23 April 2003

Final Evaluation Report for UNDP/GEF Project BRA/96/G31, "Biomass Power Generation: Sugar Cane Bagasse & Trash"

Eric D. Larson
Princeton Environmental Institute, Princeton University
elarson@princeton.edu

Table of Contents

Executive Summary

This project, referred to here as the SCP (sugar cane power) project, was originally designed as an extension of the GEF's Brazil Biomass Gasifier/Gas Turbine Power Plant Demonstration Project (BRA/92/G31) initiated in the early 1990s. The intention of that project, referred to here as the WBP (woody biomass power) project, was to demonstrate the commercial viability of biomass-gasifier/gas turbine (BIG/GT) power plant technology. The WBP project called for building and operating a commercial-scale BIG/GT power plant in Northeast Brazil using plantation-grown wood as fuel. Building on knowledge generated by the WBP, the SCP was designed to involve analytical work and technology development that would enable future implementation of the WBP-type power plant technology with sugarcane-derived biomass as fuel instead of wood. The sugarcane biomass fuels include bagasse, the fiber by-product of sugar extraction from cane stalks, and trash, the tops and leaves of the sugarcane plant that are typically burned off the field before harvest or (with harvest of unburned cane) removed at harvest and left on the field to decompose.

By using plantation-wood or sugarcane biomass as fuel, the biomass gasifier/gas turbine (BIG/GT) technology would produce electricity with essentially no net carbon emissions to the atmosphere: the amount of CO_2 emitted to the atmosphere from a BIG/GT plant is the same amount of CO_2 absorbed from the atmosphere in the growing of the plantation wood or the sugarcane residues used to fuel the BIG/GT.

The WBP and SCP projects were strongly supported by the Brazilian government, through the executing agency, the Ministry of Science and Technology (MCT). The strong governmental interest in the projects can be explained in part by the lack of indigenous fossil fuels in Brazil and consequent heavy reliance on hydroelectricity supplies that are unreliable from year-to-year due to rainfall variations. Government interest also stems from the fact that both plantation wood production and sugarcane production are important industries in Brazil from social, economic, and energy perspectives. The commercial introduction of BIG/GT technology offers possibilities for strengthening and expanding business opportunities in these industries, with related positive impacts on employment, national economy, and energy supply.

The WBP project, as originally conceived, stalled after some key technology development steps were completed, but before construction of the demonstration plant began. Before the extent of the WBP difficulties was clear, the SCP project was launched. For reasons not discussed here, the WBP demonstration BIG/GT power plant will not be built with GEF support in the WBP project. Although the SCP was originally designed as an extension of the WBP, the failure of the WBP to be completed has not affected the degree to which the SCP was able to achieve its objectives. This can be attributed to two main factors: 1) sufficient progress was made in the WBP in the development of technology (particularly atmospheric-pressure biomass gasification) to provide a good basis for evaluating the BIG/GT technology for its potential to use sugarcane biomass instead of wood; and 2) a significant component of the SCP dealt with understanding agronomic issues associated with the production, harvesting, storage, and transport of sugarcane biomass as a fuel, which required little, if any, input from WBP findings.

The SCP, which was led by staff at the Copersucar Technology Center (CTC), included a set of well-defined objectives, outputs, and activities. Each activity was well documented in at least one of the more than 100 detailed technical reports that were prepared in the course of the project. An overall conclusion regarding the implementation of the project is that it was

completed in a thorough and high-quality fashion. The project met all original objectives, and it has gone beyond these in several areas.

The project established through rigorous experiments and analysis the quality, quantity, and cost (~ US$ 1/GJ delivered to a mill) of recoverable sugarcane trash as a supplemental fuel to bagasse for power generation at sugarcane mills. The project established that the recoverable quality and quantities of trash can enable surplus power generation year round at sugarcane processing mills in Southeast Brazil, utilizing either conventional cogeneration technology or BIG/GT technology.

An unanticipated but welcome result of the project was that the favorable findings on trash availability and cost have been enthusiastically received by sugarcane mill managers and technicians. The work in the project done by researchers at the CTC provided detailed results, based on clear and transparent methodologies, on the availability, quality, and cost of trash. Prior literature on these issues was not sufficiently rigorous or detailed that investment decisions could be made with confidence. CTC has even developed a preliminary set of cane trash removal and field-treatment guidelines to facilitate practical implementation of trash recovery. Some mill managers are now using the information generated by CTC to begin using trash for energy. This commercial trash utilization activity spawned by the project is an important development, since it marks the beginning of the commercial establishment of trash utilization for energy. If this practice becomes well established commercially, this will remove one major obstacle to successfully introducing BIG/GT technology in the future.

The project also established the technical suitability of sugarcane bagasse and trash as a fuel for atmospheric-pressure gasification. Because $800K in additional funds for pilot-plant testing of bagasse and trash were made available to the Swedish gasifier company, TPS, from European sources, much more extensive pilot-plant gasification testing was completed than originally envisioned. This gives a very sound basis for scaling up the gasifier design from the pilot-plant size to a commercially-relevant scale.

The project data and analysis showed that BIG/GT technology, with trash supplementing bagasse, could enable a five-fold increase in annual electricity production from a sugarcane mill: electricity production could be increased from 50 to 60 kWh/ton cane processed (with conventional high pressure steam turbine technology firing only bagasse) to 250 to 300 kWh/ton of cane processed with a BIG/GT system using both bagasse and trash.

One activity in the project was estimating the investment costs for a first-of-a-kind commercial-demonstration BIG/GT plant. This cost is high, as would be expected for a first-of-a-kind facility. However, the cost estimate does not represent what could actually be achieved for a first-of-a-kind plant in Brazil, since it relied heavily on cost estimates from TPS for much of the equipment that would be part of the plant. The TPS cost quotes provided to CTC assumed European sourcing of equipment. Since most of the equipment could be manufactured in Brazil, where manufacturing costs would be considerably lower than in Europe, Brazilian sourcing of equipment would reduce the estimated investment cost, perhaps considerably.

An additional cost issue that the project did not address in detail is estimating what the investment costs for a BIG/GT plant are likely to be once the technology reaches commercial maturity. Prior work suggests that commercially-mature BIG/GT technology will be able to generate electricity at costs competitive with alternative generating technologies.

The Companhia Paulista de Forca e Luz (CPFL), one of the largest private electricity generating companies in Brazil, recently has indicated an interest in evaluating in detail the prospective financial viability of a "Brazilianized" first-of-a-kind plant in anticipation of taking a leading role in putting forward a follow-on project to the SCP to build a demonstration BIG/GT plant operating on sugarcane residues at a mill in Southeast Brazil.

From a capacity building perspective, the SCP project can be considered to have been quite successful, having contributed significantly to capacity development at the CTC and across a wide range of stakeholders, both in and out of Brazil. There is widespread awareness of the project amongst government agencies, private industry, universities, and non-governmental organizations in Brazil. Capabilities and knowledge have been enhanced through direct participation in different aspects of the project by CENBIO (which assisted in disseminating project information), the University of Campinas (which now has a gasifier laboratory at CTC supported by CTC staff), the Centro Tecnico Aero-Espacial and the Instituto Tecnologico de Aeronautica at Sao Jose dos Campos, SP, Brazil (which developed expertise in the design and analysis of cane cleaning processes in the course of the project), ESALQ (which undertook work relating to trash availability), Brazilian equipment suppliers such as Dedini and Codistil (which contributed to designing more steam-efficient sugarcane processing plants), and CPFL (which has developed an interest in sugarcane-BIG/GT technology as a commercial opportunity).

The CTC also has ongoing information exchanges and discussions with several important universities and research centers abroad. These exchanges are leading to the implementation of several related research programs. Such efforts will broaden the world's understanding of key issues relating to sugarcane trash use for energy, help create a critical mass of people working on these subjects, and increase awareness more broadly of the climate change problem and potential contributions of the sugarcane sector toward sustainable development, including mitigating climate change.

Considering the size of the sugarcane sector globally, and the rapidity with which harvesting of sugarcane trash could be implemented (as demonstrated by the recent uptake of this technology by some Brazilian growers), it is apparent that there is an enormous near-term potential for the introduction of sugarcane trash as a fuel to enable year-round generation of electricity at sugarcane mills. Some cane-producing regions have already implemented year-round power generation at sugar mills (Guatemala, Hawaii, Mauritius, Reunion), but in all cases fossil fuels (fuel oil or coal) are used to supplement bagasse. The use of sugar cane trash would avoid the use of fossil fuels and attendant CO2 emissions. Trash utilization could begin today in conventional power plants (boiler-steam turbines), but considerably greater reductions in CO2 emissions will result as BIG/GT technology penetrates the market.

1. Introduction

This report constitutes a final evaluation of UNDP/GEF Project BRA/96/G31, "Biomass Power Generation: Sugar Cane Bagasse and Trash." In carrying out this evaluation, the author of this report interviewed key project participants and stakeholders (see Appendix, A1), reviewed a large number of reports, memos, and other written materials relating to the project (see Appendix, A2), and participated in a meeting convened in early December 2002 by the Sao Paulo State Secretary of the Environment to discuss the possibility of commercial-scale implementation of the sugarcane-residue power generating technology that was the focus of BRA/96/G31.

2. Project Concept and Design

This project (which will be referred to here as the SCP project, "sugar cane power" project) was originally designed as an extension of the GEF's Brazil Biomass Gasifier/Gas Turbine Power Plant Demonstration Project (BRA/92/G31) initiated in the early 1990s. The intention of that project (referred to here as the WBP project) was to demonstrate the commercial viability of biomass-gasifier/gas turbine (BIG/GT) power plant technology. The design of the WBP project called for building and operating a commercial-scale BIG/GT power plant in the Northeast region of Brazil using plantation-grown wood as fuel. Building on knowledge generated by the WBP, the SCP was designed to involve analytical work and technology development that would enable future implementation of the WBP-type power plant technology with sugarcane-derived biomass as fuel instead of wood. The sugarcane biomass fuels include bagasse, the fiber by-product of sugar extraction from cane stalks, and trash, the tops and leaves of the sugarcane plant that are typically burned off the field before harvest or (with harvest of unburned cane) removed at harvest and left on the field to decompose.

