PN-AAB-144
ISN 25

Report No. 88-18

A Report of the

Office of Energy
Bureau for Science and Technology
United States Agency for International Development

ELECTRIC POWER FROM SUGARCANE IN COSTA RICA

A TECHNICAL AND ECONOMIC ANALYSIS

Prepared by:

Franklin Tugwell, Team Leader
Marcia Gowen
William Kenda
Arthur Cohen

TEM Associates, Inc.
and
Tennessee Valley Authority

Bioenergy Systems and Technology Project, 936-5709
DHR-5709-C-00-8009-00
BST-5709-R-TV-2181-00

July 1988

a

ACKNOWLEDGEMENT

The authors wish to acknowledge the support and direction from Dr. James B. Sullivan, Director of the Office of Energy, and Mr. John Kadyszewski, Program Manager of the Bioenergy Systems and Technology Project of the U.S. Agency for International Development. Management coordination from Mr. Richard Flood, TEM Associates Inc., assured the team of the key logistical and professional assistance. In Costa Rica, the team received critical guidance and institutional support from Ing. Heriberto Rodriquez, U.S.A.I.D./San Jose; in the sugar industry Ing. Juan Jose Flores S., General Manager of Banco Continental, and Ing. Antonio Ruiz M., Sub-Director of the Division of Cane Agricultural Research and Extension of LAICA; and at ICE Ing. Fernando Montoya, Department Chief of Programming and Control. Their unflagging assistance, hospitality, and committment to the team are sincerely appreciated. Throughout the study conception and analysis, the team greatly benefitted from the institutional cooperation of Mr. Gustavo Calderon at the Inter-American Development Bank. Review of the report by Mr. John Kadyszewski, Dr. Donald Hertzmark, and the Bechtel Corporation also provided important insights to the team. Finally, Belindia Hicks deserves special thanks for her untiring administrative and secretarial support on the report.

TABLE OF CONTENTS

PAGE

Executive Summary: i

Chapter 1: Background 1
- The Costa Rican Economy 1
- Electricity Demand: Implications for the Economy 2
- The Sugar Industry and Electricity Production 4

Chapter 2: Power Plant and Fuel Options 9
- Introduction 9
- The Mills 9
- Efficiency Improvements 11
- Technical Projections 11
- Power Production Projections 20
- Supplemental Fuels 20

Chapter 3: Financial and Economic Assessment of Cane Power Systems 31
- Financial and Economic Investment Models of Electric Power Production 31
- Power System Benefits 32
- Mill Modifications and Capital Costs 37
- Employment Generation and Labor Costs 37
- Fuel Costs 37
- Net Present Values and Economic Impacts of Cane Energy Systems 39
- Sensitivity Analysis 43
- Effects of Changing Electricity Prices 43
- Effects of Oil Price Changes and Petroleum Savings 45
- Effects of Substituting Cane Trash for Oil 45
- Effects of Substituting Coal for Oil 51
- Sugarcane Electricity vs. Alternative Utility Options 52
- Effects of Changing Loan Rates 52
- Effects of Utility Dispatch Factors 54
- Effects of Changing Discount Rates 54
- Potential Benefits, Risks and Policy Needs 54

C

Table of Contents
(cont.)

Appendix A: Efficient Steam Production and Use for Electricity Generation at Costa Rican Sugar Mills
- Introduction
- Factors Affecting Efficient Steam Production
- Factors Affecting Steam Usage

Appendix B: Financial and Economic Models and Data

Appendix C: Economic Analysis Methods and Assumptions
- A Suggested Method for Computing Avoided Costs

Appendix D: Trash Harvesting for Costa Rican Sugar Mills
- Procedure
- Moisture
- Harvested Unburned Cane
- Costs

Appendix E: Domestic and Imported Coal Resources for Electricity Production at Costa Rican Sugar Mills
- Costa Rican Coal
- Location of Coal Deposits and Candidate Sugar Mills
- Quantity and Quality of Domestic Coal Resources
- Lead Time Required to Develop Domestic Coal Deposits
- Imported Coals
- Relative Costs of Imported and Domestic Coals

Appendix F: Biomass-Fired Steam-Injected Gas-Turbine Generation for the Cane Sugar Industry
- Abstract
- Indroduction
- Exporting Electricity from Sugar Factories
- GSTIG Technology
- Performance and Cost Estimates of Biomass-Cogeneration Technologies
- Case Study: A Sugar Producer's Perspective
- Jamaican Context
- Southeast Brazilian Context
- Implications
- Conclusions
- Acknowledgements
- References

References

TABLES

Executive Summary:

i.1 Technical Projections of Base Cases for Sugar Industry Power Production in Costa Rica

Chapter 1:

1.1 A Comparison of Estimated Electricity Generation Costs by Fuel and Type of Producer
1.2 Cane Production by Mills and Region in Costa Rica
1.3 Agricultural Production, Value Added and Employment in Costa Rica

Chapter 2:

2.1 Technical Projections Sugar Industry Power Production in Costa Rica
2.2 Financial Cost Estimates for Supplemental Fuels in Costa Rica
2.3 International Product Price Forecasts

Chapter 3:

3.1 Investment Levels and Mill Characteristics of Models
3.2 Average Annual Cane Power Benefits
3.3 Full Avoided Cost Estimates for Electricity in Costa Rica (1987)
3.4 Average Annual Cane Power Costs
3.5 Annual Employment Generation and Labor Revenues from Cane Power Plants in Costa Rica (1988)
3.6 Financial Benefits and Characteristics of Cane Power Systems
3.7 Potential Petroleum Savings from Cane Power in Costa Rica
3.8 Financial Benefits and Characteristics of Cane Power Systems With Trash (1988)
3.9 NPV's for Discount Rate Sensitivities

Appendix A:

A.1a Evaporator Performance Based on 200 TCH Quadruple Effect (Item A)
A.1b Evaporator Performance Based on 200 TCH Quadruple Effect (Item B)
A.2a Evaporator Performance Based on 200 TCH Quadruple Effect (Item C)
A.2b Evaporator Performance Based on 200 TCH Quadruple Effect (Item D)
A.3a Evaporator Performance - Quintuple Effect Based on 200 TCH (Item E)
A.3b Evaporator Performance - Quintuple Effect Based on 200 TCH (Item F)

Tables (cont.)

Appendix B:

B.1 Financial and Economic Analysis of Electricity Production from Costa Rican Sugar Mills - CanePro Model Version 1
B.2 Financial NPV's for Best, Base and Worst Cases
B.3 NPV's for Electricity Price Sensitivity Analysis
B.4 NPV's for Oil Price Sensitivities
B.5 NPV's for Loan Rate Sensitivities
B.6 NPV's for Daily Load Factor Sensitivities
B.7 Mill Options Estimated Installed Capital Costs

Appendix C:

C.1 Economic versus Financial Analysis Assumptions for Key Variables
C.2 Data Assumptions for Sensitivity Analysis
C.3 Data Assumptions for Best, Base, and Worst Cases

Appendix D:

D.1 Trash Cost Estimates for Costa Rican Mills Based on Data from El Viejo Mill

Appendix E:

E.1 Distances by Road from Coal Fields to Candidate Sugar Mills
E.2 Total Reserves of Costa Rica Coal (Dec. 1986)
E.3 Geochemical and Energy Characteristics of Costa Rican Coals
E.4 Published Quality of Colombian and Chilean Coals
E.5 Estimated Costs per Metric Ton of Colombian and Chilean Coals
E.6 Estimated Costs per Metric Ton for Costa Rican Coals
E.7 Costs of Imported and Domestic Coals per Million Btu

Appendix F:

F.1 Cogeneration Costs Assumed in the Financial Analysis
F.2 Summary of Factory End-Use Scenarios
F.3 Levelized Fuel Prices Assumed For the Jamaica Case Study
F.4 Potential Foreign Exchange Savings to Jamaica with Alternative Cogeneration Systems
F.5 Estimated Potential Worldwide GSTIG Generating Capacity
F.6 GSTIG Electricity Generating Potential Using the 1985 Level of Cane Production

FIGURES

Executive Summary:

i.1 Financial Net Present Value Base Case
i.2 Financial Net Present Value with Trash Fuel

Chapter 1:

1.1 Zones of Sugar Production and Factory Locations in Costa Rica

Chapter 2:

2.1 Schematic: Level 3 Technical Projection
2.2 Electricity Production Cost - El Viejo Mill
2.3 Kilowatt Hours Per Ton of Bagasse - El Viejo Mill
2.4a Electricity Production by Fuel Type
2.4b Electricity Production by Fuel Type
2.5 Electricity Production Increase with Trash at El Viejo Mill

Chapter 3:

3.1 Average Annual Cane Power Benefits
3.2 Annual Cane Power Costs
3.3a Financial Net Present Value Analysis - Base Case
3.3b Economic Net Present Value Analysis - Base Case
3.4a Financial NPV and Capital Requirements
3.4b Ratio of Financial Net Present Value to Capital With and Without Trash
3.5 Best, Base, and Worst Case Analysis of Financial NPV's
3.6 Electricity Price Financial Sensitivity Analysis
3.7a Oil Price Sensitivity Financial Analysis
3.7b Oil Price Sensitivity Financial Analysis - Variable Prices
3.7c Annual Petroleum Savings by Mill
3.8 Trash Price Sensitivity Financial Analysis
3.9 Financial NPV With and Without Trash
3.10 Coal vs Oil Substitution Sensitivity Financial Analysis
3.11 Loan Rate Sensitivity Financial Analysis
3.12 Utility Dispatch Factor Sensitivity Financial Analysis

Appendix A:

A.1 Boiler Efficiency Changes in Response to Moisture Content of Bagasse
A.2 Proportional and Non-Proportional Steam Consumption

Figure
(cont.)

Appendix F:

F.1 Electricity Generating Potential of Cane-Residues-Fired Condensing-Extraction Steam Turbine

F.2 Schematic Representation of a Biomass-Gasifier Steam-Injected Gas Turbine (Biomass-GSTIG) Cogeneration Cycle

F.3 Steam Electricity Production Estimates for CEST and GSTIG Cogeneration Systems

F.4 Estimated Unit Capital Costs for Biomass-Fired CEST and GSTIG Cogeneration System

F.5 Worldwide LM2500 Industrial Installations

F.6 Financial Rates of Return and Annual Electricity exports for Cogeneration and Process-Equipment Investments.

F.7 Estimated Levelized Cost of Generating Exportable Electricity with CEST and GSTIG Cogeneration Systems

F.8 The Current Hydro-Electricity Supply "Trough" and the Sugarcane Milling Season in the State of Sao Paulo, Brazil

Abbreviations

A.I.D.	U.S. Agency for International Development
EV	El Viejo Sugar Mill
IDB	Inter-American Development Bank
kW	Kilowatt
kWh	Kilowatt hour
LAICA	Liga Agricola Industrial de la Cana de Azucar
MW	Megawatt
QA	Quebrada Azul Sugar Mill
TB	Taboga Sugar Mill
USAID	A.I.D. Country Mission

Conversion Factors

1 metric ton (ton)	=	2205 lbs.
1 metric ton	=	1.102 short tons
1 barrel oil	=	42 gallons
1 gallon	=	8.155 lbs.
1 bb. fuel oil	=	42 gals
1 gal. fuel oil	=	8.155 lbs.
Metric ton	=	2205 lbs.

Currency Equivalents
(March 1988)

Currency unit	=	Colones (CRc)
1 US$	=	73.2 CRc

Executive Summary

Overview

The overall conclusion of this report is that the production and sale of electricity for the national grid could be an excellent investment opportunity for the sugar industy of Costa Rica and would provide important benefits to the national economy. Further, selected mills could commence electricity sales soon enough to help the national electric utility handle the surprising recent surge in demand that has materialized at the same time as hydropower reserves have been reduced by drought. Depending on the options selected, the industry could contribute from 17-500 million kilowatt hours of electricity while creating additional jobs in rural areas, diversifying the sugarcane industry into attractive new by-product markets and (in the short term) displacing up to $7 million now spent for imported petroleum. However, there are important uncertainties, or risk factors that need to be addressed. The availability, and cost, of supplemental fuels for energy production in the off-season is of critical importance. The attractiveness of investments in private power production, and the amount of power that mills choose to produce, also depend heavily on decisions by public authorities concerning matters such as loan rates, import duties, and the prices they are willing to pay for power.

This report presents the findings of a team of specialists that visited Costa Rica in May of 1988 to analyze the production and sale of electricity by the sugar industry. The study was sponsored by the United States Agency for International Development and was carried out with the cooperation and assistance of the Liga Agrícola Industrial de la Caña de Azucar (LAICA) and the Instituto Costarricense de Electricidad (ICE).[1]

An earlier report prepared by A.I.D. experts (A.I.D. December 1987) surveyed the overall supply and demand for power in Costa Rica and assessed the prospects for demand management and private cogeneration. In accord with the recommendations of that earlier report, this study focuses on a particular sector, the sugarcane industry, and is charged with evaluating specific investment opportunities.

The study team chose three existing mills (Quebrada Azul, El Viejo and Taboga) to form the basis for its analysis. After visiting the mills and analyzing their power systems and sugar operations, the team then developed technical projections for four

---

[1] The team was composed of the following:
a) Dr. Franklin Tugwell, team leader and energy policy specialist;
b) Dr. Marcia M. Gowen, economist; and
c) Mr. William Kenda, mill/power specialist.
At every stage of its work the team benefited from the generous assistance of representatives of the Government of Costa Rica and the sugar industry. LAICA provided office space and computer facilities. In particular, the team would like to thank Juan José Flores S., General Manager of Banco Continental and Antonio Ruiz M., Sub-Director of the Division of Sugar Cane Agricultural Research and Extension of LAICA for their support, resourcefulness and good humor.

levels of investment and for each level estimated capital costs, electricity production and sales, and fuel options. The technical projections range from the simple sale of surplus power, without any new investments, to the installation of entirely new boiler/turbogenerator systems for year round electricity production.

Finally, to assess the possible risks associated with investments in electricity production, the team prepared sensitivity analyses to demonstrate the likely consequences of variations in such things as interest rates, fuel costs, and electricity sales prices. A key conclusion of these exercises--a point discussed further below--is the importance of domestically produced biomass fuel, principally sugarcane field residues (trash), in permitting mills to produce larger amounts of power at a cost that is competitive with other sources of electricity available to the country.

