existing import sources. In early 2007, Petrobras contracted with Golar LNG for two floating regasification and storage units (FRSU), for delivery in 2008 and 2009. The two vessels will provide for a combined 670 MMcf/d of gas sendout capacity, with the first moored in the southeast (Rio de Janeiro state, 450 MMcf/d) and the second in the northeast (Ceara state, 220 MMcf/d). In July 2008, the FRSU arrived at the Ceara site, and the Rio de Janeiro FRSU was expected to arrive in late 2008/early 2009.

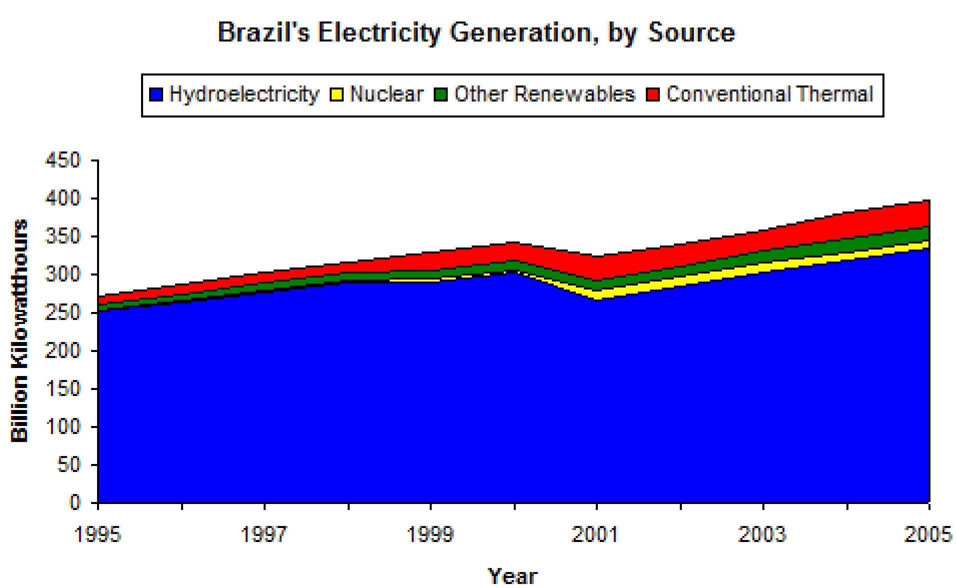
Sites for LNG Regasification Terminals in Brazil



Electricity

Brazil has the third-largest electricity sector in the Western Hemisphere.

Brazil had 90.7 gigawatts of installed generating capacity in 2005, with the single largest share being hydroelectricity. In 2005, the country generated 396.4 billion kilowatthours (Bkwh) of electric power, while consuming 368.5 Bkwh. The largest source of electricity generation is hydropower (84 percent), with smaller amounts from conventional thermal, nuclear, and other renewable sources.



Source: EIA *International Energy Annual*

Hydroelectricity

Brazil generated 334.1 Bkwh of hydroelectric power in 2005, accounting for 84 percent of its total electricity generation. Together with Paraguay, Brazil maintains the world's largest operational hydroelectric generating complex, the Itaipu facility on the Parana River, which generated 87.97 Bkwh of electricity in 2005. Many of Brazil's hydropower generating facilities are located far away from the main demand centers, resulting in high transmission and distribution losses. Brazil's heavy reliance on hydroelectricity has caused some issues in the past, especially during years of below-average rainfall. In 2008, the government announced plans to build two new hydroelectric plants along Brazil's borders with Argentina and Bolivia, representing 12,000 MW of new generation capacity. In addition, Suez Energy won a tender to build a 3,300-MW hydro station near Brasilia.

Conventional Thermal

Conventional thermal generating sources provided only a small part of Brazil's electricity supply. According to Brazil's Ministry of Energy and Mines, about 4 percent of Brazil's electricity generation in 2006 came from power plants fired by natural gas. Roughly a similar amount came from other thermal sources like coal, diesel, and fuel oil. Petrobras estimates that natural-gas fired generating capacity in Brazil could increase to 13,000 MW by 2017. Natural gas offers an alternative to the variability of hydropower but is largely dependent upon the availability of domestic and imported sources of the fuel. Brazil also has about 1,300 MW of installed coal generation capacity.