By using plantation-wood or sugarcane biomass as fuel, the biomass gasifier/gas turbine (BIG/GT) technology would produce electricity with essentially no net carbon emissions to the atmosphere: the amount of CO_2 emitted to the atmosphere from a BIG/GT plant is the same amount of CO_2 absorbed from the atmosphere in the growing of the plantation wood or the sugarcane residues used to fuel the BIG/GT. This is a key justification for GEF support for both the WBP and SCP projects. The GEF funded the WBP and the SCP projects as part of its portfolio of projects under Operational Program 7. The OP 7 program supports projects that have the objective of reducing the cost of near-commercial low-greenhouse gas emitting technologies to speed their commercialization and widespread implementation.

The WBP and SCP projects were also strongly supported by the Brazilian government, through the executing agency, the Ministry of Science and Technology (MCT). The strong governmental interest in the projects can be explained in part by the lack of indigenous fossil fuels in Brazil and consequent heavy reliance on hydroelectricity supplies that are unreliable from year-to-year due to rainfall variations. Government interest also stems from the fact that both plantation wood production and sugarcane production are important industries in Brazil from social, economic, and energy perspectives. The commercial introduction of BIG/GT technology offers possibilities (especially as pre-harvest burning of cane fields is phased out to eliminate a major source of air pollution during the harvest season) for strengthening and expanding business opportunities in these industries, with related positive impacts on employment, national economy, and energy supply.

The WBP project, as originally conceived, stalled after some key technology development steps were completed, but before construction of the demonstration plant began. Before the extent of the WBP difficulties was clear, the SCP project was launched. It now appears that a wood-chip fired demonstration BIG/GT power plant will not be built in the WBP project. The difficulties encountered by the WBP project – primarily institutional and not technical – are many and complex and will not be discussed here. However, since the SCP project was originally designed as an extension of the WBP, the reader may have some concern that the SCP would not be able to be successfully completed in the absence of successful completion of the WBP. In fact, as discussed in greater detail below, the design of the SCP project provided for flexibility that enabled successful completion of the project even without the successful completion of the WBP.

With the SCP project nearly complete, and the WBP project, as originally designed, not going forward with a commercial-scale demonstration power plant, discussions began in 2002 among stakeholders of the possibility of a commercial-scale demonstration power plant being put forward using sugarcane biomass as the fuel, rather than wood chips, and locating such a plant in the Southeast of Brazil (see Section 8). As of this writing, the Companhia Paulista de Forca e Luz (CPFL) is the leading candidate company to take such a project forward. CPFL is one of the largest private electricity generating companies in Brazil.

Although the SCP was originally designed as an extension of the WBP, the failure of the WBP to be completed as designed has not affected the degree to which the SCP was able to achieve its objectives. This can be attributed to two main factors: 1) sufficient progress was made in the WBP in the development of technology (particularly atmospheric-pressure biomass gasification) to provide a good basis for evaluating the BIG/GT technology for its potential to use sugarcane biomass instead of wood; and 2) a significant component of the SCP dealt with understanding agronomic issues associated with the production, harvesting, storage, and transport of sugarcane biomass as a fuel, which required little, if any, input from WBP findings.

The original immediate objectives of the SCP were the following:

1. Evaluate sugarcane trash availability and quality for utilization in gasification systems.
2. Evaluate alternative agronomic routes to green cane harvesting with trash recovery.
3. Test the atmospheric-pressure circulating fluidized bed biomass gasification (ACFBG) process with bagasse and cane trash to verify which modifications, if any, will be required to operate a commercial-scale plant with those fuels. Follow up the development/testing of the bagasse pressurized gasification system in Hawaii (DOE-HNEI-PICHTR project with special emphasis on the performance of the gasifier feeding system and on final gas quality).
4. Analyze the integration of a BIG/GT system with the operation of a typical sugar/alcohol mill, considering the optimum energy balance of both plants together and assessing the impacts of one on the other during normal operation and transients and identifying the modifications required in the BIG/GT plant to operate with bagasse and sugarcane trash. Determine electric energy costs.
5. Identify and evaluate environmental impacts (and propose mitigation measures for negative impacts) that could result from large-scale introduction of green cane harvesting and power production from bagasse and trash with BIG/GT systems at sugar/alcohol mills.
6. Disseminate project findings and information to the world's sugarcane producing countries.

Each objective had associated with it a set of well-defined outputs, which were generated, in this reviewer's judgment through well-coordinated and logically designed activities. Each activity is well documented in one or more of the more than 100 detailed technical reports that were prepared in the course of the project (see Appendix, A3, for list of reports and activities on which they report.)

The project scheduling was determined in large part by the requirements for meeting the first two objectives listed above. The main considerations in this regard were the time required for growing a crop of sugarcane and the window of time for normal harvesting of the cane. Activities were carried out over the course of two or more growing seasons, and the activities were generally completed on schedule.

One revision to the work plan was made at approximately the 22nd month of what was envisioned originally as a 30 month project. At that time, additional activities (within the framework of the above objectives) were identified as important to improve the chances of achieving economic viability for BIG/GT systems using sugarcane bagasse and trash. As discussed in detail later (see Section 4), the additional activities related to *i)* better understanding the potential for commercial use of "high-biomass" sugarcane varieties that could make more biomass available per hectare for power generation than existing varieties; *ii)* quantitatively understanding the cost implications of sugarcane trash recovery that involves leaving some trash on the field for its herbicide effect; and *iii)* pilot-plant gasification testing of loose bagasse and trash (in addition to the gasification of pelletized forms of these fuels that was undertaken as part of the original work plan).

No new GEF funding was required to undertake the additional activities, because some cost savings were achieved in the original work plan. The savings came from several sources:

- Some purchases of equipment or services that were originally to be done with GEF funds were done instead using Centro de Tecnologia Copersucar (CTC) funds, since delays in approval of the use of GEF funds for such purchases threatened to introduce long delays in the project. For example, if equipment for harvesting trials were not available at the time of harvest, the current harvest season would be missed, and it would be a minimum of another year before such trials could be run.
- Some equipment originally intended to be purchased (e.g., baler costing $60,000) was loaned to the project by the equipment manufacturer, at no cost to the project.
- The original work plan included a second round of gasifier testing, but the work plan specified a mid-course decision as to which specific tests would provide the most useful information for the project. The originally envisioned second-round tests were replaced in the revised work plan with a different set of tests.

The originally estimated cost of the project was US$7.4 million, consisting of $3.75 million from GEF and the balance from the Brazilian government or CTC. However, CTC invested considerably more of its own resources than originally envisioned, and additional in-kind resources were contributed by sugar mills and equipment suppliers that cooperated with CTC in carrying out the work. The actual project cost exceeded $11 million. CTC's rough accounting of other sources and amounts contributed to the project are as follows:

Cash or in-kind Contributor	Notes	Million US $
CTC	(a)	5.268
Case-New Holland	(b)	0.030
Copersucar sugar mills	(c)	1.580
EU and STEM	(d)	0.800
GEF		3.750
TOTAL		11.43

(a) These are CTC labor costs for engineers and technicians. (Costs for equipment purchases are not included. These were relatively minor.) The original project proposal to GEF was made by CTC in 1993. CTC began work shortly thereafter – before GEF funds were awarded. The original project work plan took into account this fact. Because of the seasonal dependence of the work relating to sugarcane production and harvesting, if CTC had not begun work in advance of GEF approval, the project could not have been completed on the schedule defined in the project document. The CTC activities undertaken before formal approval of the project by GEF account for about half of the indicated CTC total expenditures on the project.

(b) The Case-New Holland company provided a baler and support staff at no cost to CTC for approximately two months in each of two harvesting seasons.

(c) CTC estimates that in-kind contributions from sugar mills to the project totaled about 30% of CTC's cost contribution to the project. The mills' support included administration of experiments (mill manager, area chiefs, etc), labor for equipment operation, labor for data collection, equipment time (tractors, harvesters, trucks, etc), areas put at CTC's disposal to set up experiments, operating costs related to fuels, lubricants, and other consumables, delays in normal mill activities, and other miscellaneous costs. In addition, one sugar mill paid the full $2.2 million cost for a dry cleaning station that was used by the project for testing. This costs is not included in the total shown here, since the cleaning station subsequently went into full commercial use at the mill.

(d) The European Union (EU) and the Swedish national energy agency (STEM) provided funding support to TPS, the Swedish gasifier developer that was selected to participate in gasification testing. TPS used this support to develop a feeding system for loose bagasse and trash and to increase the number of gasification pilot tests from one to four.

3. Project Implementation

The project appears to have been implemented relatively smoothly, with only minor difficulties encountered along the way. Activities were completed generally on schedule and under budget while generating the specified substantive results.

One issue that created minor difficulties was the lack of pre-defined indices for measuring successes in the project. This was an oversight in the preparation of the project document. However, this shortcoming was recognized during the project implementation-reporting period (1999), and CTC, UNDP, and MCT (Ministry of Science and Technology) agreed at that point that a criterion for success of any particular activity would be the percentage of that activity completed. CTC subsequently has identified broader indicators of project success, impact, and sustainability, and these are discussed below in Section 4.

An additional minor difficulty arose with sub-contracting for some inputs to several of the activities. A note about this appears in the 1999 Project Implementation Report (PIR). Specifically, difficulties were encountered with contracting for: *i)* purchase/transport of bagasse samples from Brazil to Sweden for gasification tests (Activity 3.1.1); *ii)* pinch analysis of the potential for reductions in mill steam consumption (Activity 4.2.5); *iii)* aerodynamic modeling and design of cane dry cleaning stations (Activity 2.2.2); and *iv)* part of the laboratory analysis to characterize sugarcane trash as a gasifier fuel (Activities 1.3.2 and 1.3.6).

The difficulties in sub-contracting appear to have been due largely to poor coordination and communication among the three key involved institutions: CTC, UNDP, and MCT. The reasons for the poor coordination and communication are not entirely clear. Ultimately, however, the required sub-contract inputs were satisfactorily obtained, except for the pinch analysis, which was ultimately deemed (correctly, in this reviewer's opinion) not to be an essential input to the overall project.

CTC found somewhat onerous the requirement that it prepare a formal report to MCT with each invoice for payment. In retrospect, however, this reporting requirement led to the existence of a comprehensive and detailed set of project reports documenting every aspect of the work. This set of documents will likely prove very valuable in the future as additional work is undertaken at CTC and elsewhere towards commercializing the application of bagasse and trash BIG/GT systems at sugarcane factories.