Extrapolating from the cases analyzed in detail in the report, the Costa Rican sugar industry could, with minimal investment and little or no risk, produce some 17-19 million kilowatt hours per year (the equivalent of 2-3 megawatts annual capacity) for sale to the grid. But this power would be available only during the dry season when the cane is being crushed. This timing is still advantageous to Costa Rica since the dry season is when there is the greatest need for additional generation capacity because of the reduction in ICE's hydro power output. This approach would result in annual petroleum savings from surplus power production of $120,000 to $165,000 per mill studied in this report.

For all-year electricity production, higher capital investments and additional off-season fuel supplies are needed. With supportive public policies on private power sales and larger investments ($9-20 million per mill), the industry might produce as much as 400-500 million kilowatt hours of power per year (the equivalent of 50-55 megawatts annual capacity), with several larger mills providing electricity on a firm basis for the entire year. The value of net national petroleum savings produced by each of these larger mills studied would range from $1.1 to 2.2 million per year, a substantial economic benefit to the country.

The precise pattern of production, of course, would depend heavily on local conditions and the investment decisions of mill owners and managers. In either case, the power produced could be sold at a price at or below that available from alternative new sources of electricity (diesel, gas, geothermal), and would provide additional economic benefits to the nation. Among the latter are increased rural employment and farm income as well as the displacement of imported fossil fuels. The exact amount of power that can be produced, and the extent of national economic benefits, however, both depend partly on the extent to which mills are able to harvest and burn cane field residues or identify other biomass sources of fuel--the major technical uncertainty affecting the prospects for cane power production in Costa Rica.

Investment Options

Table i.1 and Figures i.1 and i.2 summarize the power output and the financial and economic returns for the candidate mills under different technical projections using the "base" case assumptions set by the team. Four levels of investments with different power output options are distinguished in the report:

Table 1.1

Technical Projections of Base Cases for
Sugar Industry Power Production in Costa Rica

Option/ Mill (M US$)	Power Export	Days Produc- (M kWh)	Fuel tion	Technical System Type(s)*	Capital Cost Attributes	Financial NPV (M US$)
Level 1						
El Viejo 1	1.6	121	Bagasse	No changes, 455 psig	0.00	0.82
Q. Azul 1	2.5	142	Bag./hydro.	No changes, 200 psig	0.00	1.10
Level 2						
El Viejo 2	9.6	121	Bagasse	Topping Turbine	1.54	2.86
Level 3						
El Viejo 3	91.9	335	Bag./Oil	Topping Turbine, plus 3 condensing turbines	9.60	2.62
Level 4						
El Viejo 4	101.6	335	Bag./Oil	New System, 850 psig	17.31	-0.09
Taboga 4	104.0	335	Bag./Oil	New System, 850 psig	19.77	2.00

* Sensitivity analyses add trash (cane field residues) to extend electricity production or subsititute cane trash or coal for oil as off-season fuels.

Figure i.1
Financial Net Present Value
Base Case

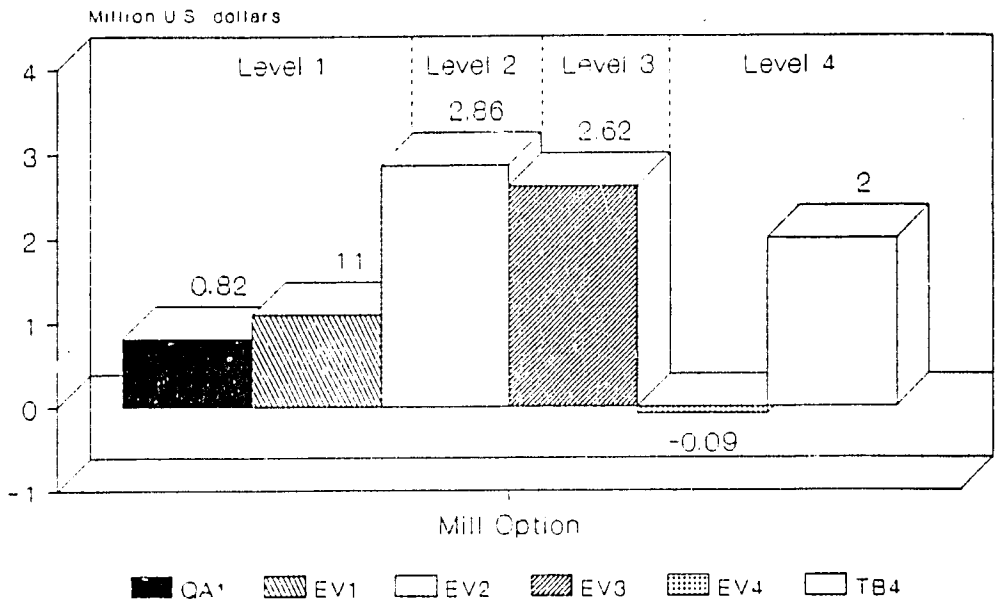
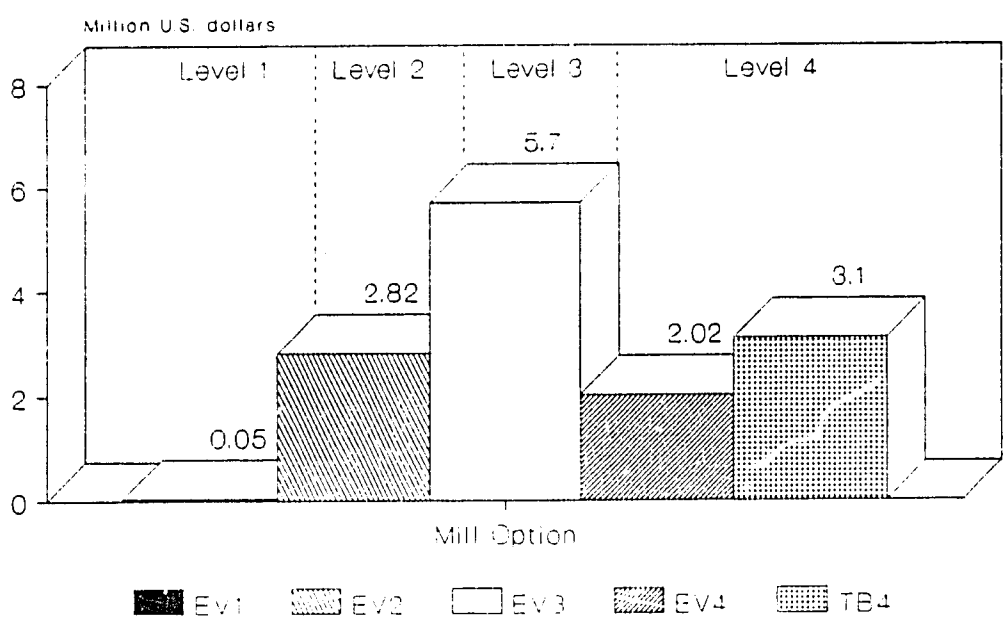


Figure i.2
Financial Net Present Value
With Trash Fuel



Note: The addition of trash fuel reduces the net profits (while increasing power output) of Levels 1 and 2 because costs for the fuel increase total costs more rapidly than increased revenue from the new power sales.

Level 1: no (capital) investment/surplus power option (EV1, QA1),

Level 2: low investment/surplus power option (EV2),

Level 3: medium investment/all-year power option (EV3), and

Level 4: high investment/all-year power option (EV4, TB4).

Both Levels 1 and 2 produce only surplus power during the cane grinding season, with Level 2 extending somewhat beyond the average four months of cane harvesting. Levels 3 and 4 assume year-round electricity production, but as a consequence must rely on supplemental fuels such as trash (cane field residues), purchased bagasse, fuel oil, or coal once the mills' excess on-site bagasse supply is depleted.

As Table i.1 indicates, the Level 1 investment option (EV1 and QA1) is financially attractive even though it results in a relatively small amount of exported power. Because it carries almost no risk--it involves no significant capital investment--it should be seriously considered by any mill in a position to do so in Costa Rica.[2] Petroleum savings to the country are over $170,000 per year for each mill studied.

Level 2 (EV2) is in many respects the most attractive option. It requires relatively little capital ($1.5 million) and extends electricity production slightly beyond the harvest season. Power production is some five times greater than Level 1 and the Net Present Value (NPV) of returns is the highest of all the investment options analyzed.[3] Although this option requires a significant capital investment and involves some risk, it is nevertheless very robust--able to survive a range of changes in electricity sale price, fuel costs, and interest rates. If they can negotiate terms approximating those of the "base case" analyzed here (see Chapter 3), the mills in Costa Rica will want to consider this option as well. Certainly El Viejo itself will find this option worth pursuing. Petroleum savings to the country are over $165,000 per year.

Level 3 (EV3) the medium investment/all-year power option, poses some important dilemmas. Power production, from the same sugar operation, is nearly ten times higher--high enough to make a significant contribution to the national grid. However, the returns to the investor are lower than in Level 2 and the risks are higher because the plant must burn oil when bagasse runs out. Capital requirements ($9 million) are five times greater and the investment is vulnerable to changes in sales price, fuel cost, and interest rates.

---

[2]Risk assessment is based on the "Best, Base, and Worst Case" analysis found in Chapter 3. Mills with low risk retain positive NPV's even in the worst case depicted. Mills with medium risk have negative NPV's in the worst case. Mills with high risk carry positive NPV's only in the best case.

[3]For a discussion of the distinction between financial and economic NPV, see Appendix C.

Because the Level 3 investment buys more efficient equipment, the plant can produce many more units of power per unit of bagasse resulting in a larger net petroleum savings to the country, about $1.1 million per year.[4] Even though the Level 3 plant must use oil for seven months of the year, the costs of bagasse/oil facilities almost always will be lower per kWh than plants fueled only with oil and the economic benefits will be higher.[5]

Note, however, that the addition of the cane field residues for fuel changes the picture dramatically for Level 3 investments (Figure i.2).[6] Using conservative estimates for the costs of this fuel makes Level 3 fully twice as attractive as the projection for Level 2 with or without the use of trash fuel.[7] Inexpensive coal could also be substituted for oil to improve the outlook.

The point here is that investors are unlikely to consider a major capital commitment of the kind involved in Level 3 unless: 1) they receive privileged access to capital and some protection from the purchasing utility against unexpected fluctuations in sales price and in the cost of alternative fuels; and/or 2) they have some assurance that they can obtain inexpensive supplemental fuels especially field residues (or similarly priced biomass fuels), for a significant part of the life of the investment.

The Level 4, "base case" technical projection (EV4 and TB4) appears less attractive than the others. It involves large investments for new boilers/turbogenerators ($17-20 million) and all-year electricity production. Although the availability of trash fuel greatly improves the outcome, and the new power plant would produce more power than is the case with Level 3, the high capital requirements and vulnerability to changes in the world and domestic economy are serious problems. The technical advantage a Level 4 investment has over a Level 3 investment is the ability to respond more quickly and more efficiently to changing steam conditions within the sugar factory.[8]

---

[4]See Chapter 3 for a discussion of economic impacts.

[5]Utility boilers designed to burn oil would be slightly more efficient than boilers designed to burn both sugarcane residues and oil but not so much more efficient as to come close to offsetting the financial and economic benefits that result from installation of modern boilers in the sugar industry that burn sugarcane residues for a significant part of the year. Although this study did not carry out an analysis, the economics of hybrid bagasse/oil facilities may compare favorably with the economics of power plants currently envisioned in the utility expansion plan.

[6]See Table 3.8.

[7]The addition of trash fuel reduces the net profits (while increasing power output) of Levels 1 and 2 because costs for the fuel increase total costs more rapidly than increased revenue from the new power sales.

[8]Steam demand within a sugar factory fluctuates during normal operations. Factory operations can be planned and managed to minimize these fluctuations although some variation will still occur. The Level 4 plant will automatically respond to changes in steam demand in the factory. Good planning and management in the sugar factory should allow Level 3 performance to approach the performance of Level 4 although the risk of reduced performance due to unexpected and unavoidable events is greater for Level 3.

The study team did examine one variation of the Level 4 technical projection (TB4) that appears attractive, but it is premised on the ability to expand the availability of bagasse fuel by importing it from a number of nearby mills. If, in addition to field residues or purchased bagasse, the mill could obtain inexpensive coal for use in the off-season, a Level 4 investment would become very attractive.

These findings, taken together, suggest that sugar mills in Costa Rica should seriously consider entering the power business--provided, of course, that ICE chooses to purchase their product on acceptable terms. To those that do, the team recommends an incremental approach: producing power from excess bagasse while exploring supplemental fuel resources, and then, if appropriate, investing in equipment needed for higher levels of production. Sales of surplus power to the grid, with little or no investment, would provide small amounts of valuable electricity in the season of peak demand and accustom mills and the utility system to this form of cogeneration. Mills with the necessary technical configuration might then want to install a topping turbine, while at the same time experimenting with the collection of field residues and reviewing the use of biomass fuels or imported coal. If supplemental fuels prove available at low enough cost, and if an appropriate contract can be obtained from the utility for full-year, firm power, selected mills might then want to move to Level 3 or 4 investments.

To facilitate the development of electricity generation and sale by the sugar industry, the team recommends that the parties at interest establish a fund that would provide financing--if possible, on concessionary terms--for feasibility studies and capital investments to mills seeking to enter the market. The eventual pattern of power production that develops is likely to be quite diverse, with some mills producing only small amounts of power and others investing in more extensive production capacity. As indicated above, Level 2 investment at El Viejo appears so attractive that mills will almost certainly want to consider it seriously. But overall, the financial and economic benefits of private power production are so significant that steps to begin serious and detailed planning for investments in this sector seem very much in order.

Policy Considerations

The technical and economic incentives favoring electricity sales by sugar mills are strong. The development of private power for Costa Rica, however, will require supportive public policies of several kinds. As noted, the character of these policies will determine both the amount of power that private investors will choose to produce, and the extent of national benefits stemming from this new form of economic activity. The areas that must be addressed include the following:

(1) Sales Prices

To attract private investment to power production, the government should agree to buy electricity at prices that reflect the utility's marginal electricity generating costs--what are generally referred to as "avoided" costs. Whether mills receive prices that reflect avoided fuel costs or avoided capacity costs, of course, depends largely on the dependability of the electricity that they supply (see Appendix C). In negotiating the terms of sale, private producers may want to seek to tie sales prices to an index of alternative fuels, such as fuel oil, with escalators and floors to ensure equitable returns to the mills and fair rates to the consumers.[9]

(2) Schedules

The utility dispatch factor, the extent to which generating equipment works at capacity, is important in determining the attractiveness of an investment in power production.[10] Mills that can generate power on a firm basis will show better returns on capital than mills that provide intermittent power during peak hours. The higher the dispatch factor agreed to in sales contract agreements, the more likely investors are going to be willing to enter the power sales business.