Nuclear Power

Brazil has two nuclear power plants, the 630-megawatt (MW) Angra-1 and the 1,350-MW Angra-2. State-owned Eletronuclear, a subsidiary of Electrobras, operates both plants. A third, 1,350-MW plant, Angra-3, remains partially constructed. In 2007, Electronuclear received permission from the Brazilian government to resume construction of Angra-3, and the company also began the process of applying for permission from Ibama (Brazil's environmental regulatory agency) to begin operations at the plant. Construction on Angra-3 began again in 2008. Electronuclear announced in August 2007 that it had begun the process of selecting a site for a fourth nuclear power plant in Brazil. According to the government, both of these new plants will use fuel produced in Brazil, rather than imported from Europe.

International Trade

In recent years, Brazil has run an overall power surplus, allowing exports to its neighbors. In 2007, Brazil began exporting electricity to Uruguay. In 2008, it exported power to Argentina during the winter in exchange for receiving electricity back from Argentina during the summer.

Profile

Energy Overview

Proven Oil Reserves (January 1, 2008E)	12.2 billion barrels
Oil Production (2007E)	2,277 thousand barrels per day.
Oil Consumption (2007E)	2,372 thousand barrels per day
Crude Oil Distillation Capacity (2008E)	1,908 thousand barrels per day
Proven Natural Gas Reserves (January 1, 2008E)	12.3 trillion cubic feet
Natural Gas Production (2006E)	349 billion cubic feet
Natural Gas Consumption (2006E)	683 billion cubic feet
Recoverable Coal Reserves (2004E)	11,148 million short tons
Coal Production (2006E)	7.0 million short tons
Coal Consumption (2006E)	23.8 million short tons
Electricity Installed Capacity (2005E)	90.7 gigawatts
Electricity Production	396.3 billion kilowatt hours

(2005E)	
Electricity Consumption (2005E)	368.5 billion kilowatt hours
Total Energy Consumption (2005E)	9.3 quadrillion Btus*
Total Per Capita Energy Consumption (2005E)	50.1 million Btus
Energy Intensity (2005E)	6,312 Btu per $2000-PPP**

Environmental Overview

Energy-Related Carbon Dioxide Emissions (2005E)	360.6 million metric tons
Per-Capita, Energy-Related Carbon Dioxide Emissions (2003E)	1.94 metric tons
Carbon Dioxide Intensity (2004E)	0.24 metric tons per thousand $2000-PPP**

Oil and Gas Industry

Organization	Petrobras: national oil and gas company with partial government ownership, Royal Dutch Shell, Devon
Major Oil/Gas Ports	Sao Sebastiao, Paranagua, Salvador, Tramandai, Sao Francisco do Sul, Aracaju, Maceio, Recidfe, Natal, Fortaleza, Belem
Major Oil and Natural Gas Basins	Campos Basin, Santos Basin
Major Refineries (capacity, bbl/d)	Paulinia-Sao Paulo (350,000), Mataripe-Bahia (293,700), Duque de Caxias-Rio de Janeiro (232,2000), Sao Jose dos Campos-Sao Paulo (241,500), Canoas-Rio Grande do Sul (180,900), Araucaria-Parana (180,900), Cubatao-Sao Paulo (162,900), Betim Minas Gerais (144,800)

* The total energy consumption statistic includes petroleum, dry natural gas, coal, net hydro, nuclear, geothermal, solar, wind, wood and waste electric power. The renewable energy consumption statistic is based on International Energy Agency (IEA) data and includes hydropower, solar, wind, tide, geothermal, solid biomass and animal products, biomass gas and liquids, industrial and municipal wastes. Sectoral shares of energy consumption and carbon emissions are also based on IEA data.
**GDP figures from OECD estimates based on purchasing power parity (PPP) exchange rates.

Links

EIA Links

EIA - Historical Energy Data on Brazil

U.S. Government

CIA World Factbook - Brazil
U.S Embassy in Brazil
U.S. State Department's Consular Information Sheet - Brazil
U.S. State Department's Background Notes on Brazil

Foreign Government Agencies

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Agência Nacional do Petróleo (ANP) (National Petroleum Agency)
Ministério de Minas e Energia (MME) (Ministry of Mines and Energy)

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Economist Intelligence Unit
Economist Intelligence Unit ViewsWire
Edmonton Journal
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Financial Times
Gazeta Mercantil
Global Insight
Global Power Report
Houston Chronicle
Infopetro Bulletin
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International Herald Tribune
International Oil Daily
International Petroleum Finance
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Latin American Weekly Report
Latinnews Daily
Lloyd's List
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Sunday Express
U.S. Department of State
U.S. Energy Information Administration
U.S. Security and Exchanges Commission
Valor Economico
Water Power & Dam Construction
World Gas Intelligence
Worldwide Projects
Wood MacKenzie Ltd.
World Gas Intelligence
World Markets Analysis

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