From a broader implementation perspective, the project can be considered to have been quite successful. There is widespread awareness of the project amongst government agencies, private industry, universities, and non-governmental organizations in Brazil, as well as amongst sugarcane industries worldwide. Capabilities and knowledge at Brazilian institutions have been enhanced through direct participation in different aspects of the project, including at CENBIO (which assisted in disseminating project information), the University of Campinas (which now has a gasifier laboratory at CTC supported by CTC staff), the Centro Tecnico Aero-Espacial and the Instituto Tecnologico de Aeronautica at Sao Jose dos Campos, SP, Brazil (which developed expertise in the design and analysis of cane cleaning processes in the course of the project), ESALQ (which undertook work relating to trash availability), Brazilian equipment suppliers such as Dedini and Codistil (which contributed to designing more steam-efficient sugarcane processing plants), and CPFL, the private electric utility in Sao Paulo state (which has developed an interest in sugarcane-BIG/GT technology as a commercial opportunity).

In addition to involving a number of institutions directly in the project, awareness of the work in the project was raised via a widely-distributed regular newsletter. (See Appendix, A4, for newsletter distribution list.)

4. Project Results

This section briefly summarizes the main achievements associated with each of the six objectives of the project. The final project report (available in draft at the time of this writing) provides quantitative, integrated, and comprehensive discussion of all of the work undertaken in the project.

4.1. Immediate Objective 1: Evaluate sugarcane trash availability and quality for utilization in gasification systems.

Output 1.1. The most important result from this set of activities was the accurate measurement of the amount of trash produced (trash produced per unit of sugarcane stalk) for common commercial varieties of sugarcane grown in Southeast Brazil. The careful measurements made in this work help to clarify the actual potential supply of sugarcane trash in SE Brazil. Prior to this work being completed, authors in the literature reported a wide range of trash production rates, so there was considerable uncertainty about the actual availability of trash in any specific case. For purposes of designing a trash-fueled power plant, accurate trash production rates, of the type determined in this project, are essential inputs.

Output 1.2. This output actually belongs logically under immediate objective 2, which is where it is discussed in this report.

Output 1.3. This set of activities involved detailed physical and chemical characterization of sugarcane trash as a fuel for gasifiers or boilers. Characterizations were separately developed for three components of the trash: green leaves, dry leaves, and tops. Extensive, detailed data of this type were not previously available in the literature. They are essential data for designing effective and reliable trash gasifiers or boilers.

Output 1.4 (supplemented by Outputs 1.7 and 1.8 defined in the revised work plan). The costs and benefits of removing trash from unburned fields at harvest was systematically investigated, and recommendations were developed regarding the extent to which trash removal should be undertaken. Generically, the potential benefits of leaving trash on the field include weed control, wind and rain erosion protection, increased soil infiltration of water/reduced soil surface evaporation of water, reduced soil temperatures, and increased soil biological activity. Potential costs of leaving trash on the field include fire hazard during and after harvest, more difficulties with mechanical cultivation, more difficult ratoon fertilizing, more difficult selective weed control, reduced cane yields due to delayed ratooning and formation of gaps between sprouts, and an increase in populations of pests that thrive under trash blankets.

The project found that the extent of recommended trash removal depends on specific conditions at the field such as cane variety, stage of cut, topography, climate, and other factors. Based on the collected data the project formulated guidelines under which trash *(a)* removal is always recommended, *(b)* can be removed after technical and economic considerations are examined, *(c)* can be partially removed. These guidelines are now starting to be used by some sugarcane owners who are collecting trash for use as fuel in existing combustion systems.

The project work paid special attention to the effect on weed growth of trash removal or trash blanketing. The effect of trash removal on weed growth was examined through field experiments with removal rates ranging from 0% (no trash removed) to 100% (all trash removed). The main finding of this work was that a minimum of ⅔ of the trash should be left on the field in order (with no other field treatment) to achieve an herbicidal effect equivalent to that achievable with chemical or physical weed treatments. It was further learned that under some weather conditions or with some specific pest or weed species present, even a ⅔ trash blanket may not be sufficient to fully control weeds.

Output 1.5 (supplemented by Outputs 1.9 and 1.10 defined in the revised work plan). The effort in this set of activities focused initially (in the original work plan) on evaluating experimental sugarcane clones that were bred for high biomass yield, with little regard to sugar yield. High biomass clones can produce significantly larger amounts of trash and bagasse, making them especially attractive for biomass-based power production at a sugarcane mill. However, most of the high biomass clones that CTC evaluated in its initial work gave unacceptable sugar yields. Since sugar is the most important revenue source, even when there is substantial biomass-energy byproduct from sugarcane production and processing, the experimental high-biomass clones offered little economic benefit relative to existing commercial clones. Furthermore, to develop any new experimental clone into a commercially viable species requires 12 or more years to achieve.

After these conclusions were reached, CTC identified a different strategy to pursue in this work, which they implemented as part of the revised work plan. The approach involved looking at a wide variety of already-commercialized cane species to identify ones with both high sugar yield and high biomass yield. Surprisingly, some species with nearly identical sugar yields had considerably different biomass contents. Traditionally, cane species used commercially are chosen for their good sugar yield, with no regard to fiber content (or with preference given to lower fiber contents). If energy production from the biomass is factored into the economics of sugarcane processing, a different choice of species might be appropriate.

Traditionally a "contribution margin" calculation is done to assess the economical viability of a cane species before it is selected for production. This calculation actually penalizes fiber content. Thus, CTC recommended a modification to the calculation when electricity is intended as a co-product with sugar. The modified calculation would consider such factors as production cost of electricity, cost of trash recovery, quantities of trash and bagasse available, potential electricity revenues, and others. Using this modified approach, CTC analysts examined the overall cost impact of a variety of high-fiber canes. They concluded that a sugarcane variety with higher than conventional fiber (bagasse) content would be unlikely to increase economic gains to the sugar/energy producer. However, they also concluded that a variety with higher trash content may be able to increase economic benefits, but only if the value of the trash is sufficiently high.

4.2. Immediate Objective 2: Evaluate alternative agronomic routes to green cane harvesting with trash recovery.

All of the activities under this objective were aimed at developing and evaluating equipment for harvesting and processing sugarcane trash to prepare it for use for energy at the mill. An equally important task was to develop a quantitative understanding of the cost of recovering and delivering trash to a mill using different strategies. Different agronomic routes to trash recovery will result in different quantities of trash being available at a mill.

Four agronomic routes were identified for detailed investigation at the start of the project. Two of these involved harvesting unburned whole cane and two involved harvesting unburned chopped cane. After expending some effort (see Output 2.1), the whole cane routes were deemed unviable. The project findings regarding the two chopped-cane harvesting routes led CTC engineers to identify another, lower-cost route for trash recovery with chopped-cane harvesting. This route was investigated in detail as part of the revised work plan. After completing this project CTC is planning to continue to develop effective trash recovery systems because a number of existing sugar mills have expressed strong interest in utilizing trash for energy.

Output 2.1. This set of activities involved the development of a mechanical harvesting machine for unburned whole-cane. The machine was developed, but had some limitations that led to it being abandoned for this project. The machine was unable to efficiently cut fields producing more than 70 tonnes of cane per hectare. This threshold yield level is low by SE Brazil standards. More importantly, the increasingly popular choice among cane growers in Southeast Brazil for mechanical harvesting is chopped-cane harvesting. The CTC opted to pursue green-cane harvesting options involving chopped cane, which would be more familiar to area farmers. (CTC engineers feel that the technical limitations on whole-cane harvesting could be overcome with considerably more effort, but chose to pursue chopped-cane harvesting, which was more promising.)

Output 2.2. One option for trash collection is to transport the stalk and some trash (or all trash) together to the mill site, where the trash would be separated from the stalks before milling. To achieve the separation, a "cane cleaning station" is needed. Prior to the start of the project, CTC had developed a prototype cleaning station, which was installed at the Quata Sugar mill during the 1994/95 crop. As part of the SCP project, design modifications were made to this prototype, having in mind commercial-scale application of the technology. Extensive testing of the modified prototype was carried out (including in the revised work plan, as defined by Output 2.7), with considerable success. One sugar mill has already commissioned CTC to build a commercial-scale unit for immediate use. The rationale for this mill's investment decision (despite not using trash for energy) is that the cleaning station reduces fiber content that is sent to the cane mills, which reduces sugar losses and maintenance costs. The estimated payback time on this investment is about two years (not considering use of trash for electricity generation).

Output 2.3. Some of the agronomic routes to trash collection would involve harvesting the cane and leaving some or all of the trash on the field. The trash on the field would then be collected for transport to the mill. One set of activities focused on developing and analyzing the feasibility of baling field trash and transporting bales to the mill. Pre-project work by CTC identified large square bales as the most promising geometry for baling. In the project, two candidate trash baling technologies were identified, one made by Case-New Holland and one made by Claas. The Case-New Holland unit was selected for testing in large part because Case agreed to contribute in-kind support to the project in the form of a loaned baler and personnel to support its use. Subsequently, baling measurements were carried out over two different harvest seasons. The measurements focused on quantifying efficiency of trash baling and transport (i.e., the fraction of original fiber material that is actually delivered to the mill), along with the cost of these activities. Satisfactory results were obtained.

Output 2.4. Trash bales cannot be fed directly into a gasifier (or conventional boiler). This set of activities focused on understanding the feasibility and cost of processing bales of trash delivered to a mill into a form suitable for feeding to a gasifier (or boiler). Purchase and field testing of equipment was originally envisioned, but insufficient budget was allowed for this. As a result, CTC borrowed small-scale equipment from several sources to run pilot-scale tests. Reasonable results were obtained, but the test data were not sufficient to allow reliable scale up of the equipment. Considering the test results and CTC's experience in the design of cane milling equipment (knives, shredders, etc.), a detailed design of a trash-bale processing system has been prepared. Given the immediate interest among sugarcane mills in the use of trash for energy, CTC is planning to continue development efforts in this area after the end of the SCP project.

Output 2.5. This set of activities (together with Output 1.2 and, in the revised work plan, Output 1.7) involved comprehensive measurements and analysis of each of five agronomic routes to trash harvest and recovery. The main results from this analysis were detailed quantitative mass balances for each route. From these results, the quantities of trash that would be available at the feed point to a gasifier (or boiler) were determined. In all cases, the amount available for feed to the gasifier is less than the total trash produced on the field due to harvesting, baling, transport, and shredding losses. The magnitude of the losses varied considerably between different agronomic routes.