(3) Financing

Because power sales are for national use, the government may want to consider assuring access to investment capital (domestic or international) on favorable terms. Innovative financing arrangements might also improve the attractiveness of such investments. Arrangements such as third-party financing, "build, operate, transfer (BOT)" deals, and debt/equity swaps, are becoming increasingly common in the power business.

(4) Taxes and Duties

Special consideration by the government regarding import duties and taxes for private power producers may be appropriate, reflecting the fact that private investments directly reduce the need for public sector investment in this area.

(5) Research and Development

Public support for research and development might be appropriate in several areas of technical uncertainty. The first such area concerns the production and utilization of alternative fuels--especially sugarcane field residues and plantation wood. Not only are these materials potentially available in abundance, but their use could displace fossil fuels and make important contributions to the rural economy.

---

[9]The team suggests that negotiators may want to tap the extensive experience of Hawaiian sugar mills and the Hawaiian utilities in setting forth the contractual terms for private power production.

[10]See the sensitivity analysis of dispatch factor variations in Chapter 3.

The second area for research and development is in the uses of gas turbine technology for electricity production. Mounting evidence suggests that an important new set of technical alternatives--involving gasifiers and steam-injected gas turbines--may make the use of biomass resources such as bagasse and cane residues usable at higher levels of efficiency than ever before. Research on these technologies, supported by A.I.D., has stimulated growing interest in this field, and the Costa Rican sugar industry may find it possible to take advantage of this new knowledge (See Appendix F).[11]

The conclusions and policy needs of this study are quite consistant with previous cane power analyses conducted by the Office of Energy for the region. For countries with a substantial sugar industry and the need for additional generation capacity, cane electricity production for sale to the grid should be seriously considered. Few other alternatives offer a utility the ability to bring additional power sources on line in the short run. As shown in this study, the reasons for the lack of existing cane energy projects in the region stem primarily from current policy, rather than technical and financial, barriers. A concerted effort by the utilities and governments to address the need for private power guidelines and the initiation of several projects prove the advantages of using indigenous agro-processing resources for national electricity production.

---

[11] For a recent review of this research, see Appendix F and Robert H. Williams and Eric D. Larson, May 1988, "Aeroderivative Turbines for Stationary Power," Center for Energy and Environmental Studies, Princeton University.

Chapter 1

Background

The Costa Rican Economy

The Costa Rican economy has turned a corner since the early eighties. It is now following a steadier path towards economic recovery. GDP growth, which fell to a negative 7.3% in 1982, grew on average from 1984-86 at 4.2% in constant prices. Inflation dropped to 15% in real terms in the same period, down from 82% in 1982. Real income is rising again, approaching 1975 levels. Over the last two years, surges of 60% and 80% occurred in non-traditional agricultural and manufacturing exports, respectively. This foreshadows important structural changes in the economy towards an export-led recovery that has been heralded as key to successful long term development.

The Government of Costa Rica (GOCR) and external donors worked closely together in recent years in an effort to decrease the country's debt burden through structural reform and economic assistance. Large flows of donor assistance helped Costa Rica meet or reschedule its financial obligations, and crucial export-led reforms are bringing in more foreign currency to the country. Central Bank losses and basic commodity subsidies have been reduced significantly, the latter dropping by almost 50% from U.S. $31 million in 1984 to U.S $15.5 million in 1987.

Despite these healthy signs, the Costa Rican economy has suffered chronic foreign exchange shortages, with balance of payments losses averaging $385 million annually from 1984 to 1987. In its successful efforts to broaden its economic base, the country has incurred massive debts due, in part, to rapid expansion of imports. Costa Rica has only limited additional capacity to reduce imports if the country plans to continue increasing nontraditional exports. A recent World Bank study found that few import subsititution options still exist in the economy, since three-quarters of the country's imports are now used as intermediate goods in manufacturing (World Bank 1986).

Consequently, Costa Rica is faced with maintaining a delicate balance in its economy. It is attempting to continue expanding exports at projected rates of 35% per annum, to generate foreign exchange, while also decreasing its public sector debt. The government promoted competition in the financial sector recently by permitting the opening of private banks. Most of the country's financial arrears is held by national banks, with over 70% of the banks' portfolios in arrears beyond 3 months as compared with only 2% in the newer, private banking system (Ministry of Finance 1987).[1] To foster greater competition in its economy, the Costa Rican Government recently initiated efforts to "democratize," or convert to cooperatives, some public sector industries where financially and politically feasible.

---

[1] Private banks have greater restrictions on levels and length of lending.

In summary, the country is faced with steady growth and structural changes in the agricultural and manufacturing sectors combined with new efforts to privatize appropriate industries. Against this is posed a tenacious debt. If economic growth continues, Costa Rica will confront strong demand for expansion in its electric sector.

Electricity Demand: Implications for the Economy

Costa Rica must increase its baseload electrical capacity due to the unexpectedly rapid growth in demand as well as the recent drought that has seriously reduced its hydro generation during the dry season (A.I.D. December 1987). Future electricity demand in Costa Rica will affect the economy by (1) requiring high capital investments, and (2) creating persistant losses to the government if revenues are unable to keep pace with rapidly rising generation and operating costs.

The Government of Costa Rica projects that it will need an estimated $1.67 billion to double its generation capacity to 1,700 MW by 2005 (A.I.D. December 1987). While plans exist for tapping indigenous geothermal potential by 1992 and coal after 2000, near term demand can only be met by an expansion of petroleum-based thermal generation. Both ICE's short term and long term expansion plans in diesel and geothermal will require a large infusion of outside capital and, as a result, a heavy outflow of foreign exchange.

Revenues produced under the current tariff structure are insufficient to pay for escalating electricity generation and operating costs. In 1986 the national utility reported losses (A.I.D. December 1987). By ICE's calculations, thermal-based electricity expansion will incur fuel costs alone that are estimated at 6¢/kWh, as contrasted with current industrial tariff rates that average 4-7¢/kWh. Already tariffs have been pushed up at the rate of 17%, 15% and 22% in 1985, 1986 and 1987, respectively, to keep pace with inflation. If ICE builds three new 36 MW thermal systems, as planned, the country will be incurring high costs. Currently, it estimates cost for existing units at over 7¢/kWh for diesel-gas generation and 5¢ kWh for bunker-C based generation.

The government is quite open to the possiblity of exploring new energy alternatives that reduce public debt and recurrent costs. Given Costa Rica's current debt and balance of payments problems, it wants to minimize further oil imports. The country is looking for indigenous energy solutions that make the best use of its limited investment funds. In a recent study (A.I.D. December 1987) that compared power generation costs from alternative fuels, estimated costs for cane energy rated highly favorably against the utility's alternatives currently under consideration (Table 1.1). This report, based on a more intensive investigation of specific cases, supports the conclusions of that earlier survey.

Table 1.1

A Comparison of Estimated Electricity Generation Costs by Fuel and Type of Producer

Production Fuel	Capacity (MW)	Project	Year	Energy (GWh) Firm	Energy (GWh) Average	Investment Cost (US$/kW)	Cost Without Fuel* (US¢/kWh)
ICE's Expansion Plans[1]							
Hydro	96	Ventanas Garita	1987	373	516	-	NA
	32	Sandillal	1993	140	140	1,421	4.0
	24	Toro I	1994	72	18	947	2.4
	66	Toro II	1994	189	315	529	1.4
	177	Angostura	1996	664	996	1,500	3.3
	154	Siquirres	1998	630	760	1,765	4.4
Gas	32	Gas Turbine	1989	224	224	627	NA
	64	Gas Turbine	1990	448	448	627	NA
	32	Gas Turbine	1991	224	224	627	0.9
	32	Gas Turbine	1992	224	224	627	0.9
	64	Gas Turbine	1995	448	448	627	0.9
Geo.	55	Miravalles I	1991	389	389	2,179	4.4
	55	Miravalles II	1993	389	389	1,743	2.9
	55	Miravalles III	1997	389	389	1,743	2.9
	55	Miravalles IV	1999	389	389	1,743	2.9
Coal	125	Carbon	2000	723	723	1,587	3.7
Diesel-	-	Current	1988	-	-	-	9.0
Thermal	36	Expected	1989	-	-	-	7.0
Estimates for Alternative Fuels[2]							Total Costs
Cogen.	3	Option	1989-91	-	-	-	3.2-8.6
Sugar	90	Option	1989-91	-	-	-	2.0-5.6
Micro-Hydro	200**	Option	1989-91	-	-	-	3.4-6.8
Geo.	4-700	Option	1992-99	-	-	-	6.0-7.0

* ICE's estimates include only fixed operational and O+M costs; no fuel costs are included; Hagler, Bailly values reflect total production costs.

** Between 500kW and 5,000 kW systems.

[1] Source: ICE projections, April 1988.

[2] Source: A.I.D./Hagler Bailly December 1987.

The Sugar Industry and Electricity Production

The Costa Rican sugar industry faces a healthy domestic market, with annual demand growing at 3% per year on average. As contrasted with many countries in Central America and the Caribbean, the industry is not heavily dependent on international markets. In 1986-87, over seventy-five percent of total production was consumed domestically. The country exported only 23% of total production.

The sugar industry, like that of other countries, is undergoing structural changes due to shifts in the comparative advantage of different crops and land uses within the country. Given consistantly low world prices (7-9 US¢/lb) and domestic production costs averaging 11-14 U.S. ¢/lb, the sugar industry prefers to sell internally where the market has been expanding at 3% per year and prices are set at 17 US¢/lb. The majority of these returns (63%) flow back to cane growers, which are still predominantly small landholders in Costa Rica. Only 37% of the market price goes to the 22 sugar processors. Marketing and payments are handled by the sugar marketing cooperative, LAICA (Liga Agricola Industrial de la Cana de Azucar).

In the 1986-87 season, twenty-two mills in Costa Rica produced 2.35 million metric tons of cane, down slightly from 2.48 million metric tons in 1985-86. As shown in Table 1.2, the majority of cane (49%) is grown in the Guanacaste region. LAICA projects continued increases in national production, with the market shares of domestic consumption and exports remaining at similar levels over the coming five years.

In terms of relative importance, the sugar industry constitutes the third largest traditional agricultural crop in Costa Rica. It comes behind only coffee and bananas in total value added to the economy and almost ties bananas as the second largest employer in agriculture. In 1986, direct revenues from sugar represented almost 7% of the total value-added earned from traditional agricultural crops and 2% of total export earnings. Sugar processing provided over 14% of the total agricultural worker hours in 1986 (Table 1.3). Sugar, coffee and banana crops are generally complementary, using the same workers, but at different times of the year. With the zafra or harvest season lasting only 100-120 days (up to four months) during the dry season, a large portion of the agricultural labor force is composed of workers who switch between crops.

Electricity production from the Costa Rican sugar industry holds the potential of relieving a portion of public sector electricity debt and, possibly, saving scarce foreign exchange that otherwise would be required for thermal expansion. Further, cane energy production from excess mill bagasse (Figure 1.1) can diversify and strenghen the agro-processing sugar industry in the country. The sugar industry can best survive intense competition in the international sweetener market by exploring additional co-products (Brown 1986). The Hawaiian sugar industry currently obtains 20% of its profits from energy sales. If the sugar industry in Costa Rica can provide electricity to the grid at or below the utility's expected long-run marginal costs, the country should foster such investments.

Table 1.2

Cane Production by Mills and Region in Costa Rica

Region/Mill	1986-87 (MT)	1985-86 (MT)
Mesa Central		
Argentina	84,654.77	83,111.36
Costa Rica	85,601.39	85,489.27
El General	71,093.76	61,434.24
Esmeralda		16,782.05
La Hilda	15,229.98	16,826.24
La Luisa	20,236.17	19,789.98
Ojo de Agua	34,594.03	35,424.57
Porvenir	47,695.68	50,610.27
Providencia	48,219.46	48,975.82
San Ramon	35,813.83	29,131.06
Victoria	206,168.36	200,991.86
SUBTOTAL	649,307.43	648,566.72
Pacific Coast		
El Palmar *	279,014.84	295,666.97
El Viejo *	248,520.75	248,239.77
San Gerardo	13,393.89	18,643.69
CATSA	225,317.40	327,019.01
Taboga *	296,491.89	326,147.42
SUBTOTAL	1,062,738.77	1,215,716.86
Atlantic Slope		
Cutris	63,699.31	51,528.42
Queb. Azul *	157,983.76	139,595.32
Santa Fe	57,887.33	61,825.51
SUBTOTAL	279,570.40	252,949.25
Atirro	159,216.17	159,102.86
Florencia	67,845.21	66,783.55
Juan Vinas	138,501.00	141,233.55
SUBTOTAL	365,562.37	367,119.96
TOTAL	2,357,178.96	2,484,352.79

*Mills selected for field visits.

Source: Liga Agricola Industrial de la Caña de Azucar. 1988. Informe de Labores: Perioda 86-87. San Jose, Costa Rica.

Table 1.3

Agricultural Production, Value Added and Employment in Costa Rica

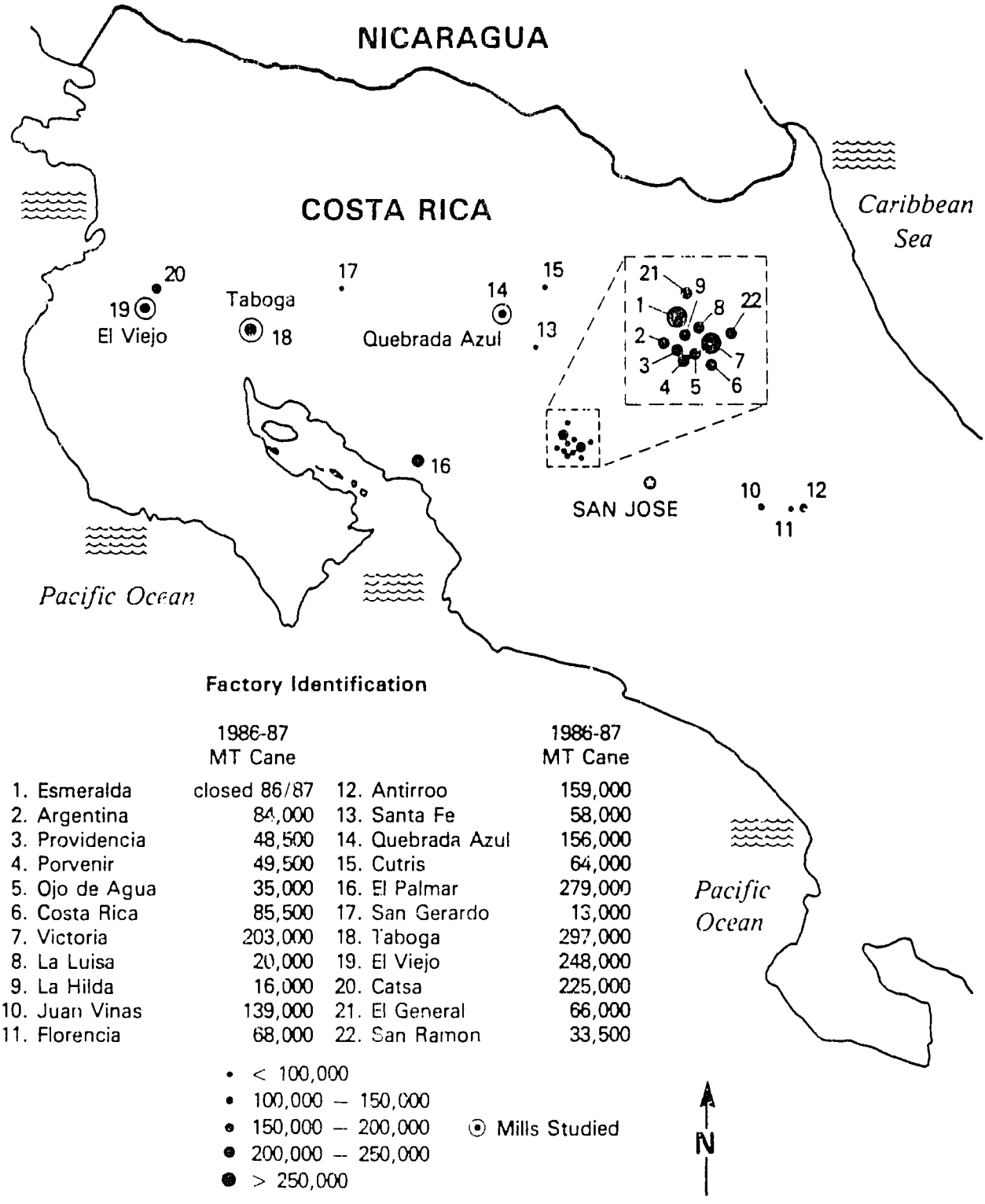
(1987)

Crops	Value Added (%)	Export Value (M US$)	Export Value (%)	Employment (%)
Traditional Agriculture	100	641.8	58	100
Sugar	5	16.9	2	14
Coffee	28	330.0	30	43
Bananas	21	237.7	21	15
Other*	46	57.2	5	28
Non-Traditional	NA	471.8	42	NA
Total	100	1113.6	100	NA

* Includes meat products.
NA = Not Available
Source: Departamento de Contabilidad Social.

FIGURE 1.1

Zones of Sugar Production and Factory Locations in Costa Rica



Factory Identification

	1986-87 MT Cane		1986-87 MT Cane
1. Esmeralda	closed 86/87	12. Antirroo	159,000
2. Argentina	84,000	13. Santa Fe	58,000
3. Providencia	48,500	14. Quebrada Azul	156,000
4. Porvenir	49,500	15. Cutris	64,000
5. Ojo de Agua	35,000	16. El Palmar	279,000
6. Costa Rica	85,500	17. San Gerardo	13,000
7. Victoria	203,000	18. Taboga	297,000
8. La Luisa	20,000	19. El Viejo	248,000
9. La Hilda	16,000	20. Catsa	225,000
10. Juan Vinas	139,000	21. El General	66,000
11. Florencia	68,000	22. San Ramon	33,500

- < 100,000
- 100,000 – 150,000
- 150,000 – 200,000
- 200,000 – 250,000
- > 250,000

⊙ Mills Studied

Chapter 2

Power Plant and Fuel Options

Introduction

As noted earlier, the primary objective of this study is to evaluate a range of investment options by which the Costa Rican sugar industry might begin commercial production of electricity for the national grid. To achieve this objective, the study team selected technical projections for four levels of investment and for each level estimated capital costs, expected electricity production, and fuel options.[1] These projections range from the simple export of surplus power, without new investment, to the production of much larger quantities of electricity following the purchase and installation of completely new boiler and turbogenerator systems (see Table 2.1). The economic and financial analysis in Chapter 3 assesses the costs, benefits, and risks associated with each technical projection.

The Mills

The team chose three existing mills to form the basis for its analysis of investment alternatives. These are the El Viejo and Taboga mills in the Guanacaste area and the Quebrada Azul mill in San Carlos. The mills were chosen on the grounds of: 1) technical suitability, including size and location; 2) availability of data; and 3) the expressed interest of management in electricity production.

This analysis focuses primarily on the El Viejo mill as representative of Costa Rica's larger mills with good technical potential for power export.[2] The team included Quebrada Azul because it is a small mill with excess bagasse fuel and because the small hydro installation on site enlarges the mill's electricity export capacity. Although Taboga in most respects resembles El Viejo, its location close to supplies of supplemental fuel (bagasse transported from other locations) makes it a better model of large-scale power production using these resources.

---

[1] As discussed below, these four projections were selected from more than a dozen options possible on the basis of technical appropriateness for the specific mills analyzed, efficiency in steam utilization and financial attractiveness.

[2] The El Viejo mill has already purchased--but not yet installed--a used, 455 psig boiler for its operations. In this respect it may be more technically "ready" for power export than other mills.

Table 2.1

Technical Projections
Sugar Industry Power Production in Costa Rica

Option	Power Export (Million kWh)	Days Production	Fuel Type(s)	Technical System Attributes	Capital Cost (Million US$)
Level 1					
El Viejo 1	1.6	121	Bagasse	No changes, 455 psig	0.00
Q. Azul 1	2.5	142	Bag./hydro. Trash*	No changes, 200 psig	0.00
Level 2					
El Viejo 2	9.6	121	Bagasse Trash*	Topping Turbine	1.54
Level 3					
El Viejo 3	91.9	335	Bag./Oil Trash, Coal*	Topping Turbine, plus 3 condensing turbines	9.60
Level 4					
El Viejo 4	101.6	335	Bag./Oil	New System, 850 psig	17.31
Taboga 4	104.0	335	Bag./Oil Trash, Coal*	New System, 850 psig	19.77

*Cane trash or coal are substituted for oil in the fuel sensitivity analyses. Capital costs are for incremental power plant investments.

Efficiency Improvements

For each of the mills examined there are important opportunities for efficiency improvements that, by conserving steam for power production, would make good economic sense if the mill were to begin selling electricity. With the exception of Level 1 projections (no investments, low power production), the technical projections presented in this study assume that candidate mills take advantage of these opportunities, and, where applicable, the capital estimates include these costs associated with improving mill and power plant efficiencies. Appendix A presents a brief overview of the factors affecting efficient steam production in sugar operations; it may serve as a general guide to the kinds of modifications assumed in the technical alternatives described below.

Technical Projections

In order to depict a variety of cogeneration opportunities for the Costa Rican sugar industry, the team choose technical configurations that range from the simple sale of surplus power by small and medium-sized mills up to the construction of a complete new boiler-turbogenerator system for year-round electricity production. The four levels chosen represent specific mill/power plant configurations of increasing complexity and expense, and were prepared to allow prospective investors to compare the costs and benefits associated with a range of options.

Because sugar mills differ significantly, the precise capital investments recommended by the team--summarized in Appendix B--were necessarily tailored to individual sites. The modifications and new equipment suggested represent changes at each mill designed to optimize steam use for electricity production while maintaining productive sugar options and minimizing investment costs.[3] A special concern was the efficient utilization of steam during the unavoidable periods of mill downtime associated with the crushing season.

The specific modifications detailed below represent the best judgments of the team as to how to achieve these objectives, using specific cooperating mills as case studies, while illustrating the costs and benefits of several levels of investment and

---

[3]The team analyzed, but then rejected as financially unattractive, more than a dozen additional mill/power plant configuration. These included, among other things, Bagatex 20 processing and flu-gas drying of bagasse. Two turbogenerator configurations, in particular, would be of interest at El Viejo mill should lower capital costs be realized (perhaps by the purchase of used equipment). One is a 455 psig inlet pressure single extraction (200 psig) and condensing at 2 or 3 inches of mercury unit acting as a topping turbine with the existing back pressure turbogenerators and mill drives. The second is small 200 psig condensing turbogenerators operating in parallel with existing units. Low pressure (15 to 25 psig) turbogenerators condensing at 3 inches of mercury absolute were also considered from the standpoint of acting as power generating heat-sinks for existing sugar factory exhaust steam pressure (15 to 25 psig) systems.

power production. In suggesting new mill configurations, the team took into consideration, among other things, the age and general condition of existing equipment, the record of mill performance, site-specific fuel options (such as the likely availability of imported bagasse or coal) and managerial constraints of various kinds.[4]

Where these judgments might differ from those of other industry experts--as, for example, in the choice of an 850 psig boiler rather than a 1200 psig boiler in Level 4--the text or notes in the following technical descriptions present the team's rationale.

Note, all options presented in this report assume that the utility will allow the mill to dispatch power from the mill power plant to the grid in such a way that the mill can generate the maximum power possible under prevailing steam and power usage conditions in the sugar factory. The dispatch terms of the contract between the utility and the sugar factory are important to the success of sugar mill cogeneration investments because they affect the cost and efficiency of electricity production. Power available for dispatch will vary--for example from in-crop days to off-crop days--but such variability can be scheduled. If utility managers force the mill power plant to reduce power output below optimum for the factory, the efficiency of power production at the mill will drop. (See Chapter 3 for sensitivity analysis.) For example, if the amount of power sent to the utility is decreased to 60% of the optimum, the steam rate per kWh generated could increase from 25% to 50 percent. This, in turn, decreases the kWh generated per unit of fuel.

Level 1: No New Investment, Low Surplus Power Production (El Viejo 1, Quebrada Azul 1)

The first technical projections involve the use of excess bagasse to produce electricity during the milling season and, where sufficient bagasse fuel is available, for short periods after the mills stop grinding cane. The power thus sold would have a high value to the national grid because it would be available during the dry season when hydroelectric potential is reduced. However, the amount of power available would be small. Of the two cases examined, the larger mill, El Viejo, would be able to sell 1.6 million kilowatt hours over 121 days (El Viejo 1). The mill would operate as it does now but with its new 200,000 lbs/hr. boiler (455 psig, 660°FTT) installed. In addition, steam wastage--currently programmed to minimize the surplus bagasse problem--would be curtailed to reduce consumption of bagasse. In order to keep electricity generation efficient and export to the utility constant during the usual downtime stops for repairs or when cane is lacking, the factory will need to

[4]Note again that the team assumed that equipment added is all new. In practice, interested mills might be able to significantly reduce their investment costs by purchasing used equipment.

cease milling and slow down pan operations; however, the evaporators would need to continue to operate on water at reduced capacity in order to condense steam.[5]

The case labeled Quebrada Azul I represents a second variation on the "no investment" surplus power scenario. Quebrada Azul is typical of a small mill and has higher boiling house steam consumption than the larger factories. With no improvements to the factory except a reduction in steam wastage, Quebrada Azul has sufficient bagasse, boiler capacity and generating capacity to export power to the grid.[6] The mill also has the advantage of an installed 330 kW hydroelectric generator. It would sell 2.5 million kilowatt hours, with about half coming from the on-site hydro facility, over 142 days.[7]

Where small factories, such as Quebrada Azul, have surplus bagasse and excess boiler capacity with a steam generating rate in excess of 2 pounds steam per pound of bagasse, they might consider installing a 625 kW condensing turbogenerator operating at boiler pressure and condensing at 3 inches of mercury absolute. Such a unit would be used to control excess bagasse supply and at the same time develop revenue from the sale of electricity. At 16 lbs/kW steam rate for a 200 psig unit, 10,000 pounds per hour of steam would be required, equivalent to 2.27 metric tons of bagasse per hour. The installed cost of such a unit, including switchboard and other electrical work would be approximately $108,000 in local cost and $404,000 in foreign cost. For 2228 hours of grinding this would provide an additional 1,392,500 kWh of export power and at the same time control the excess bagasse problem.

---

[5]Since the factory has high lost time during the season (due to lack of cane and to equipment breakage), available bagasse must be spread over many downtime hours, as assumed in this study's technical configuration. To produce required steam flows under normal operating conditions (approximately 195,000 lbs. of steam per hour) will require 39.6 MT of bagasse per operating hour, while 49.5 MT are produced each grinding hour. Approximately 2% of the 49.5 MT produced will be lost or used to meet filter bagacillo requirements. Downtime and off-season power production assumes a steam rate of approximately 55,000 lbs. of steam per hour. Exhaust steam will be condensed by evaporating water in the sugar factory evaporators and/or pans. Water required for condensing exhaust steam is assumed to be equal to the maximum maceration capacity of the mill and the capacity of the mixed juice/clarified juice pumping system.

[6]When operating the back pressure turbogenerators (1200 kW and 400 kW) during downtime periods, the 20 psig exhaust steam would be condensed in the sugar factory's evaporators or an empty pan by boiling water. If sufficient water can be delivered to the pan floor, use of pans is preferable.

[7]The study team has assumed that Quebrada Azul would not be able to utilize field residues. This is partly because of the heavy rainfall in the San Carlos area, partly because of the local terrain, and partly because of the need for storage space at the mill. Mostly importantly, the inefficient boiler system greatly reduces the number of kWh that can be produced from a ton of trash making trash use not financially attractive.