Output 2.6. This set of activities (together with Output 1.10 in the revised work plan), was designed to determine quantitatively the costs of trash delivered to a mill. The starting point for the analysis was a "baseline" situation characterized by mechanical harvesting of unburned chopped cane, with trash separated from the cane during harvest and left on the field. The additional cost to bring trash to the mill was determined relative to this baseline. Three alternative trash recovery routes were examined: *1)* trash baled on the field, *2)* trash and cane transported together to the mill, where trash would be separated from the stalk in a dry cleaning station, and *3)* some of the trash transported with the cane to the mill, where it is separated from the cane in a dry cleaning station. In each case, all of the following impacts on cost were considered in the analysis: additional equipment and operating cost (e.g., baler, bale transport, bale shredder, added trucks for loose trash transport, etc.), agronomic effects (changes in chemical herbicide use, changes in cane yield due to various factors, changes in soil preparation costs due to compaction from operation of additional equipment, reduced stalk milling capacity due to increase in fiber (trash) that carries over with the cane to the mill, reduced juice extraction efficiency arising from sugar being carried out with the added fiber leaving the mills.

The total cost of trash for the three alternatives ranges from $13.7 per dry ton to $31.1 per dry ton, corresponding to $0.8/GJ to $1.8/GJ. At the lower end of this range, sugarcane trash would be an economically attractive fuel. This is confirmed by the considerable interest in recovering trash for use as energy that has been expressed to CTC in the course of the project by some sugar mills.

4.3. Immediate Objective 3: Test the atmospheric-pressure circulating fluidized bed biomass gasification (ACFBG) process with bagasse and cane trash to verify which modifications if any, will be required to operate a commercial-scale plant with those fuels. Follow up the development/testing of the bagasse pressurized gasification system in Hawaii (DOE-HNEI-PICHTR project).

Output 3.1. These activities, together with those under Output 3.2 (defined in the revised work plan), demonstrated the successful pilot-scale feeding and gasification of bagasse, trash, and mixtures of bagasse and trash. Issues around which there was concern and uncertainty before the testing started included the ability to feed loose material, problems with ash softening or melting, gasifier and cracker operating stability, tar content in the gas following the tar cracker, other potentially problematic contaminants in the gas (e.g., NH_3 that would result in unacceptable NO_x emissions if burned in a gas turbine), and sufficiency of the gas calorific value for gas turbine firing.

The tests were carried out by the TPS company at its pilot plant facility in Nykoping, Sweden. Three one-week test campaigns were run with pelletized bagasse as fuel and four one-week campaigns were run using loose trash as fuel (the product of shredding some 1000 trash bales shipped from Brazil to Sweden). The total number and magnitude of the planned testing was larger than originally envisioned. The larger scope of work was made possible by grants totaling about $800,000 given to TPS by the European Union and the Swedish government.

The overall conclusion from the testing at TPS was that both bagasse and trash are acceptable gasification feedstocks, and data were collected to allow modeling of the gasification process for operation on these fuels at larger (commercially-relevant) scales.

The Hawaii pressurized gasification project was terminated several years ago due to a shortfall in funding. At the point of termination, a successful method for effectively feeding loose bagasse into the pressurized gasifier had not yet be found.

4.4. Immediate Objective 4: Analyze the integration of a BIG/GT system with the operation of a typical sugar/alcohol mill, considering the optimum energy

balance of both plants together and assessing the impacts of one on the other during normal operation and transients and identifying the modifications required in the BIG/GT plant to operate with bagasse and sugarcane trash. Determine electric energy costs.

Output 4.1. The majority of these activities were carried out by TPS, the Swedish gasifier and engineering company, under a subcontract. Building on the pilot-plant gasification data collected as part of Immediate Objective 3, TPS analyzed a variety of BIG/GT process configurations for stand-alone plants producing electricity only and cogeneration plants producing electricity and process steam to run the sugar/alcohol factory. TPS based all of its designs around the General Electric gas turbine model LM2500 PH. The basic LM2500 gas turbine is a very well established commercially for natural gas applications. The "PH" variant is designed specifically for gasified biomass as fuel. It was developed as part of the GEF's wood BIG/GT project (WBP). TPS calculations indicate that in a stand-alone power plant, a BIG/GT combined cycle built around the LM2500 would produce about 30 MW of electric power. Other gas turbines could have been selected for this analysis, but TPS's good understanding of the LM2500 PH technology (as a result of TPS participation in the wood BIG/GT project) and the fact that the scale of the LM2500 is well suited for many sugarcane processing facilities, made this an appropriate choice.

The TPS plant optimization and mill-integration analysis examined a number of issues, most of which do not impact overall plant efficiency significantly, but which are important from the standpoint of practical operation. For example, TPS examined the impact of operating on different mixes of bagasse and trash as fuel, ranging from 100% bagasse to 100% trash. TPS also examined the impact of fuel drying integrated in the overall process design or carried out independently from the plant.

Based on thorough analyses of a variety of BIG/GT plant configurations, TPS carried out the preliminary basic engineering for one cogeneration design, selected in consultation with CTC engineers, for the Sao Francisco sugar mill in Barrinha, Sao Paulo. This mill was chosen by CTC on the basis of it being representative of many mills in Southeast Brazil, its experience with unburned sugarcane harvesting, the willingness of its management to cooperate with the project, and other factors.

On the basis of the preliminary basic engineering process design, TPS estimated the investment and operating/maintenance costs for the BIG/GT plant. The cost estimate was for a first-of-a-kind plant, with a target accuracy for the investment cost of $\pm$30%. TPS expects (not unreasonably) that costs for future plants will fall with experience and learning from earlier plants. Also, costs for future plants that are larger than the one considered in this project (which would be appropriate for larger sugarcane processing facilities in Brazil) would improve over the initial-plant cost estimate as a result of scale economy gains.

The plant cost estimate provided by TPS was relatively high and would likely make this first-of-its-kind commercial-scale plant uncompetitive commercially with a plant using conventional technology. This is not an unexpected result for a first-of-its-kind demonstration. However, the estimated cost was also high because TPS based it on European sourcing of equipment, with no adjustments made for Brazilian conditions. Most of the equipment inside the plant could be (or already is) manufactured in Brazil. Brazilian costs for such equipment are likely to be considerably below European-sourced costs. Estimating the cost reduction that could be achieved compared with the original TPS estimate is an important activity that was not in the original scope of work of the project. It is a critical next step for moving forward with a commercial-scale demonstration project, since it will enable an understanding of what minimal level of GEF grant funding would be needed, and it would help attract outside private investor participation in the project. (See discussion of next phase in Section 8.)

Output 4.2. The majority of these activities were carried out by CTC in tandem with the analysis by TPS described under Output 4.1. The TPS analysis focused inside the battery limits of BIG/GT facilities. The CTC analysis focused on understanding in detail the sugarcane processing facilities energy demands (that would need to be supplied by the BIG/GT system), potential improvements in energy efficiency of the process, and the coupling of the outputs of the BIG/GT facility (primarily electricity and process steam) with inputs required by the sugarcane milling facility.

If other factors are unchanged, lower process steam requirements provide significant economic benefits for a BIG/GT cogeneration system relative to a conventional cogeneration system. For this reason, one key focus of this work was understanding how existing sugarcane processing facilities could reduce their process steam consumption. It was originally envisioned that Linnhof-March, a highly-regarded company specializing in the application of "Pinch Analysis" to identify energy efficiency improvement opportunities in industrial plants, would be hired to help identify process-steam reduction opportunities. However, agreement could not be reached with Linnhof-March on the terms for a sub-contract, so CTC undertook the work itself, tapping its considerable experience and modeling capabilities relating to the energy design of sugar/alcohol factories. CTC used these capabilities to examine the relative thermodynamic and economic attractiveness of mill modifications that might be undertaken, such as replacing steam drives with electric drives and adjusting process steam pressures. They ultimately identified considerable cost-effective process steam reductions that could be achieved.

Output 4.3. These activities involved CTC developing the overall preliminary engineering design for the integrated sugarcane processing mill and BIG/GT. A key technology-development effort in these activities was the development of a bagasse/trash dryer, which is required for the BIG/GT system to bring the moisture content of the fuel to a level sufficiently low to enable an adequate quality gas to be produced by the gasifier. CTC had previously developed a bagasse drying technology that is at present in use in some mills in Southeast Brazil. CTC modified their design to enable integration with a BIG/GT system and for handling trash as well as bagasse.

CTC incorporated their various technology development and mill energy analyses into mill-integrated BIG/GT designs for which they developed detailed physical plant layout drawings. CTC also developed investment and operating cost estimates for equipment outside the battery limits of the TPS analysis. The CTC and TPS analyses were merged to produce the final preliminary engineering design for mill-integrated BIG/GT facilities.

Output 4.4. In this effort CTC engineers estimated the cost of electricity generation from integrated sugar mill – BIG/GT systems using inputs from previous activities and assuming different financing conditions. The scope of the analysis includes the cost of delivering trash and bagasse fuel to the BIG/GT plant and the cost of any modifications to the mill (e.g., to reduce steam consumption). CTC has developed detailed financial models for sugarcane mills, which were modified and used for the analysis of electricity costs. The analysis was carried out for the first-of-a-kind plant with capital costs based on European sourcing of equipment. Not surprisingly (see discussion above under *Output 4.1*), the cost of electric power production is non-competitive with these assumptions.

The power cost is dominated by capital investment (~50% of the total cost of power), with fuel cost, interest expense, and income tax accounting for an additional ~10% each. CTC concludes from its cost analysis that it should be feasible to reduce the cost of power production to between \$0.05 and \$0.06 per kWh in the longer term for BIG/GT plants at this scale. This conclusion does not consider thermodynamic improvements that might be undertaken to improve overall efficiency. This would effectively increase the kW output of the plant for the same fuel input. On this basis, one may conclude that the estimate of \$0.05/kWh to \$0.06/kWh may be a relatively conservative (high) estimate, although process design, engineering, and cost analysis more detailed than carried out in this work is required to be more confident of this conclusion.

4.5. Immediate Objective 5: Identify and evaluate environmental impacts that could result from large-scale introduction of green cane harvesting and power production from bagasse and trash with BIG/GT systems at sugar/alcohol mills.

Assessed under this objective were *(i)* potential changes in emissions of greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4), and regional pollutants (particulate matter, PM, and other gases), *(ii)* potential changes in soil erosion, nutrient cycling in the soil, and soil properties (including micro-organism populations); and *(iii)* potential changes in herbicide and pesticide application rates.