Level 2: Low Investment, Medium Surplus Power Production (El Viejo 2)

The second technical projection prepared by the study team assumes the same operating conditions for the El Viejo mill, but includes the addition of a new 3500 kW, 455 psig turbogenerator exhausting at 200 psig. This topping back pressure turbogenerator will exhaust its steam to the existing factory's 1500 kW turbogenerator and to the plant milling turbines.[8]

The addition of the topping turbine, an investment of just over US$ 1.5 million, would allow El Viejo 2 to produce 9.6 million kWh, operating for 121 days.[9] Note that this represents a more than fivefold increase in the power export over Level 1 options (Table 2.1). Should the mill also use the field trash available on its lands as a fuel, it might produce 13.4 million kWh and operate fully 194 days.[10]

---

[8]It assumes that approximately 3-5% of the 200 psig exhaust is used for miscellaneous factory high pressure steam uses. In cases where sugar mill boilers are producing steam at a significantly higher pressure than the throttle steam pressure required by the factory prime movers (turbogenerators, steam engines and mechanical driver turbines) and process equipment, and where there is a market or use for additional power generated, a turbogenerator with suitable steam inlet-outlet pressures can be installed in the power system between the boiler and the existing prime movers to generate additional electricity. Because it is located, in terms of steam pressure, at a higher pressure than the inlet pressure of the existing prime movers, it is often referred to--as it is here--as a "topping" turbine. While most topping turbogenerator installations are back-pressure units, single- and double-extraction condensing turbines can also be used where a power system configuration makes this desirable and/or economical. Note that Quebrada Azul does not have the technical capability, given its boiler system, to upgrade to a Level 2 technical configuration.

[9]The capital costs of this and subsequent technical options are on an installed basis and include a building to house the new generator and switchgear. The step-up transformer (4160 VAC to 13,800 VAC) and step-down transformer (4160 VAC to 440 VAC) would be specified for outdoor installation. Necessary high and low pressure piping plus all insulation are also included.

[10]Depending on the heat tolerance of the mechanical turbines and existing turbogenerators, the steam will undoubtedly have to be desuperheated--the team assumes that El Viejo has already incorporated a desuperheater in its plans for the new 200,000 lbs./hr. boiler.

Level 3: Moderate Investment, High All-Year Power Production (El Viejo 3)

The third technical projection depicts the consequences of adding three 3,750 kW condensing turbogenerators to the mill configuration described in Level 2.[11] The topping turbine would remain the same, with a rating of 3,750 kW (see Figure 2.1). New investments would be made to reduce the boiling house and evaporator steam consumption from 1100 to 975 pounds steam per metric ton of cane per hour and to increase the boiler feedwater temperature from 203°F to 250°F.

Given the capacity of the existing 455 psig boiler and the variable steam demands of the factory, one single or double extraction/condensing turbogenerator could not perform efficiently at the varying power loads and extraction steam flows and still meet the minimum and maximum steam flows required by turbogenerator design in the intermediate and low pressure sections. Analysis determined that three parallel straight condensing turbogenerators could perform relatively efficiently under El Viejo conditions during both in-crop and off-crop periods when operated as indicated in Figure 2.1.

The Level 3 projection involves a major capital investment, approximately US$ 9.6 million, and would produce 91.9 million kWh, over a full-year operating schedule of 335 days. After running out of bagasse fuel, the mill would switch to fuel oil. If cheaper, coal could be used but with increased capital cost to handle, store, and process it. If the mill utilized field trash, it would back out a portion of the imported petroleum or coal and save foreign exchange, but would also slightly increase capital costs.[12]

The three new condensing turbines would operate in parallel after the topping turbine and before the desuperheater and existing mill back pressure turbines. At least two of the condensing units would be kept in an operating or "warmed up" condition whenever the mill is grinding cane. This would enable them to immediately use surplus steam caused by mill stoppage. If a long mill stop is anticipated, due to lack of cane or mechanical breakdown, the third condensing unit would be "warmed up" and started. Figure 2.1 (schematic) shows the operation of the system during "in-crop" grinding hours and during "off-crop" and mill downtime operating hours.

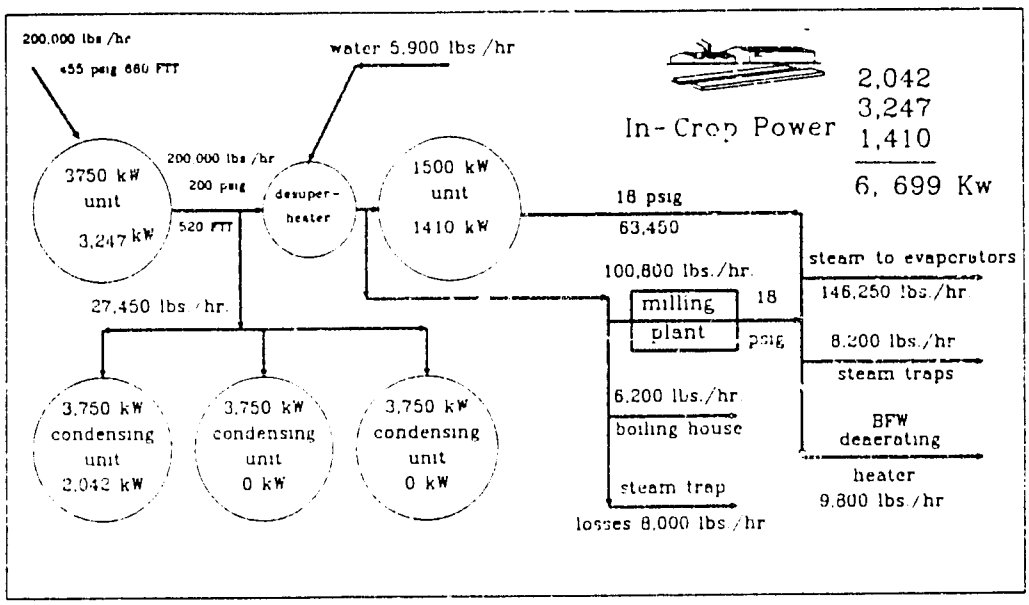
---

[11] These turbogenerators would operate at 200 psig and condense at 3 inches mercury absolute.

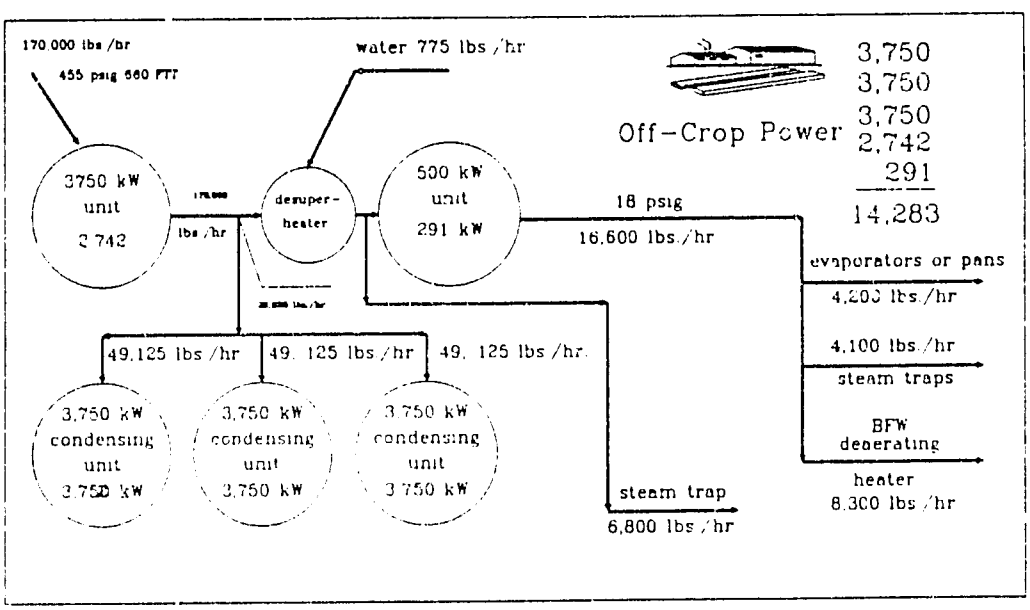
[12] Capital cost increases for using cane field residues are due to the following changes: 1) an increase in baler capacity to 22 tons per hour; 2) installation of a second bale breaker; 3) installation of bale handling payloaders and a bale stacking crane; 4) addition of a 20 acre bale storage area with an adequate vehicle surface, drainage and fire protection system.

Operation During Crop

Figure 2.1
Schematic: Level 3 Technical Projection



Operation Out of Crop



The three new condensing units could also be operated with the existing 200 psig boilers. Having three units adds operating flexibility and security to the sugar factory. In the event of a failure in one single or double extraction condensing turbogenerator, plant operation would cease. The disadvantages are the number of units that need to be operated efficiently and maintained and their inability to immediately adjust to changing steam loads as double extraction condensing units can. The period of time that the overall system would operate at less than optimal efficiency would undoubtedly be greater for three units.

Level 4: Major Investment, High All-Year Power Production (El Viejo 4)

The fourth technical projection envisions the installation of a completely new power system, including a new boiler and a new double extraction condensing turbogenerator, both of which would operate at 850 psig and 825° FTT, condensing at 3 inches of mercury absolute.[13] The new power system would cost a total of US$ 17.3 million installed and would produce 101.6 million kWh during a full year schedule of 335 days.[14]

---

[13]Although a 1200 psig boiler turbogenerator would be more efficient in theory--it would produce 426.6 kWh/ton of bagasse compared to 389.9 kWh/ton for a 850 psig boiler--the higher pressure system poses enough operating problems in sugar power generation to justify choosing the lower pressure. These problems include much more stringent feedwater requirements (the 1250 psig plant in Hawaii uses a demineralizer for feedwater makeup).

[14]The new boiler will have an airheater and an economizer operating on flue gas. The flue gas temperature to stack will be 285°F to 415°F. Air temperature from the airheater will be 360°F to 450°F. Boiler feedwater temperature from the economizer will be 370°F to 400°F. Feedwater entering the economizer will be 340°F. A feedwater heater operating on 200 psig steam will raise the deaerating heater feedwater (250°F) to 340°F. The blowdown will be continuous in the 2% to 4% range and will pass through flash tanks, flashing into the 15 psig system. The boiler will be equipped to fire on bagasse and fuel oil and will have a CAD travelling grate capable of withstanding furnace temperatures generated by 20% moisture bagasse (here and throughout this text moisture content refers to wet basis, or mcwb). It will be equipped with a fly ash arrestor.

Note: A boiler alternative would be to eliminate the economizer and replace it with more boiler feedwater heaters. The airheater would be enlarged to provide air at higher temperature, possibly up to 500°F. The exit gas temperature from the airheater would be higher and consideration could then be given to a Rader two-pass type flue gas bagasse dryer. This would give a bagasse moisture in the 32 to 37% range and the boiler efficiency would be materially improved as would the bagasse combustibility (burnability) when compared to firing 49% to 51% moisture bagasse.

This system, with higher steam pressure and temperature, enables the sugar mill to produce steam more efficiently from bagasse and also enables the turbogenerators to produce more kilowatt hours per pound of steam to the turbine throttle. These two factors plus the ability of the unit to quickly compensate and adjust to fluctuating steam and power loads, both of which are common in a sugar mill, makes it an excellent type of generating unit for a sugar mill. The turbogenerator must be specified so that it can operate efficiently across the wide range of throttle and extraction steam flows found during the in-crop and off-crop periods.

The new turbogenerator would extract steam at 200 psig and 15 psig and be able to operate in full condensing mode with minimum extraction flows when the vacuum is 2 inches mercury absolute. The unit would be rated at 19,500 KVA at 0.8 PF or 15,600 kW. It would be housed in an enclosed building having a positive airpressure and roof ventilator. The building would have a bridge crane and the boilers and turbogenerators will have complete instrumentation. Capacitors are budgeted for improving the factory and system power factor.

Bulk bagasse storage capacity sufficient for 24 hours operation (960 metric tons) would be installed with automatic storing and discharging. A bagasse baler and a bale breaker for surplus bagasse would also be included.[15] The installed cost of the baling system (included in the overall capital estimate) is approximately US$ 135 thousand.

The boiling house and condensate return system would have equipment added to improve steam economy and recover heat from all condensate points. Multiple condensate storage tanks would be provided for condensate contamination testing and for reserve storage. A deaerating feedwater heater and a small feedwater makeup evaporator would be installed for off-season use. The evaporators would be converted to quintuple effect units with flash pots and primary, secondary and tertiary juice heating with vapor. A minimum of four additional 2,000 square foot juice heaters would be added to the system. The vacuum pans would continue to operate 100% on first cell vapors.[16]

As with Level 3, the improvements envisioned at El Viejo should reduce the sugar factory's boiling house and evaporator steam consumption from 1100 lbs. per metric ton of cane per hour to 975 lbs., and possibly lower. The boiler feedwater temperature would be increased to 250°F prior to the boiler feed pumps.

---

[15]The type proposed is an AMBACO Model BH "Auto-Tie" Hole Baler with a 6 inch diameter vent hole similar to the one at PROAGRO in El Salvador.

[16]The shift from a quadruple to a quintuple effect evaporator in the sugar factory improves energy performance by about 10 percent.

Level 4: Major Investment, High All-Year Power Production (Taboga 4)

The last technical option (TB4) is included in order to depict a hypothetical case in which a conveniently located larger mill, such as Taboga, could draw on surplus fuels available at mills close enough to make transport economically feasible. The technical system envisioned is the same as that described in Level 4 for El Viejo (EV 4): a completely new, high-pressure boiler and turbogenerator.[17] The investment of over US$ 19 million would enable the export of 104 million kWh of electricity to the national grid.

The bagasse fuel supply system of TB4 would have the following characteristics:

a) One large AMBACO BH "Auto-Tie" Hole Baler (22 MT Bagasse/hr.) would be installed in the Meseta Central mill in the Grecia area having the largest amount of surplus bagasse. Surplus bagasse from other mills in the area would be hauled in bulk to this central baling station, and the baled bagasse would be shipped immediatly to Taboga for storage until needed in the off-season. The baled bagasse will decrease in moisture to 20% after 90 days storage at Taboga.[18]

b. Surplus bagasse from the El Palmer mill would be hauled in bulk to Taboga where it would be baled and stored.[19]

---

[17] The Taboga boiler will differ in that it will have a maximum continuous rating of 250,000 lbs. of steam per hour, and will be equipped to fire bagasse, fuel oil and/or coal. The efficiency of the boiler firing coal will be 84.6% and fuel oil 86.9%. Bagasse could be fired simultaneously with either fuel oil or coal. The added steam capacity of the Taboga boiler will increase costs about $1.5 million. The coal receiving, storage, conveying and firing equipment used in the fuel sensitivity analysis (Chapter 3) adds at least $850,000 to the base EV4 cost. The design of the CAD travelling grates, firing chutes, distribution rotors and combustion air distribution for coal firing must allow for the differences in the combustion characteristics of the two fuels, coal and bagasse, which may or may not be fired separately during plant operations. Modifications of existing bagasse burning boiler plants of similar size to burn coal and bagasse both separately and simultaneously have cost in excess of $1.2 million, which indicates the complexity of designing or redesigning a boiler to burn both fuels.

[18] The Bagatex 20 system was evaluated for use but was found to be too expensive as the one-time licensing cost to treat 150,000 metric tons of bagasse would amount to US$ 512,250. The only advantage of the Bagatex 20 treatement is that 20% moisture content is reached in 20 days rather than 90 days with the hole type baler. Where dry bagasse is needed sooner than 90 days for higher power generation during the dry season, Bagatex 20 may prove to be economically advantageous.

[19] An AMBACO type compactor for densifying bagasse before bulk shipment could possibly reduce bulk shipping costs depending on the hauling rates for low density bulky material.

The Taboga mill currently has a baler, but the mill would have to set aside approximately 35 acres for storing baled bagasse and cane trash.

As with the earlier technical projections, the Taboga mill can substantially reduce its fuel oil or coal--the former by over 1 million gallons per year--requirements by firing cane trash from its own fields as well as bagasse imported from other factories.

Power Production Projections

Although it is clear that each mill in Costa Rica choosing to sell electricity will have to analyze its technical system and configure its boiler/turbogenerator system according to its own needs and circumstances, it is possible to determine a rough range of production possibilities on the basis of the technical projections described here. If the various mills were to export electricity at Level 1, the annual total from the industy would range from 17-19 million kilowatt hours. If in addition to this lower level production by the smaller mills, the five largest mills were to produce at the more efficient Level 3 represented by the higher investments of EV3, the annual total production from the industry would range from 400-500 million kilowatt hours. Although these are very rough estimates, they do help illustrate the range of power production that might realistically be expected from differing investment patterns, even without the installation of any entirely new boiler/turbogenerator system of the kind hypothesized for Level 4.

Supplemental Fuels

Because they permit the production of electricity for a more extended period after the end of the crushing season, supplemental fuels are extremely important to the financial success of many cane power investments. The cost of electricity production and the number of kWh produced per ton of bagasse at each level of investment are shown for El Viejo in Figure 2.2 and 2.3. To make the larger investments financially attractive, the mill must produce power throughout the year. Year-round production greatly improves capital utilization and permits the negotiation of contracts with the utility that pay both avoided fuel and capacity charges to the sugar factory.[20] But year-round production requires supplemental fuels. The fuels examined for this study from least to most expensive are: a) purchased bagasse; b) cane field residues (also called trash); c) plantation wood; d) fuel oil; and e) coal.

Because Costa Rican mills currently use fuel oil as a supplemental fuel, and because the other proposed fuels are either new to these mills or require several years to develop, the "base case" economic and financial analysis assumes that the mills will use fuel oil after they run out of bagasse. Sensitivity analyses in Chapter 3 review the economic and financial attractiveness of using fuel oil at different prices. Figures 2.4a and 2.4b show how much of the electricity sold to the utility will be produced from each type of fuel under the scenarios presented in this report.

---

[20]See Appendix C for an explanation of the distinction between these charges.

Figure 2.2
Electricity Production Cost
El Viejo Mill

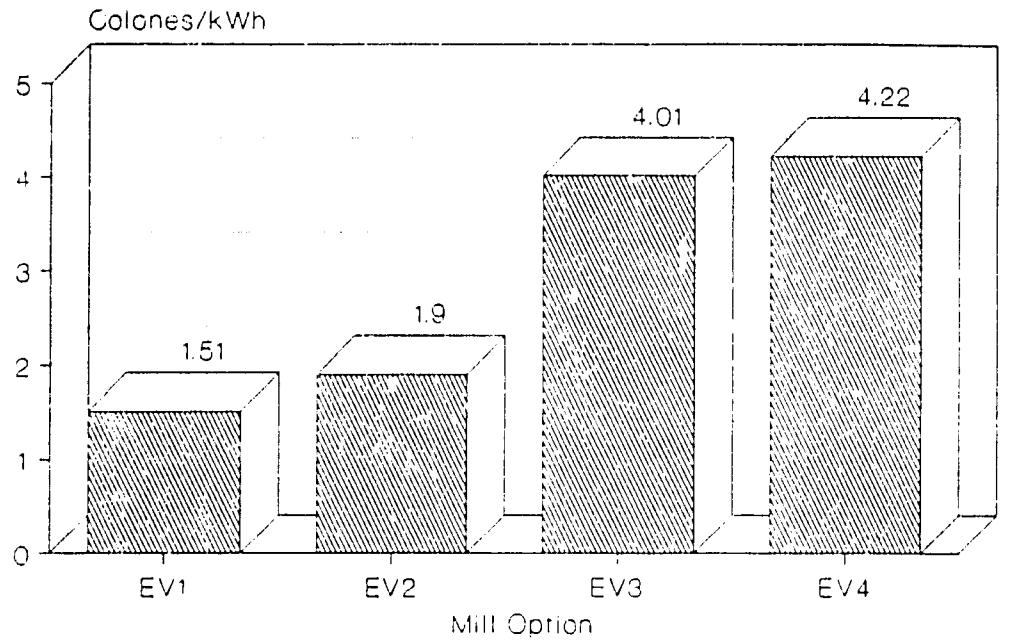


Figure 2.3
Kilowatt Hours Per Ton of Bagasse
El Viejo Mill

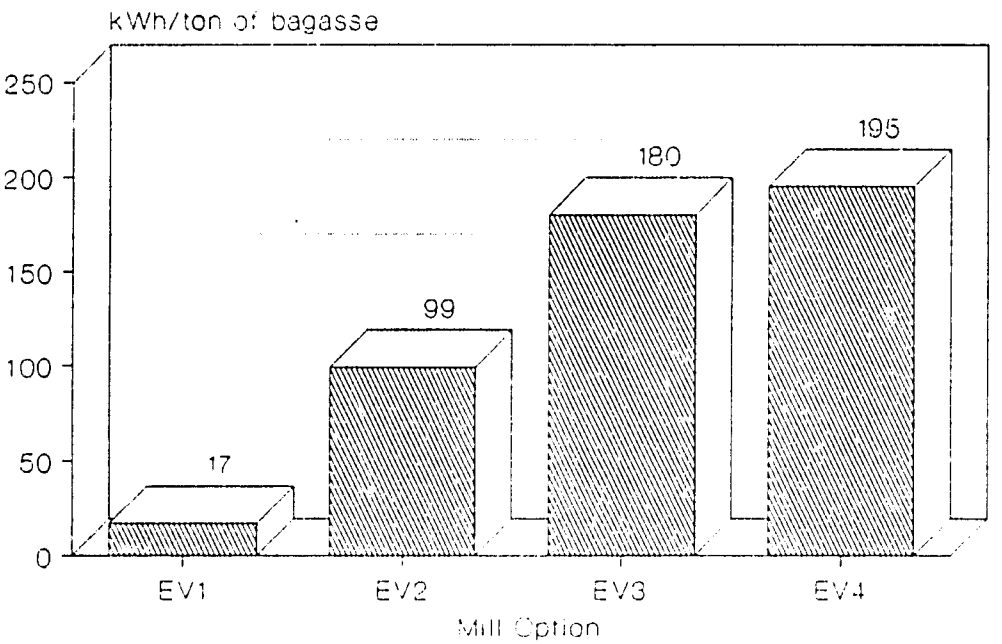


Figure 2.4a
Electricity Production by Fuel Type

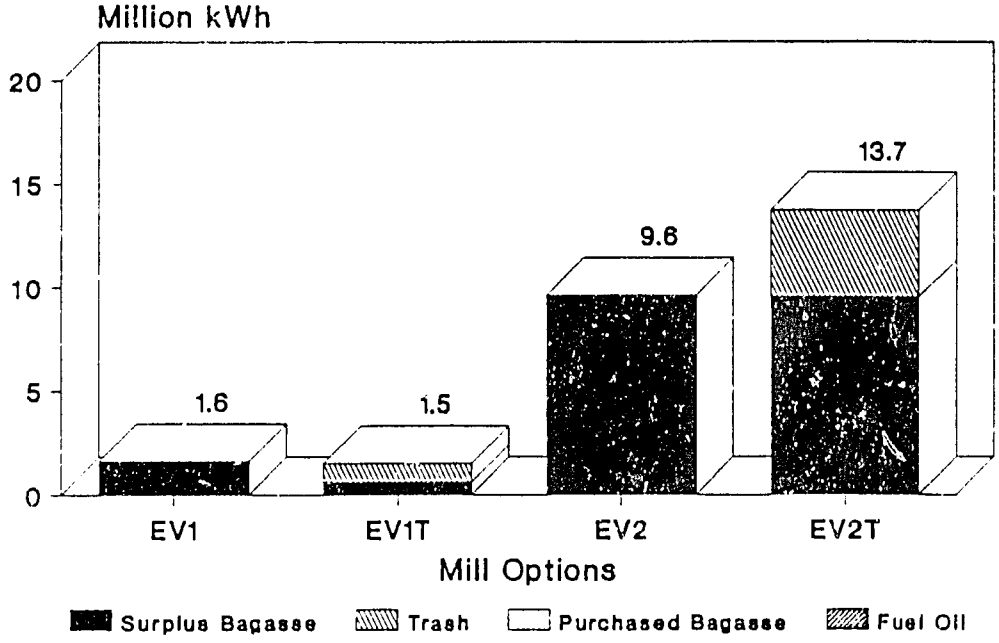
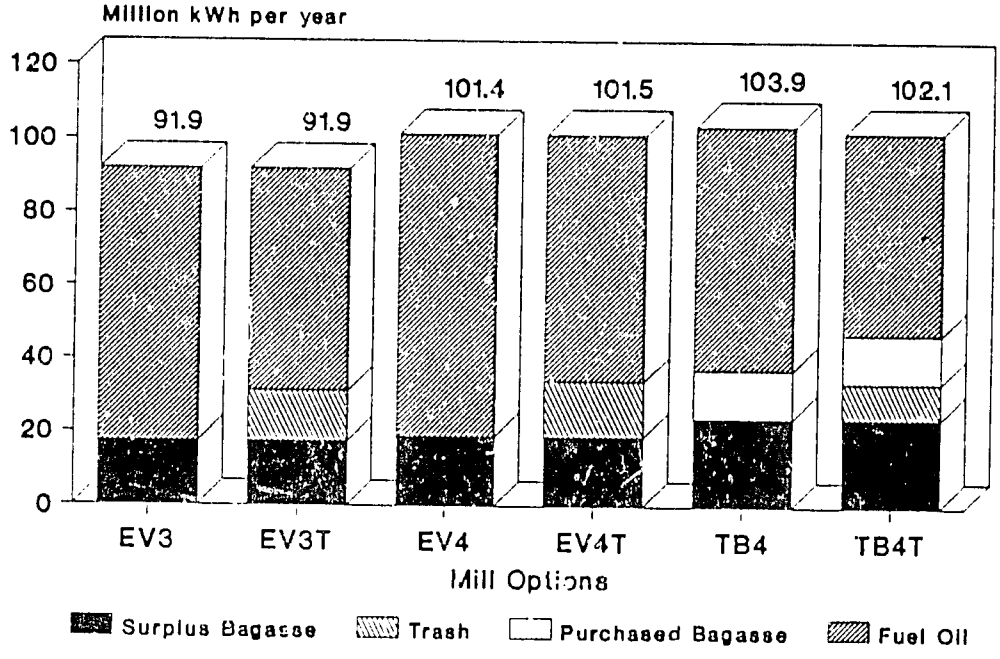


Figure 2.4b
Electricity Production by Fuel Type



Purchased Bagasse

The Level 4 projection for Taboga includes analysis of purchasing waste bagasse from nearby mills to replace oil during off-season operation. Bagasse could be transported and stored in wet or baled form with baling and storage facilities at one or several mills. The case labelled TB4 includes capital costs for bagasse baling equipment and storage facilities for the Taboga Mill and one other mill in the Mesita Central area. The estimated cost for a ton of purchased bagasse is 276 colones (US$3.65) MT, including 146 colones (US$2) paid to the contributing mill and a transport cost of 6 colones per kilometer for an average distance of 20 kilometers.[21]

Cane Residues (trash)

An accumulating body of experimental and practical evidence suggests that cane field trash is an important but neglected resource, one that appears to be the least cost fuel for combustion, after mill bagasse, in many locations around the world.[22]

(a) Trash Quantities

The precise amount of fiber available from cane trash can be expected to vary with plant varieties, climate and soil conditions, cultivation procedures, and harvesting practices. Available evidence suggests that where the cane is hand harvested without burning, the fiber in the trash can be expected to equal or exceed that which reaches the mill in the harvested stalks.[23]

---

[21] In practice, the payment for the contributing mill might be waived, since the disposal of excess bagasse is often a problem for which a mill must expend funds.

[22] The La Romana Mill in the Dominican Republic currently harvests cane trash for use as a feedstock in the production of the chemical furfural. Commercial harvesting of residues for boiler fuel is now practiced at the Tarlac Mill in the Philippines. A recent review of this evidence is available in the published results of the A.I.D. Cane Energy Symposium held in April 1987. See Marcia Gowen, et. al., Cane Energy Utilization Symposium; A Report from the 2nd Pacific Basin Biofuels Workshop, Vols. I and II (A.I.D., Washington, D.C.).

[23] Alex Alexander and his associates at the University of Puerto Rico measured the dry-matter content of machine-harvested cane stalks and residues and concluded that for each 7.9 tons of stalks there were associated 6.7 tons of tops and leaves. Assuming that some 15% of the weight of the stalk was compose of sucrose and other sugars, these data suggest that fiber quantities in stalks and trash were about equal. They also indicate that trash removal is less effective when the harvest is carried out by machine. See Alex Alexander, The Energy Cane Alternative (New York: Elsevier, 1985), 46.

The most detailed examination of this matter, a study conducted in the Dominican Republic by Professor Allan Phillips of the University of Puerto Rico, concluded that, on average, there was 0.67 metric tons of crop residues left in the field (at 50% moisture) for every ton of cane stalks harvested.[24] The cane involved was topped and cut by machete, without burning. A.I.D. is currently working with the Hawaiian Sugar Planter's Association to collect more detailed technical economic environmental information on trash quantities and to discover the most appropriate means of trash harvesting under different conditions.[25]

Except in seed fields, sugarcane is burned before harvest in most locations in Costa Rica. Because of this practice, the amount of residues is much smaller. If electricity production becomes a profitable activity--and cane trash a valuable commodity--mills may want to experiment with harvesting unburned cane. The increased cost of harvesting cane may prove worthwhile if the quantities of trash can be more than doubled and the cost of collection reduced.