Output 5.1. Quantitative estimates of changes in CO_2, CH_4, PM, and other pollutant gases that would result from widespread implementation of BIG/GT systems in the Brazilian sugar/alcohol industry were made in this set of activities. These estimates (reported below) were completed relatively early in the project. Better values for some parameters values used in the analysis were subsequently developed as a result of other work in the project, and revised estimates will be given in the final report. However, the revised estimates are not expected to be significantly different from the original estimates.

The estimates of specific emissions (kg of emission per tonne of sugarcane biomass burned or gasified) were based either on results of wind-tunnel sugarcane burning tests (published in 1995 by researchers from the University of California, Davis) or on "emission factors" recommended by the Intergovernmental Panel on Climate Change (IPCC) or the US Environmental Protection Agency. Also, changes in direct and indirect emissions were considered, including substitution of electricity from CO_2-generating fossil fuels with electricity from CO_2-neutral BIG/GT systems, increased consumption of CO_2-generating diesel fuel in machinery to collect and transport the biomass to the BIG/GT plant, and fossil-fuel derived CO_2 emissions associated with production and application of herbicides, pesticides, fertilizers, and soil conditioning chemicals. The CO_2 derived from fossil energy spent in the fabrication and maintenance of tractors, trucks and machinery is also included. The "baseline" over which changes in emissions are calculated assumes "business-as-usual" in the sugarcane industry, i.e., field-burning of sugarcane trash and conventional bagasse-burning boilers at mills.

In the case of CO_2 emissions, the impacts for three different trash recovery scenarios with chopped-cane harvesting of unburned cane were estimated: (1) 100% of trash entrained with the harvested cane and transported together to the mill; (2) trash separated from the cane during harvest, with 100% of the trash transported to the mill separately from the cane; and (3) same as scenario (2), but with only 50% of the trash transported to the mill, with the balance left on the field. By far the most significant impact on CO_2 emissions was the displacement of fossil-fuel generated electricity with electricity from trash and bagasse. Overall, in scenarios (1) and (2), net emissions of CO_2 in Brazil as a whole (assuming 300 million tonnes of sugarcane harvesting per year) would be reduced by about 40 million tonnes per year. The reduction would be about 26 million tonnes per year for scenario 3.

For emissions of CH_4, CO (carbon monoxide), NO_x (oxides of nitrogen), and PM, the situation was postulated in which harvesting practices would be changed from 100% burnt cane harvesting (with 10 tons of dry matter burnt per hectare) to burning only 45% of the cane fields. The trash from the remaining 55% of fields would be collected and transported to the mill for power production. For this scenario, two levels of emission reductions (due to reduced field burning) were calculated. The reductions estimated using IPCC emission factors were considerably higher than those estimated from wind tunnel cane-burning tests. Total annual emission reductions from reduced cane burning in Brazil, assuming 300 million tonnes of cane harvested annually, were estimated to be 8,500 - 58,500 tonnes of CH_4, 527,000 – 1,230,000 tonnes of CO, and 29,000 – 90,000 tonnes of NO_x. For particulate matter, emission reductions were estimated considering trash use in a BIG/GT or in a conventional boiler. Reductions were significant in both cases (compared to field burning), but much more substantial using BIG/GT than using a conventional boiler.

Output 5.2. This set of activities sought to quantify what incremental impacts the recovery of trash for power generation would have on field soils. Water erosion and nutrient cycling through the soil were examined, as were impacts of applying industrial residues (e.g., stillage) to the soil. Impacts on soil properties were also examined.

A main conclusion from the soil erosion work was that soil covered with trash will suffer less water erosion than bare soil. Aside from erosion issues, water infiltration into the soil was found to be considerably faster with trash left on the field. However, in neither case could generalizable quantitative results be obtained due to the strong influence of soil physical properties, ground topography, and other factors.

The main nutrients of interest for cane growing are nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. The experimental measurements made on nutrient cycling produced the surprising result that nutrient return to the soil is not significant from green trash left on the soil. While the experiments found that nutrients are removed from the field when trash is removed, the experiments also found that when the trash was left on the field, the rates of mineralization – the processing of minerals found in the trash into forms accessible to the cane plants – were extremely low. In the case of nitrogen mineralization, this was not unexpected, since it was know previously that crop residues having nitrogen content less than 18 g/kg and a carbon/nitrogen ratio above 20 exhibit low nitrogen mineralization rates over the course of a year. Average sugarcane trash contains 4.6 – 6.5 gN/kg trash, with a C/N ratio greater than 60.

Unlike the case with changes in nutrient cycling, changes in soil organic matter can only be observed over extended time periods, so no conclusions could be reached on this topic in the course of the project. However, based on the fact that cane fields in Brazil have been burned for centuries – a process that returns little organic matter to the soil – the impact of trash removal on soil organic matter is probably not large.

Output 5.3. These sets of activities revolved around understanding the impacts of trash removal on weeds and pests from an environmental perspective. The discussion under Output 1.4 (above) addressed these issues from an economic perspective.

Output 5.4. The results from this set of activities were not yet translated into English at the time of this writing.

Output 5.5. The results from this set of activities were not yet translated into English at the time of this writing.

4.6. Immediate Objective 6: Disseminate project findings and information to the world's sugarcane producing countries.

Output 6.1. Project findings were summarized in English on a quarterly basis in a newsletter with a worldwide circulation list (see Appendix, A4). This was an excellent dissemination mechanism. Posting project findings on an internet site would be another useful mechanism for disseminating information to a much broader number of people.

By agreement among CTC, UNDP, and MCT (Ministry of Science and Technology), it was decided that instead of preparing two workshops as called for in the original set of activities, CTC would present papers at a key sugar-industry conference in Northeast Brazil, as well as at the International Society of Sugar Cane Technologists meeting, the most important international meeting of the sugarcane industries that takes place once every three years. In addition to presenting papers at these meetings, CTC engineers and agronomists also presented papers at a variety of other meetings and in various publications. A complete list of conferences and papers is provided in Appendix, A4.

As a result of paper presentations, as well as direct interactions between CTC engineers and other stakeholders, a wide range of Brazilian and international institutions had the opportunity to build capacity in technical areas relevant to BIG/GT implementation in the sugarcane industries. The networking and capacity building aspects of the project were especially encouraged by the MCT. Among the other Brazilian institutions impacted positively by the project were:

- CENBIO, the Center for Biomass Energy Information based at the University of Sao Paulo, which assisted the dissemination of information generated by the project.
- Prof. Luiz Cortez' research group in the Department of Agricultural Engineering at the University of Campinas, which set up an experimental biomass gasification laboratory at the CTC, which CTC is helping to support.
- CTA, the Centro de Tecnologia Aerospatial at Sao Jose dos Campos, which developed expertise in the analysis and design of cane cleaning processes.
- ESALQ, the agricultural branch of the University of Sao Paulo (located in Piracicaba), which participated in research relating to trash collection and its agronomic impacts.
- CPFL, the private electric utility in the Sao Paulo area, which has become informed about power generation opportunities in the sugar industry.
- Brazilian sugarcane industry equipment suppliers, including Dedini and Codistil, which provided inputs to the analysis of energy-efficiency improvement opportunities undertaken in the project.

In addition, CTC engineers interacted with a number of international institutions, including

- Australian Sugar Research Institute
- Mauritius Sugar Industry Research Institute
- Ministry of Sugar, Cuba
- Cenicana, the sugar industry research organization of Colombia
- Sugar Milling Research Institute, South Africa
- University of Delft, Netherlands, which is seeking to bring together all Brazilian organizations involved with gasification technology to work jointly.

5. Findings

An overall conclusion regarding the project is that it has been completed in a thorough and high-quality fashion. The project has met all original objectives, and it has gone beyond these in several areas.

Importantly, the project has contributed significantly to capacity development at CTC and across a wide range of stakeholders, both in and out of Brazil (as discussed in Section 3). Internally at CTC, aside from more-substantive capacity building that has occurred, project management and reporting practices used for the SCP project are being incorporated as standard practice for a wide range of projects inside CTC. CTC also has ongoing information exchanges and discussions with several important universities and research centers in Brazil and abroad. These exchanges are leading to the implementation of several related research programs. Such efforts will broaden the world's understanding of key issues relating to sugarcane trash use for energy, help create a critical mass of people working on these subjects, and increase awareness more broadly of the climate change problem and potential contributions of the sugarcane sector toward sustainable development, including mitigating climate change.

The project established through rigorous experiments and analysis the quality, quantity, and cost (~ US$ 1/GJ delivered to a mill) of recoverable sugarcane trash as a supplemental fuel to bagasse for power generation at sugarcane mills. The project established that the recoverable quality and quantities of trash can enable surplus power generation year round at sugarcane processing mills in Southeast Brazil, utilizing either conventional cogeneration technology or BIG/GT technology.

An unanticipated but welcome result of the project was that the favorable findings on trash availability and cost have been enthusiastically received by sugarcane mill managers and technicians. The CTC work has provided detailed results, based on clear and transparent methodologies, on the availability, quality, and cost of trash. Prior literature on these issues was not sufficiently rigorous or detailed that investment decisions could be made with confidence. CTC has even developed a preliminary set of cane trash removal and field-treatment guidelines to facilitate practical implementation of trash recovery. Some mill managers are now using the information generated by CTC to begin using trash for energy. This commercial trash utilization activity spawned by the project is an important development, since it marks the beginning of the commercial establishment of trash utilization for energy. If this practice becomes well established commercially, this will remove one major obstacle to successfully introducing BIG/GT technology in the future. Even if BIG/GT technology is ultimately not successful, the penetration in trash use resulting from the project (and resulting CO_2 emissions reductions) can be considered a success.

The project also established the technical suitability of sugarcane bagasse and trash as a fuel for atmospheric-pressure gasification. Because $800K in additional funds for pilot-plant testing of bagasse and trash were made available to the gasification company, TPS, from European sources, much more extensive pilot-plant gasification testing was completed than originally envisioned. This gives a very sound basis for scaling up the gasifier design from the pilot-plant size to a commercially-relevant scale.

The project data and analysis showed that BIG/GT technology, with trash supplementing bagasse, could produce a five-fold increase in annual electricity production from a sugarcane mill: electricity production could be increased from 50 to 60 kWh/ton cane processed (with conventional high pressure steam turbine technology firing only bagasse) to 250 to 300 kWh/ton of cane processed with a BIG/GT system using both bagasse and trash.

One activity in the project was estimating the investment costs for a first-of-a-kind commercial-demonstration BIG/GT plant. This cost is high, as would be expected for a first-of-a-kind facility. However, the cost estimate does not represent what could actually be achieved for a first-of-a-kind plant in Brazil, since it relied heavily on cost estimates from TPS for much of the equipment that would be part of the plant. The TPS cost quotes provided to CTC assumed European sourcing of equipment. Since most of the equipment could be manufactured in Brazil, where manufacturing costs would be considerably lower than in Europe, Brazilian sourcing of equipment would reduce the estimated investment cost, perhaps considerably.

An additional cost issue that the project did not address in detail is estimating what the investment costs for a BIG/GT plant are likely to be once the technology reaches commercial maturity. Investment costs for a first-of-a-kind commercial-scale demonstration plant will be higher than costs that would be reached after a series of commercial-scale BIG/GT plants have been built. Building several plants would enable "cost learning" and gaining of manufacturing economies and scale economies. With commercially-mature investment cost levels, prior work by others suggests that BIG/GT technology will be able to generate electricity at costs competitive with alternative generating technologies. However, it is important that competitive "commercially-mature" costs be demonstrated with a high degree of confidence in order to attract early private sector investment.

Considering the size of the sugarcane sector globally, and the rapidity with which harvesting of sugarcane trash could be implemented (as demonstrated by the recent uptake of this technology by some Brazilian growers), it is apparent that there is an enormous near-term potential for the introduction of sugarcane trash as a fuel to enable year-round generation of electricity at sugarcane mills. Some cane-producing regions have already implemented year-round power generation at sugar mills (Guatemala, Hawaii, Mauritius, Reunion), but in all cases fossil fuels (fuel oil or coal) are used to supplement bagasse. The use of sugar cane trash would avoid the use of fossil fuels and attendant CO_2 emissions. Trash utilization could begin today in conventional power plants (boiler-steam turbines), but considerably greater reductions in CO_2 emissions will result as BIG/GT technology penetrates the market.

6. Recommendations

As noted earlier, the project estimated investment costs for a first-of-a-kind commercial demonstration BIG/GT plant in Brazil. However, the project did not give sufficient attention to understanding the extent to which vendor-quoted costs (which were based on European sourcing of equipment) were relevant to Brazilian application of the technology. In hindsight, it is unfortunate that the exercise of cost-reduction optimization for the first-of-a-kind plant was not included in the scope of work of the project. With the total investment cost estimate based on European sourcing of major equipment, a first-of-a-kind BIG/GT would be expensive. However, with all other factors being equal, Brazilian-sourcing of equipment should significantly reduce costs.

Anecdotal evidence noted by Regis Leal (CTC) suggests that cost reductions would be significant. For example, a European-sourced high pressure (65-80 bar) steam turbine system for year-round electricity production at a sugar mill in Mauritius had an installed cost of about $1500/kW. He estimates that a similar plant in Brazil designed for milling-season operation only costs about $600/kW.

Because the original cost estimate for a first-of-a-kind commercial demonstration plant does not reflect what it would cost in practice in Brazil, it is important that a thorough analysis be undertaken to determine costs if cost-reduction optimization were pursued. An effort to develop a cost estimate for a “Brazilianized” plant would involve modest expense and require 5 or 6 months of effort. TPS has indicated a willingness to absorb a significant share of this cost, and CTC is also willing to absorb some of the costs. If additional funds via MCT or GEF could be made available (either within or outside of the present project), this relatively modest cost estimating effort could have very important consequences for moving forward with the demonstration project. CTC had evidently requested additional funds from MCT/UNDP during the last year of the project to carry out this effort, but funds have not been made available.

7. Lessons Learned

Some key lessons learned are distilled from earlier discussions in this report.

- Flexibility in the original design of the project was important. It enabled successful completion of the project, even when the WBP project, around which some of the SCP project activities were to focus, did not move forward as expected.
- Indicators for measuring success of the project should have been better defined at the outset of the project, since in the course of the project there was uncertainty (looking in from the outside) as to whether or not the project was achieving its objectives. Nevertheless, the project has been successful by any measure.
- The careful and thorough documentation and communication to stakeholders of project results is important. This is exemplified in the fact that some cane growers in Sao Paulo have gained confidence in trash utilization through CTC’s work, and they are already adopting recommendations on trash recovery developed during the project.
- In the GEF’s OP7 projects such as the SCP project (which are designed to accelerate commercialization of new technology), special attention must be paid to understanding prospective investment costs and optimizing the reduction of these.
- For project activities tied to seasonal cycles, such as sugarcane harvest cycle, it is especially important that equipment procurements and other preparations be done in a timely fashion. Otherwise, there is the risk of significant delays in the project (due to having to wait until the next season).
- There is considerable interest in Brazil and around the world in seeing successful sugarcane biomass BIG/GT technology commercialized. This is evidenced by funding and in-kind contributions from outside organizations (e.g., EU funding for gasification tests) and the consistent interest in CTC’s results exhibited by companies and research organizations in Brazil and worldwide.

8. Assessment of Potential Phase II for Project

The term “Phase II” project here refers to a BIG/GT hardware demonstration effort that would follow on BRA/96/G31. The original design of Phase II was to have involved trial operation of the WBP with bagasse and cane trash. Since the WBP plant will not be built with GEF support, the consideration for Phase II now involves building a plant designed specifically for firing with sugarcane residues.

A meeting was convened by Jose Goldemberg, Sao Paulo State Secretary of the Environment, on 4 December 2002 in Sao Paulo to discuss with stakeholders the prospects for a phase II project. The discussion in this section of the report is based primarily on the results of that meeting,[1] together with conversations the author had with CTC staff and Isaias Macedo on 3 December 2002 and with Jose Goldemberg on 5 February 2003. This section also reflects information from a meeting the author had with GEF staff members (Alan Miller, Eric Martinot, Catherine Vallee, Jaime Porto Carrera, Karin Shepardson) in Washington on 13 November 2002 to discuss the possibility of a Phase II project.

The participants at the 4 December meeting were

- Jose Goldemberg and his staff members, Suani Coelho and Roberto Moreira
- Carlos Castro, UNDP/GEF
- Jaime Porto Carrera, World Bank/GEF
- Ivonice Campos, Brazil Ministry of Science and Technology
- Eduardo Carpentieri, CHESF (and manager of WBP project)
- Regis Leal and Tadeo Andrade, CTC
- Paulo Cezar Tavares, CPFL
- Eric Larson

At the meeting, Jaime Porto Carrera indicated that the World Bank/GEF would not provide grant support to the WBP project for the construction and operation of a commercial demonstration wood-fired BIG/GT in Northeast Brazil (see Section 2). Porto Carrera indicated that WB/GEF wanted to use the funds instead to support a demonstration project at a sugarcane mill in Southeast Brazil.[2] The amount of available GEF support indicated by Porto Carrera is about $50 million. A key concern expressed by Porto Carrera was the need for a private-sector investment partner with commercial experience in the power sector to become involved with the demonstration project. Mr. Tavares of the CPFL indicated that CPFL was considering becoming involved in the project, together with CTC and a host sugarcane mill.

During the first week of February, CPFL made the decision that it would evaluate more deeply its participation in the commercial demonstration of a bagasse/trash fired BIG/GT plant at a sugarcane mill. Important factors that probably contributed to this positive decision were government calls for and support of increased thermal generating capacity on the largely-hydroelectric grid and expected legislation providing incentives for renewable electricity.[3] Jaime Porto Carrera has recently indicated that CPFL will be seeking an advance of some GEF funds to enable them to evaluate the financial viability of a demonstration project.

---

[1] The meeting was conducted in Portuguese, which I do not understand well. Therefore, the conclusions in this report are based largely on subsequent conversations I had with other participants of the meeting.

[2] GEF staff members, with whom I discussed this shift of funds felt that it would not involve major new approvals by GEF, which would introduce significant delays.

[3] The legislation that is being developed stipulates that 15% of all new electric power generation after 2006 must be renewable (defined as wind, biomass, or small-hydro) up to a total renewable contribution of 10%. The minimum guaranteed tariff would be 80% of the national-average retail tariff. The current national average retail tariff is about 140 Reais per MWh (about $40/MWh). One publication from Ministry of Mines and Energy indicates expected payments of 156-400 R/MWh for renewable power ($45-115/MWh) under the new law. In addition, wheeling costs for renewable power will be discounted 50% relative to regular wheeling costs.

CTC has recently entered into an agreement with Petrobras to examine the potential use of natural gas at sugarcane mills. In this context, one technology configuration that might be investigated for the Phase II demonstration project is co-firing the gas turbine with gasified sugarcane residues and natural gas. While this would involve some fossil fuel use, the configuration would have several potentially important advantages: it would enable the use of a larger gas turbine (and attendant scale economies on cost); it would reduce technical risk, since the gas turbine might be able to operate entirely on natural gas if the gasification system must be shut down for maintenance or adjustments during the trial operation period; and including natural gas in the project may make the project attractive for Petrobras to participate in it.

One final comment on the Phase II project. If a sugarcane BIG/GT project proceeds, it would be very beneficial if Eduardo Carpentieri were engaged as project manager. Carpentieri has more knowledge and experience with relevant technical issues, as well as experience in dealing with relevant complex institutional issues (fuel supply contracts, power sales contracts, etc.), than anyone else in Brazil. His involvement in Phase II would significantly improve the chances for success of that project.

Appendix

A1. LIST OF INTERVIEWEES

Manoel Regis Lima Verde Leal
Centro de Tecnologia Copersucar
Fazenda Santo Antonio, s/nº – CP 162
13400-970 Piracicaba, SP
ph: 019-429-8217
email: regis@copersucar.com.br

Suleiman Jose Hassuani
Gestor de Tecnologia
Gerencia de Tecnologia
Centro de Tecnologia Copersucar
Fazenda Santo Antonio, s/nº – CP 162
13400-970 Piracicaba, SP
ph: 019-3429-8114
email: suleiman@copersucar.com.br

Isaias Macedo de Carvallo
former Director
Centro de Tecnologia Copersucar
ph: 019-3289-4801
email: IsaiasMacedo22@aol.com

Jose Goldemberg
Secretary of the Environment
Government of the State of Sao Paulo
Av. Prof. Frederico Hermann Jr., 345
Alto de Pinheiros
05489-900
Sao Paulo, SP

Alfredo Eduardo Carpentieri
CHESF
Recife, Brazil
carpenti@chesf.gov.br

Carlos Castro
UNDP/GEF
SNC Quadra 2 Bloco A
Ed. Corporate Financial Center –7º and.
70712 900 Brasilia – DF
ph: 061 329 2036
e-mail:castro@undp.org.br

A2. LIST OF WRITTEN MATERIALS

Centro de Tecnologia Copersucar, BRA/96/G31 Draft final project report to UNDP/GEF, December 2002 (in English).