Researcher Barney Eiland and others at the U.S. Department of Agriculture facility in Florida have measured available trash in fields that have been burned and then mechanically harvested. His conclusion is that, in general, 2-3 metric tons of dry matter can be recovered from fields that yielded 20 tons/acre at harvest. The Florida experience thus suggests that 2.7-4.0 tons of trash (at 25% moisture) can be harvested from burned cane fields for every 20 tons of cane stalks harvested.[26]

In the case of the El Viejo estate, where production of cane is estimated at 110 tons per hectare (43.3 tons/acre) this suggests that as much as 16-22 tons of trash might be collected per hectare. For an estate harvest of approximately 195,000 tons of cane, 28-39,000 tons of trash might be harvested. From the lands of farms supplying cane to the mill, an additional 15-21,000 tons might be collected, for a total of 43-60,000 tons of high quality fuel. The advantage of adding trash is that it allows mills that only produce electricity during the milling season (Figure 2.5) to extend the generation period.

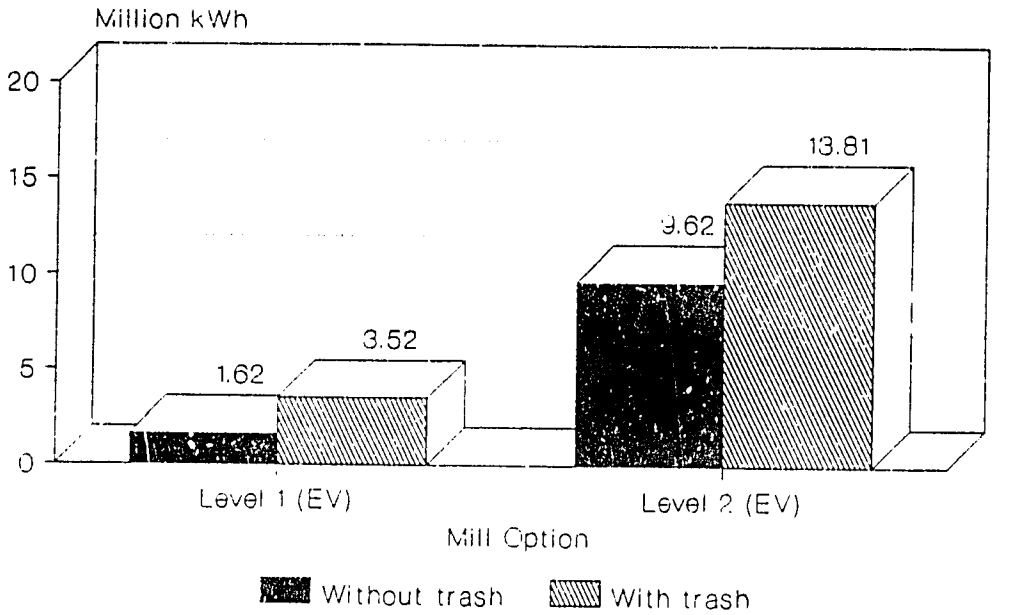
---

[24]The study was sponsored by the Electric Utility of the Dominican Republic. For further details, see the summary in Allan Phillips, "Cane Crop Residue for Biomass Fuel," available at the Department of Agricultural Engineering, University of Puerto Rico, Mayaguez, Puerto Rico.

[25]Experiments sponsored by A.I.D. are currently under way in Jamaica to test a specially designed cane trash baler, and in Hawaii to test the performance of standardized round- and square-type balers. Later in the year field trials are also planned at the Nong Yai Mill in Thailand.

[26]See B.R. Eiland and J.E. Clayton, "Unburned and Burned Sugarcane Harvesting in Florida," Transaction of the ASAE (Vol. 26, No. 5, 1983). As Eiland stresses, of course, the challange is in collecting the material at a cost that makes economic sense.

Figure 2.5
Electricity Production Increases With Trash at El Viejo Mill



Because of the experimental character of cane trash harvesting methods and the lack of experience with this agricultural procedure in Costa Rica, the study team has assumed, for purposes of the sensitivity analysis, that the mill could collect approximately 2/3 of these materials, and these only from the fields owned and controlled by the mill itself--some 11 tons for each 110 tons of cane harvested--or a total of 19,636 tons.[27]

Based on experimental evidence in Puerto Rico, the Dominican Republic, and Hawaii, this study assumes that the trash will reach the boiler with a moisture content of 25 percent. Again, this is based on experience with unburned cane, and it is possible that the material in Costa Rica may have a lower moisture content.[28] The gross calorific value is set at 6053 Btu/lb.[29]

(b) Trash Costs

The study team's estimate of the cost of harvesting, transporting, storing and processing trash fuel is summarized in Appendix D. Although the precise methods used will vary by location and farm, the study team assumed the residues in Costa Rica will be harvested using a tractor-drawn PTO-powered rake (to windrow the material) and a rectangular baler of the kind that is currently used to bale hay, and will be transported to the mill by the same methods used to transport harvested cane.[30]

The trash will be stored in dispersed locations and carried to the mill as needed after the harvest. At the mill the trash will be prepared for combustion in a "tub" grinder. The costs for these operations are based on current costs incurred by the mill for similar activities. Costs for the harvest equipment, delivered to Costa Rica, are based on quotes from Ford-New Holland Corporation. The findings, reported in Appendix D and Table 2.2, suggest an average price, delivered to the boiler, of 867 colones (US$ 11.80) per metric ton.[31]

---

[27] This number is based on the judgement of team members after a visual review of post-harvest fields on the El Viejo estate.

[28] If the trash moisture content is less than 20%, boiler modifications may be necessary to avoid problems in combustion.

[29] The gross calorific value of bagasse, at 50% moisture, is set at 4007 Btu/lb.

[30] Since the El Viejo mill currently employs workers to collect residues into windrows for burning, the costs associated with this procedure are treated as savings.

[31] Experience to date at other locations suggests a wide range of costs for the collection, storage, transport, and preparation of cane trash for fuel. The lowest are those of La Romana Mill in the Dominican Republic, which has been able to deliver fuel at US$ 7.10 per metric ton.

Table 2.2

Financial Cost Estimates for Supplemental Fuels in Costa Rica
(Estimates for El Viejo Mill)

Fuel Type	Purchased Bagasse	Trash	Wood	Fuel Oil	Imported Coal***	Domestic Coal****
GCV (Btu/lb.)*	4,007	6,053	4,007	18,230	12,825	7,200
Boiler Efficiency	75%	75%	75%	87%	85%	85%
NCV to Steam (Btu/lb.)**	3,005	4,540	3,005	15,842	10,850	6,120
Low Cost (US$/ton or bb.)	$1.99	$10.00	417.59	$14.00	$68.00	$54.00
Baseline Cost (US$/ton or bb.)	$3.65	$11.80	$19.85	$18.00	$73.00	$57.00
High Cost (US$/ton or bb.)	$7.70	$15.00	$22.12	$22.00	$78.00	$60.00
Low Cost/million Btu	$0.30	$1.00	$2.65	$2.58	$2.84	$4.00
Baseline Cost/million Btu	$0.55	$1.18	$3.00	$3.32	$3.05	$4.22
High Cost/million Btu	$1.16	$1.50	$3.34	$4.05	$3.26	$4.45

* Gross Calorific Value

** Net Calorific Value after boiler loss

*** All costs are for fuels delivered to the mill at El Viejo. Imported coal costs include an arbitrary US$ 3.00 for port conversion costs.

**** Figures for Uatsi coal, the least cost domestic coal available to El Viejo. See Table E.7 in Appendix E.

Conversions: 1 bb. fuel oil = 42 gals
1 gal. fuel oil = 8.155 lbs.
Ex. rate US$ = 73.2 colones
Metric ton = 2205 lbs.

Plantation Wood

The analysis of non-utility power generation in Costa Rica prepared for A.I.D. by Hagler, Bailly and Company (A.I.D. December 1987) reviews recent research on the potential of fuelwood from plantations in Costa Rica. The conclusion is that the resource base is sufficient to sustain large quantities of production on a sustainable basis--more than 16 million tons of commercial wood. The review also concludes that the delivered cost of a ton of kiln-dried wood fuel would range from 1287.9-1619.7 colones (US$ 17.59-22.12), for an average cost of 1,453 colones (US$ 19.85) per ton delivered to the plant.[32] For this study the team assumes that wood has the same calorific value and combustion characteristics as field trash (at 25% moisture).

As this data suggests (see Table 2.2), if the estimates from earlier studies are correct, wood would be more expensive than field residues, but might be more attractive than fossil fuel alternatives to supplement bagasse at sugar mills.[33] As is the case with trash, it is clear that the use of wood fuels to "back out" fuel oil or coal should be explored by investors who must rely on these fossil fuels for electricity production in the off season. Because the economic benefits to the country would be much larger, due to foreign exchange savings and greater employment when compared to other energy sources, the Government of Costa Rica may want to consider policies to encourage plantation wood development and use.

Fuel Oil

Sugar mills in Costa Rica currently burn fuel oil as a supplemental fuel. This study assumes, for purposes of the technical projections and the financial and economic analysis, that the mills would turn to petroleum as the primary supplemental fuel when they run out of bagasse in the "off" season. Should they find it possible to supply all their fuel needs with field residues, wood, or other lower-cost biomass fuels, the team expects that they will do so.

The world petroleum market is volatile, making it hard to estimate fuel oil prices with any accuracy. The present study uses a baseline cost of US$ 18 per barrel as a conservative figure for the short run (Table 2.2).[34] A sensitivity analysis in Chapter 3 reviews the implications of prices that are lower or higher than this baseline number. Because many energy policy experts anticipate a tightening of the

---

[32]See A.I.D. December 1987. "Non-utility Power Generation in Costa Rica: Potential, Impediments, and Policy Issues," Washington, D.C.: December, 1987, pp. 2.38-2.47.

[33]Because wood is not currently produced at a commercial scale--and a five to six year lead time is necessry for large-scale production--the economic and financial analysis of Chapter 3 does not assume that wood fuels will be available.

[34]This price may be lower for periods in Costa Rica because of refinery imbalances.

world petroleum market in the mid to late 1990's, the possibility of price increases in fuel oil represents a key area of risk to investors in cane power systems (see Table 2.3). To the extent that they are unable to utilize cane trash as a fuel, investments in the "high investment, high production" scenarios--Level 3 and 4--are highly sensitive to these price changes.

Coal

Coal is not an established fuel in Costa Rica, and there is considerable uncertainty about the cost of coal as a supplemental fuel for power generation at sugar mills. This uncertainty applies both to domestic coal, which is just at the point of development in Costa Rica, as well as to coal imported from Colombia, Chile or elsewhere. Coal varies in its quality (energy value as well as ash, sulphur and water content) and is expensive to transport. Appendix E assesses the delivered costs of various coals to EL Viejo and Taboga mills.

As Table 2.2 indicates, imported coal may prove less expensive than fuel oil as a source of power for electricity production at some Costa Rican mills. Note, however, that the cost of coal in Table 2.2 does not include the capital cost of handling, storing, and processing the coal for combustion at the mill. To illustrate the financial and economic results of utilizing imported coal instead of oil in the off season, Chapter 3 includes a sensitivity analysis of this option for the El Viejo and Taboga Mills.

As Appendix E demonstrates, domestic coal in Costa Rica is more expensive than imported coal on a delivered energy basis, and the mills examined in this study are unlikely to use it unless prices for imported coal increase or government policies provide incentives to promote the product from domestic mines.

Table 2.3

International Product Price Forecasts

Products	Price (1988 US$/bbl) 1990	1995
LPG	15.80	20.54
Prm. Unleaded Gasoline	26.35	33.20
Reg. Unleaded Gasoline	25.00	31.00
Prm. Leaded Gasoline	26.70	32.70
Reg. Leaded Gasoline	24.50	30.50
Naphtha	18.50	26.35
Kerosene	25.10	31.10
Jet Fuel	25.50	31.50
High-speed Diesel	24.50	30.50
Low-speed Diesel	24.10	30.10
Low-sulfur Fuel Oil	19.50	24.50
High-sulfur Fuel Oil	18.50	23.50

Source: Petroleum Project, Resource Systems Institute, East-West Center. June 1988.

Chapter 3

Financial and Economic Assessment of Cane Power Systems

The conclusion of this study is that the production of power for sale to the grid in Costa Rica makes financial and, certainly, economic sense to the mills and the country as a whole. The least risky alternative is to simply tighten mill operations and sell small amounts of excess power to the grid during the harvest season. This would involve no investment and would contribute, if all mills were to do so, some 17-19 million kilowatt hours of power per year. With moderate investments many mills can increase power output and total net benefits. Cane power production would benefit the country as a whole by drawing upon the financial and managerial skills of the private sector, creating additional jobs in rural areas, diversifying the sugar industry into an attractive new by-product market, and replacing imported fuel with less expensive domestic feedstocks.

Financial and Economic Investment Models of Electric Power Production

To determine the attractiveness of cane power production and to identify key factors influencing the commercial success of the systems, the team applied an investment model developed for sugar mill power investments (CANEPRO VERSION 1) to generate scenarios for the target mills based on varying capital investment and power output assumptions (see Appendix B). The team conducted both financial and economic analyses to show the private and public sector incentives. Sensitivity analyses are made on key variables in the scenarios--electricity purchase price, loan rates, fuel costs, and power load rates--to determine the risk associated with each of these factors.

The four investment levels developed for the mills, based on technical options in Chapter 2, include:

- Level 1: no investment and low energy output (using waste bagasse from mill operations to generate surplus electricity for sale during the cropping season);
- Level 2: low investment and moderate power output (making small capital investments to increase and somewhat extend electricity production);
- Level 3: moderate investments and high, year round power output (keeping existing mill boilers but making higher capital investments in new turbogenerators to extend power production year round); and
- Level 4: high investments and high, year round power output (investing in new high pressure boilers and going to year round energy production).

Table 3.1 categorizes various scenarios for the mills at these different levels. A base case is developed for each mill using the most likely benefit and cost assumptions. The base case uses financial prices, current market prices, for all variables (see Appendix C). The only exception is for interest rates, as explained later.

Power System Benefits

Mills receive direct benefits from the sale of electricity to the grid (electricity revenues) and indirect savings through displacing previous energy used, in this case electricity and petroleum. Displaced fuel savings are valued at the industrial tariff for electricity and at the current market price in Costa Rica for residual fuel oil. The direct benefits are discussed below. Figure 3.1 and Table 3.2 shows the magnitude and composition of benefits for each of the mills in the study.