Centro de Tecnologia Copersucar, BRA/96/G31 – Phase 2, powerpoint slides prepared for 4 December 2002 meeting at CETESB with Prof. Jose Goldemberg and others (in English).

Centro de Tecnologia Copersucar, BRA/96/G31 – Phase II, Biomass Power Generation Sugarcane Bagasse and Trash, powerpoint slides, May 2002 (in English).

Centro de Tecnologia Copersucar, Technical project reports Nos. RLT-01 to RLT-93, produced during September 1997 to May 2001 (most in Portuguese).

Centro de Tecnologia Copersucar, BRA/96/G31 Newsletter, Nos. 01-08, covering December 1997 – October 2000 (in English).

Centro de Tecnologia Copersucar, BRA/96/G31 Project Document, July 1996 (in English).

Centro de Tecnologia Copersucar, BRA/96/G31 Substantive Revision, undated (in English).

Centro de Tecnologia Copersucar, *Brazilian Biomass Power Generation: Sugarcane Bagasse Extension*, report to the Global Environment Facility/UNDP, September 1993 (in English).

GEF, *Second Overall Performance Study of the GEF (OPS2)*, "Box 3.3: Setting the Stage for Biomass Power in Brazil," undated (in English).

Letter of Agreement between Executing Agent (MCT) and Implementing Agency (CTC) for supplementary activities, undated (in English).

Ministerio da Ciencia e Tecnologia, "*Geracao de Energia por Biomassa de Cana-de-Acucar e Residuos, Projeto BRA/96/G31 – Fase II*, October 2001 (in Portuguese).

Ministerio da Ciencia e Tecnologia, Consult Letter to GEF-UNDP regarding Project BRA/96/G31 – Phase II, undated (in English).

UNDP Brazil Country Office, BRA/96/G31 Progress Report covering June 2001 – March 2002 (in English).

UNDP Brazil Country Office, BRA/96/G31 Minutes of Meetings 07-08-09 May 2002 (in English).

UNDP Brazil Country Office, Service Contract Nr. 137/97 between UNDP, MCT, and CTC regarding BRA/96/G31, 24 July 1997 (in English).

UNDP/GEF Project Implementation Report (PIR) for BRA/96/G31: 1999, 2000, 2001, 2002 (in English).

A3. LIST OF DETAILED TECHNICAL REPORTS

These reports were generated during the project. The subject of each report is indicated briefly in this list (right column), along with the activity number defined in the Project Document (or in the revised work plan that was generated in mid-project).

RLP-01 SEPTEMBER 1997

RLT-01	Activity 1.4.1	Trash in the Field
RLT-02	Activity 1.1.2	Plan for Experiments
RLT-03	Activity 1.5.1	Selection of Clones
	Activity 1.5.2	Evaluation of Clones
RLT-04	Activity 2.2.1	Prototype Cane Dry Cleaning Station
RLT-05	Activity 3.1.1	Prepare Bagasse and Trash Samples for Preliminary and Final Testing

RLP-02 NOVEMBER 1997

RLT-06	Activity 1.1.1	Initial Report on Trash Availability
RLT-07	Activity 1.5.3	Field Test Planting
RLT-08	Activity 2.1.1	Report on Copersucar Harvester
RLT-09	Activity 2.2.1	Prototype Optimization
RLT-10	Activity 2.3.2	Selection of Large Baler
RLT-11	Activity 2.5.6	Field Test of Combine
	Activity 5.2.7	Field Test Combine – Extractor of
RLT-12	Activity 4.2.2	Mill Selection and Characterization
RLT-13	Activity 5.3.4	Soil Microorganisms

RLP-03 JANUARY 1998

RLT-14	Activity 2.2.1	Prototype Optimization
RLT-15	Activity 2.3.1	Summary of Baling Tests
		(Newsletter 01)

RLP-04 MARCH 1998

RLT-16	Activity 2.4.1	Market Survey for Shredder
	Activity 2.4.2	Model Selection
RLT-17	Activity 2.5.1	Report on Route Selection
RLT-18	Activity 5.1.1	Energy Balance/CO_2 Emission
RLT-19	Activity 5.1.2	Methane Emissions/Other Grenhouse Gases
RLT-20	Activity 5.1.3	Particulate Emission

RLP-05 MAY 1998

RLT-21	Activity 1.3.8	Trash Quality Report
RLT-22	Activity 2.3.3	Purchase of Baler
RLT-23	Activity 2.3.4	Equipment for Bale Recovery and Transport
RLT-24	Activity 2.6.3	Model Preparation and Tests
RLT-25	Activity 4.2.5	Steam Economy Improvement

		(Newsletter 02)

RLP-06 JULY 1998

RLT-26	Activity 2.1.2	Modifications/Adaptations/Fiels Test
RLT-27	Activity 2.2.1	Prototype Optimization
RLT-28	Activity 2.5.3	Field Test – Loader Transporter
	Activity 2.5.4	Field Test Conventional Loader
RLT-29	Activity 2.6.2	Trash in Field
		(Newsletter 03)

RLP-07 SEPTEMBER 1998

RLT-30	Activity 2.6.1	Data Preparation
RLT-31	Activity 4.2.3	Analysis of ed Information
RLT-32	Activity 4.3.2	Pre-Dryer Design – Equipment Sizing

RLP-08 NOVEMBER 1998

RLT-33	Activity 1.1.3	Tests
RLT-34	Activity 1.5.5	First Cut Evaluation and Report
RLT-35	Activity 2.5.2	Field Test of Copersucar Harvester
	Activity 2.5.5	Field Test – Continuous Loader
RLT-36	Activity 4.2.7	Basic and Process Engineering

RLP-09 JANUARY 1999

RLT-37	Activity 1.1.4	Analysis and Report – Potential Trash Biomass
RLT-38	Activity 1.4.5	Evaluate Benefits/Problems
RLT-39	Activity 2.5.8	Field Test of Trash Baler
RLT-40	Activity 4.2.10	Cost Assessment
RLT-41	Activity 5.4.1	Manpower: Agricultural Systems
		(Newsletter 05)

RLP-10 MARCH 1999

RLT-42	Activity 1.4.3	Minimum Trash for Weed Control
RLT-43	Activity 2.1.3	Pre-Commercial Design e Report
RLT-44	Activity 2.5.9	Cleaning Station Data Analysis

RLP-11 MAY 1999

RLT-45	Activity 1.2.1	Potential (S.Paulo/Northeast)
	Activity 1.2.2	Recovery Potential
	Activity 1.2.3	Final Report on Trash Availability
RLT-46	Activity 2.4.3	Specification of Shredder
	Activity 2.4.4	Purchase and Field Tests
	Activity 2.4.5	Shredder Test Report
	Activity 2.4.6	Shredder Design
RLT-47	Activity 2.5.10	Final Report

RLT-48	Activity 4.3.9	Ductwork Design
RLT-49	Activity 5.2.1	Soil Conservation
RLT-50	Activity 5.2.2	Nutrient Recycling
RLT-51	Activity 5.2.3	Agricultural and Industrial Residues
RLT-52	Activity 5.2.4	Soil Physical Properties

RLP-12 JULY 1999

RLT-53	Activity 2.6.1	Data Preparation Final Reports

RLP-13 SEPTEMBER 1999

RLT-54	Activity 2.6.4	Simulation Model
RLT-55	Activity 2.6.5	Costs and Final Report
RLT-56	Activity 4.2.4	Battery Limits Definition
	Activity 4.2.6	Assistance to ed on Bagasse
	Activity 4.2.7	Basic and Process Engineering
RLT-57	Activity 4.3.1	Project Coordination
	Activity 4.3.3	Equipment Specifications
	Activity 4.3.4	Layout Assembly Drawings
	Activity 4.3.6	Bagasse Handling and Feeding
RLT-58	Activity 4.4.2	Model for the Energy System
RLT-59	Activity 4.4.3	Financing Options
RLT-60	Activity 5.3.1	Herbicidal Effects of Trash on Soil
		(Newsletter 06)
		(Newsletter 07)

RLP-14 NOVEMBER 1999

RLT-61	Activity 4.2.1	Coordinate Project Development Between ED and CTC
RLT-62	Activity 1.3.1	Proximate Analysis
	Activity 1.3.3	Heating Value
	Activity 1.3.5	Ultimate Mineral Analysis
	Activity 1.3.8	Trash Quality Report
RLT-63	Activity 1.4.2	Experiments with 100-0% Trash
	Activity 1.4.6	Definition of Areas to Remove Trash
	Activity 1.4.7	Final Report on Agronomic Effects
RLT-64	Activity 1.5.6	Monthly Evaluation for 2nd CUT
RLT-65	Activity 2.3.5	Tests and Improvements
	Activity 2.3.6	Final Report on Baler
RLT-66	Activity 4.2.11	BIG-GT Sugar Mill Integration Coordination Final Rpt.
RLT-67	Activity 4.3.1	Project Coordination
RLT-68	Activity 4.3.5	P and I Diagram
RLT-69	Activity 4.3.7	I&C Specifications
RLT-70	Activity 4.3.8	Electrical Diagram
RLT-71	Activity 5.3.2	Effect of Trash on Insect Population
RLT-72	Activity 5.3.3	Agricultural Insecticides

RLT-73	Activity 5.5.1	Impact Analysis
	Activity 5.5.2	Mitigation Measures
	Activity 5.5.3	Final Report

RLP-15 JANUARY 2000

RLT-74	Activity 1.3.4	Fuel Density
RLT-75	Activity 1.5.7	Final Evaluation and Report
RLT-76	Activity 2.6.4	Simulation Model
RLT-77	Activity 2.6.5	Costs and Final Report

RLP-16 APRIL 2000

RLT-78	Activity 1.7.1	Assessment of Existing Information
RLT-79	Activity 1.8.1	Experiments with 50% of the Available Trash
	Activity 1.8.2	To Continue the Experiments with 100%, 66%, 33% and Zero Trash on Soil
RLT-80	Activity 1.9.3	Analysis and Report
RLT-81	Activity 2.2.2	Standard Cleaning Station
RLT-82	Activity 2.6.5	Costs and Final Report (see also RLT-55 and RLT-77
RLT-83	Activity 3.2.1	Trash Baling Samples
RLT-84	Activity 3.2.2	Preparation of Samples for Shipment
RLT-85	Activity 4.2.1	Project Coordination
RLT-86	Activity 4.3.10	Pre-Dryer Cost Assessment

RLP-17 JUNE 2000

RLT-87	Activity 1.7.2	Harvesting Tests with Partial Cleaning
	Activity 1.7.3	Test Performance of the Harvester
	Activity 1.7.4	Analysis and Report
	Activity 1.7.5	Project Coordination

RLP-18 MAY 2001

RLT-88	Activity 1.8.1	Experiments with 50% of the Available Trash
	Activity 1.8.2	To Continue Experiments with 100%, 66%, 33% and Zero Trash on Soil
RLT-89	Activity 1.10.2	Economic Evaluation Partial Trash Collection
RLT-90	Activity 4.4.1	Data Collection for Costing
RLT-91	Activity 4.4.4	Final Report: Power Costs
RLT-92	Activity 5.4.2	Manpower: Power System
RLT-93	Activity 1.3.8	Coordination Final Report

OCTOBER 2000

		(Newsletter 08)

DECEMBER 2002

RLT-094	Activity 1.9.3	Selection of High Biomass Sugar Cane Varieties
RLT-095	Activity 2.7.1	Harvester Adjustment for 50% Trash

	Activity 2.7.2	Tests of the Station Prototype
	Activity 2.7.3	Cane Impurities Separator
	Activity 2.7.4	Improvements on the Rotating Brush
RLT-096	Activity 1.8.1	Experiments with 50% Available Trash
	Activity 1.8.2	To Continue Experiments with 100%,66%,33% and Zero Trash on Soil
RLT-097	Activity 1.10.1	Economic Analysis of High Biomass Sugar Cane Varieties
RLT-098	Activity 1.8.1	Experiments with 50% Available Trash
	Activity 1.8.2	To Continue Experiments with 100%,66%,33% and Zero Trash on Soil
	Activity 1.8.3	Final Report
TPS-02/02		Evaluation of the Pilot Plant Test on Cane Trash
TPS-02-25		Process Engineering Evaluation Report:Technical Specification for a GE LM 2500 Biomass Power Plant Using Sugar Cane Fuels

A4. LIST OF OUTREACH ACTIVITIES

Poster and/or oral presentations on the project were given at a wide variety of conferences, and newsletter was published regularly (8 issues during the project period). Below are the conference talks and papers prepared, followed by the newsletter mailing list.

Significant Conferences or Presentations (in terms of international recognition and reach and/or domestic relevance):

Fourth Meeting of the Permanent Forum on Renewable Energy
Recife, Pernambuco, Brazil, 7-9 July, 1998. (Poster exhibit and two oral presentations of project objectives and scope.)

First Brazil/Germany Congress on Renewable Energies
Fortaleza, Ceará, Brazil; 28 September to 2 October, 1999.

First World Bioenergy Conference
Seville, Spain; June 2000.

Progress in Thermochemical Biomass Conversion
Innsbruck, Austria; September 2000.

Workshop on Energy and Cogeneration in the Sugar Mills
International Society of Sugar Cane Technologists (ISSCT), 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, 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; October 2001.

International Seminar on Cane and Energy
Ribeirão Preto, Sao Paulo, Brazil; November 2001.

Engineering Workshop on Energy Management in Raw Cane Sugar Factories
International Society of Sugar Cane Technologists (ISSCT), Berlin, Germany; October 2002.

Second Global Environment Facility Assembly Workshops
Beijing, China; October 2002.

Less Significant Events
(that nevertheless contributed to increasing awareness in the sugar cane sector and amongst the general public of renewable energy, sugar cane trash recovery and use, and global environmental issues)

Opportunities to Generate Power from Biomass
CENBIO, São Paulo, Sao Paulo, Brazil; March 1999.

Economic uses of Sugar Cane Trash
Piracicaba, Sao Paulo, Brazil, April 2002.

Third Meeting on Energy in the Rural Area – AGRENER 2000
Campinas, Sao Paulo, 2000.

XXXII Workshop on Green Cane – Experience Gained
Jaboticabal, Sao Paulo, Brazil; June 2002

Agronomic Week
Espírito Santo do Pinhal Agronomy College, University of São Paulo, Espírito Santo do Pinhal, SP, Brazil; August 2002.

Workshop on Sugar Cane Cycle and the Environment
Itumbiara, GO, Brazil; November 2002.

Mailing List for Newsletter

Bureau of Sugar Experiment Station - BSES
Dr. Colin C. Ryan
P.O. Box 86
Indooroopilly, Queensland 4068 - Australia

Ing. Luis Eduardo Zedillo Ponce de Léon
GEPLACEA
Paseo de la Reforna 1030
Lomas de Chapultepec - 11000 México D.F.

Dr. Mario Melgar
Director General, CENGICAÑA
Ga. Calle 6-38, Zona 9, Ed. Tivoli Plaza, Of. 6-5
Guatemala, C.A.

Dra. Stephanie A. Whalen
HARC - Hawaii Agriculture Research Center
99-193 Aiea Heighs Drive
Aiea HI 96701 Hawaii - USA

Dr. Peter Hewitt
SASA-South Africa Sugar Association Experiment
Station - Mount Edgecombe 4300
Private Bag X02 - Natal - South Africa

Dr. Graeme Bullock - General Manager
Sugar Research Institute
P.O. Box 5611/239-255 NEBO Road
Mackay, Queensland 474 - Australia

Dr. James E. Irvine
Texas Agricultural Experiment Station
2415 East Highway 83
Weslaco, Texas 78596-8399 - USA

Fred E. Reed, Jr., P.E.
Cogentrix, Inc.
9405 Arrowpoint Boulevard
Charlote, NC 28273-8110

Dr. JM Quevauvilliers
Union St. Aubin Milling Co. Ltd.
1St Fllor, Cerne, House - Chaussée
Port Louis - Mauritius

Mr. Denis Pilot
Belle Vue Mauricia S.E
Mapou
Mauritius

Dr. A. Ismael Cuellar
Director General, INICA
Ave. Van-Troi - N° 17203, Boyeros
Cidad de La Habana – Cuba

Dr. James Cock
CENICAÑA
Plaza Norte, Av. 34, Norte 44N-36
Apartado Postal 9138 - Calli, Valle – Colombia

Ing. Agr. Guilhermo Fada
Est. Exp. Agro-Industrial Obispo Colombres
C.C. nº 9 - 4.101 - Las Talitas
Tucumán - R. Argentina

Dr. Jean-Claude Autrey - Director
Mauritius Sugar Industry Research Institute
Reduit
Mauritius

Dr. B. S. Purchase – Director
Sugar Milling Research Institute
University of Natal - Private Bag X10
Dalbridge 4014 - South Africa

Dr. Eoin Wallis
Sugar Research and Development Corporation
P.O. Box 12050, Elizabeth Street
Brisbane, Queensland 4002 – Australia

Dr. Lars Waldheim
TPS Termiska Processer AB
Studsvik, S-611 82 Nyköping
Sweden

Larry K. Mellinger
Trinity International Partners
Suite 1200 - 815 Connecticut Avenue, N.W.
Washington, D.C. 20006

Dr. Charles M. Kinoshita, P.E., PhD
Hawaii Natural Energy Institute
University of Hawaii at Manoa
2540 Dole Street. Honolulu, HI 96822

Dr. Harry Harris
The University of Southern Queensland
Faculty of Engineering and Surveying
Toowoomba, Queesland 4350 – Australia

Dr. Roberto J. Kwok
Hawaiian Commercial & Sugar Company
A Division of A&B - Hawaii, Inc.
P.O. Box 266, PUUNENE, Hawaii 96784 - USA

Dr. Eric Larson
Princeton Environmental Institute
Guyot Hall, Washington Rd., Princeton Univ.
Princeton, NJ 08544-1003 – USA

Dr. Dan Jantzen
Winrock International
1611 North Kent St, Suite 600
Arlington, VA

Dr. Bob Williams
Princeton Environmental Institute
Guyot Hall, Washington Rd., Princeton Univ.
Princeton, NJ 08544-1003 – USA

Dr. Terry Dixon
Sugar Research Institute
Box 5611 - MackayMail Centre
Australia 4741

Dr. PJ Nielsen
Manager Agricultural Services
New South Wales Sugar Milling Cooperative Ltd.
Broadwater Mill, Broadwater NSW 2472 –
Australia

Dr. Scott Q. Turn, Ph.D.
University of Hawaii at Monoa
2540 Dole Street, Homes Hall 246
Honolulu, HI 96822

Dr. Alvaro Zapata
CIPAV
Cra. 35 A Oeste # 3 - 66 - A. Aereo 20591
Cali - Colombia

Dr. Kenichiro Yamaguchi
Mitsubishi Research Institute, Inc.
3-6, Otemachi 2-Chome
Chiyoda-Ku, Tokio - 100.8141 Japan

Dr. Carlos O. Briceño B.
CENICAÑA
Calle 58N Nº 3BN-110 - Apartado Aéreo 9138
Cali, Valle - Colombia

Dr. Paulino López
Ministerio del Azúcar
Calle 23, Nº 171 entre N y O
Vedado, C. Habana

TUDelft – Delft University of Technology
Cees Timmers, MSc
P.ºBox 5048 – 2600 GA Delft
Holanda

TUDelft – Delft University of Technology
Jans Andries
Mekelweg 2
2628 CD Delft, Holanda

Mr. Collin Green
Programme Officer, Technology
P.O. Box 260 124 – D-53153
Bonn - Germany

Mr. K. R. Locklin
Managing Director – Reef
727 Fifteenth St. NW . 11th Floor
Washington , D.C. 20005

Mr. Dana R. Younger
2121 Pennsylvania Ave., NW
Room Nº F-9K -148
Washington, DC 20433 USA

Martin Junginger
Padualaan 14
NL-3584 CH Utrecht
Holanda