The price ICE pays to the mills for electricity is the key to profitability for cane power systems. Due to the immediate need for additional generation capacity in the near term, officials at ICE indicated during team visits that ICE might pay a premium price for years 1-5 and then drop the price down after year 5 to its avoided cost. The premium price suggested was 5 colones per kWh (6.8 US ¢/kWh), with the price beyond year 5 up for negotiation.

The avoided cost methodology is used for calculating the economic or marginal costs of electricity in Costa Rica (Appendix C). A recent power sector analysis (A.I.D. December 1987) estimated a range of avoided costs based upon different energy sources (Table 3.3). Thermal, geothermal, and gas turbines are the current (thermal) and planned (geothermal and gas turbines) peaking energy sources for ICE; thus their costs represent marginal costs to the grid and weighted averages are used for setting the purchase prices.

Two areas of major uncertainty remain: the actual production costs when these plants come on-line and dates for coming on-line. Actual electric generation costs are notorious throughout the world for far exceeding earlier estimates. Dates of actual production are particularly problematic for geothermal power. Gas turbines, though expensive to run, can be expected to come on-line relatively soon. Geothermal start-up dates are far more uncertain if serious delays are encountered in construction and financing.

Table 3.1

Investment Levels and Mill Characteristics of Models

Level/Mill	Capital Investment	Power Output	Equipment	Fuel
Level 1				
Quebrada Azul (QA)	None	Low	No Modifications	Bagasse
El Viejo 1 (EV1)	None	Low	No Modifications	Bagasse Trash*
Level 2				
El Viejo 2 (EV2)	Low	Low	Topping Turbine	Bagasse Trash*
Level 3				
El Viejo 3 (EV3)	Medium	High	Topping and (3) Condensing Turbines	Bagasse, Oil Trash, Coal*
Level 4				
El Viejo 4 (EV4)	High	High	New Boiler, Double Extraction and Condensing Turbine	Bagasse, Oil Trash, Coal*
Taboga 4 (TB4)	High	High	New Boiler, Double Extraction and Condensing Turbine	Bagasse, Oil Trash, Coal*

* Trash or coal are added or substituted for oil in EV1, EV2, EV3, EV4 and TB4 in the fuel sensitivity analyses.

Figure 3.1
Average Annual Cane Power Benefits

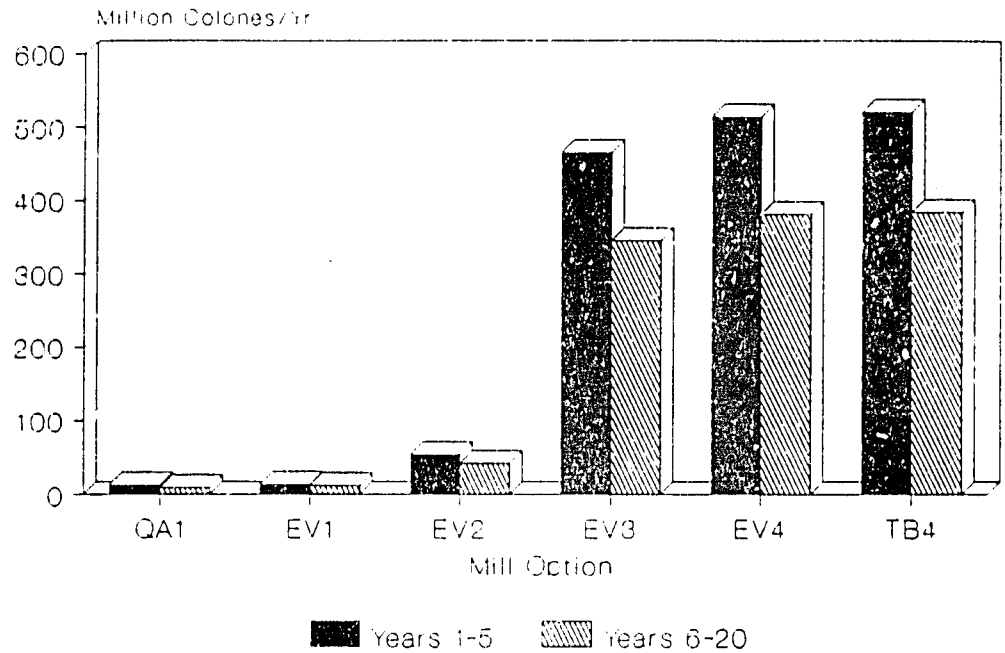


Table 3.2

Average Annual Cane Power Benefits
(Million Colones/year)

	Mills					
Benefits	QA1	EV1	EV2	EV3	EV4	TB4
Years 1 - 5						
Elec. Rev.	12.6	8.1	48.1	459.7	507.8	520.0
Displaced Fuel						
Elec.	0.0	1.6	1.6	1.6	1.6	0.0
Oil	0.0	4.6	4.6	4.6	4.6	0.0
Total	12.6	14.3	54.3	466.9	514.1	520.0
Years 6 - 20						
Elec. Rev.	9.3	6.0	35.6	340.2	375.8	384.8
Displaced Fuel						
Elec.	0.0	1.6	1.6	1.6	1.6	0.0
Oil	0.0	4.6	4.6	4.6	4.6	0.0
Total	9.3	12.2	41.8	346.4	382.0	384.8

Table 3.3

Full Avoided Cost Estimates for Electricity in Costa Rica
(1987)

Period	System	ICE's Avoided Costs			
		Peak		Off-Peak	
		(US ¢/kWh)	(CRc/kWh)	(US ¢/kWh)	(CRc/kWh)
Up to 1989**	Existing Thermal Units	8.3-10.5	6.2-7.7	*	*
After 1989***	Geothermal	5.1	3.7	3.1	2.2
	Gas Turbine	7.3	5.4	*	*
	Honduras	-	-	3.0	2.2

* Off-Peak avoided costs are for purchased power from Honduras.

** Includes only avoided energy cost component, no capacity charge since using existing thermal units.

*** Includes full avoided costs, an avoided energy and capacity charge since building new power plants to meet expanding demand.

Source: A.I.D. December 1987. Appendix D.

To account for these uncertainties, low and high electricity price scenarios are used in the sensitivity analyses. If ICE's plans proceed smoothly, the low price scenario might be expected. The high price scenario uses costs that might be projected if serious problems arise in the power expansion plans. The data assumptions used in the scenarios are:

- Low Electricity Purchase Prices:

Years 1-5	5 CRc/kWh	6.8 US¢/kWh
Years 6-20	3 CRc/kWh	4.1 US¢/kWh

Current plans for expanding ICE's base generation into geothermal are expected to be on target, coming within five years. In the short run, the electricity purchase price for years 1-5 is expected to be 5 CRc/kWh (6.8 US¢/kWh) based upon estimates provided by ICE officials, but to drop down to a weighted average of geothermal peak and off-peak avoided costs for years 6-20, which is 3 CRc/kWh (4.1 US¢/kWh).

- Medium (Base Case) Electricity Purchase Prices

Years 1-5	5 CRc/kWh	6.8 US¢/kWh
Years 6-20	3.7 CRc/kWh	5.1 US¢/kWh

Like the low price scenario, electricity purchase prices in the short term remain at 5 CRc/kWh but after year 5 they fall to 3.7 CRc/kWh. This price reflects the avoided costs for geothermal power and includes an allowance for construction delays or other unforseen eventualities in the current expansion plans.

- High Electricity Purchase Prices:

Years 1-5	5.8 CRc/kWh	7.9 US¢/kWh
Years 6-20	4.2 CRc/kWh	5.7 US¢/kWh

Higher generation costs are projected in this scenario to reflect the failure of geothermal to come on-line as fast as currently planned forcing ICE to rely in the short term on existing thermal units and gas turbines, and in the long term on high-priced gas turbines and geothermal. The purchase price in years 1-5 (5.8 CRc/kWh) represents an average of thermal (6.2 CRc/kWh) and gas (5.4 CRc/kWh) peak avoided prices; the long term high price in years 6-20 represents an average of the geothermal weighted average (3.02 CRc/kWh) and gas turbine peak price (5.4 CRc/kWh).

Mill Modifications and Capital Costs

Mills face four possible financing options, which greatly alter total capital costs and the feasibility of the investment. Mills can either use only equity, a possibility in Level 2, or a debt/equity arrangement that can be based on concessional, national or private interest rates. Without access to concessional rates (7-11%), mills face extremely high finance charges, 26% at national banks and 31% at private banks in nominal terms. Given the existing loan period restrictions and prohibitive costs of private banks, mills would probably prefer going to national banks for large investments if they cannot access concessional loans.

Since much of ICE's electricity expansion is concessionally financed in Costa Rica, an argument can be made for allowing mill operators access to concessional rates for electricity investments, provided they sell to the national grid. Up to 60% of ICE's project loans are financed by the Inter-American Development Bank (IDB). Since the private banks and sugar industry have a good history of debt collection and repayment, respectively, the country might benefit from allowing a portion of the capital loans associated with cane power systems to be concessionally financed with payment going through the private banking sector.

For simplicity, only one lending institution and interest rate for any investment, a concessional, national or private rate, is used in each run of the model. The base case uses a moderate concessional rate, 11%, based on the assumption that electricity investments for sale of power to the national grid should receive the same financial rate structure as faced by the national utility. Sensitivity analyses on the interest rates show the effect of different financing arrangements on project viability.

Employment Generation and Labor Costs

Generating power from bagasse increases labor demand at the power plant and, if trash is collected, in the field. Relative to other costs (Table 3.4), labor's contribution ranges from 2% in the case of large power systems (EV3, EV4, and TB4) to nearly 100% for the no investment surplus power option (QA1, EV1). Total workdays generated by the power plants vary from 3,652 to 10,050 days per year depending upon the option (Table 3.5). Trash collection adds another 200 days of work for each 1000 tons of fuel used per year. In value terms, the power plant jobs can contribute 2.5 to 6.8 million colones per year per factory to the rural economy, which equates to $33,000 to $90,000.

Fuel Costs

Prices for the various fuels--bagasse, trash, fuel oil, and coal--are presented in Appendix D and summarized in Chapter 2. As seen in Table 3.4 and Figure 3.2, fuel costs are significant in Levels 3 and 4 due to fuel oil use. As discussed later, the significant cost saving realized from substituting trash or coal for oil are sufficient to warrant serious attention by the mills and government.

Figure 3.2
Annual Cane Power Costs

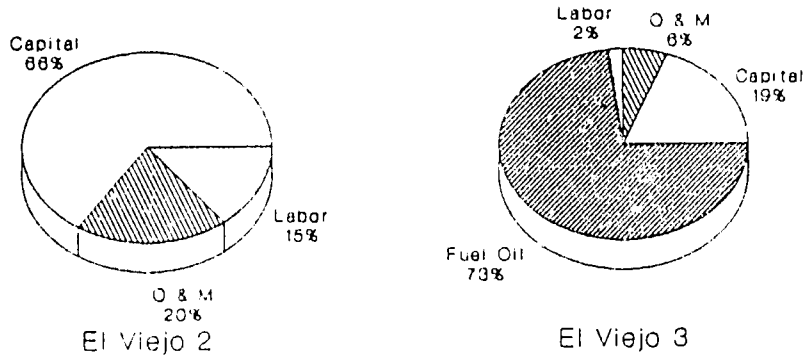


Table 3.4

Average Annual Cane Power Costs
(Million Colones/year)

Costs	QA1	EV1	EV2	EV3	EV4	TB4
Year 1						
Capital*	0.0	0.0	33.8	211.0	380.7	434.8
Op/Maintenance	0.0	0.0	3.4	21.1	38.0	43.4
Fuel						
Purchased bag.	0.0	0.0	0.0	0.0	0.0	4.4
Cane Trash	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	267.3	244.3	195.9
Labor	2.9	2.5	2.5	6.8	6.8	6.8
Total	2.9	2.5	39.7	506.2	669.8	685.3
Years 2 - 20						
Capital	0.0	0.0	11.3	70.5	127.3	145.3
Op/Maintenance	0.0	0.0	3.4	21.1	38.0	43.4
Fuel						
Purchased bag.	0.0	0.0	0.0	0.0	0.0	4.4
Cane Trash	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	267.3	244.3	195.9
Labor	2.9	2.5	2.5	6.8	6.8	6.8
Total	2.9	2.5	17.2	365.7	416.1	395.8

*Includes equity in year one capital costs.

Table 3.5

Annual Employment Generation and Labor Benefits from Cane Power Plants in Costa Rica (1988)

Mill*	Employment** (days/yr)	Employment** (M CRc/yr)	Wage Income (M US $/yr)
QA1	4,260	2.86	0.039
EV1	3,652	2.45	0.033
EV1T	5,871	3.95	0.054
EV2	3,652	2.45	0.033
EV2T	5,871	3.95	0.054
EV3,3T	10,050	6.75	0.092
EV4,4T	10,050	6.75	0.092
TB4T	10,050	6.75	0.092

Source: Team estimates. Assumes 8 hour labor day.

* Mill options followed by a "T" are ones utilizing cane field residues (trash) as fuel.
** Reflects employment at the power plant only. Additional jobs in the fields are created by trash collection.

Net Present Values and Economic Impacts of Cane Energy Systems

Present value analyses of the mills show cane energy production to be attractive at a variety of investment levels (Figure 3.3a and 3.3b). From a financial perspective, mills could expect to receive anywhere from US$ one to three million in net returns before taxes. Only one option, EV4, loses money. Applying Costa Rica's business tax rate, the net present values fall by 50 percent.

In economic terms, at medium electricity prices, all low power levels of investment are attractive to the country but high power scenarios show negative NPV's due to their dependency on imported fuel oil. The highest economic returns are realized with extended electricity production at low power output, investment Level 2.

Beyond the net returns of the investment, the mills and country must compare the capital and foreign exchange requirements and amount of power exported for the various options (Figure 3.4a, 3.4b and Table 3.6). Levels 1 and 2 require little or no capital, and similarly have zero or low foreign exchange needs. In contrast, Levels 3 and 4 often have NPVs near Level 2, but require US$ 10 to 20 M of capital, and can draw off from US$ 6.7 to 8.7 M in foreign exchange for 11 to 13 MW power sales. When comparing options, the low investment/low power and moderate investment/ high power scenarios (option EV2 and EV3) may fare the best overall in terms of financial NPVs, foreign exchange and capital requirements when compared to power ouput.

Figure 3.3a
Financial Net Present Value Analysis
Base Case

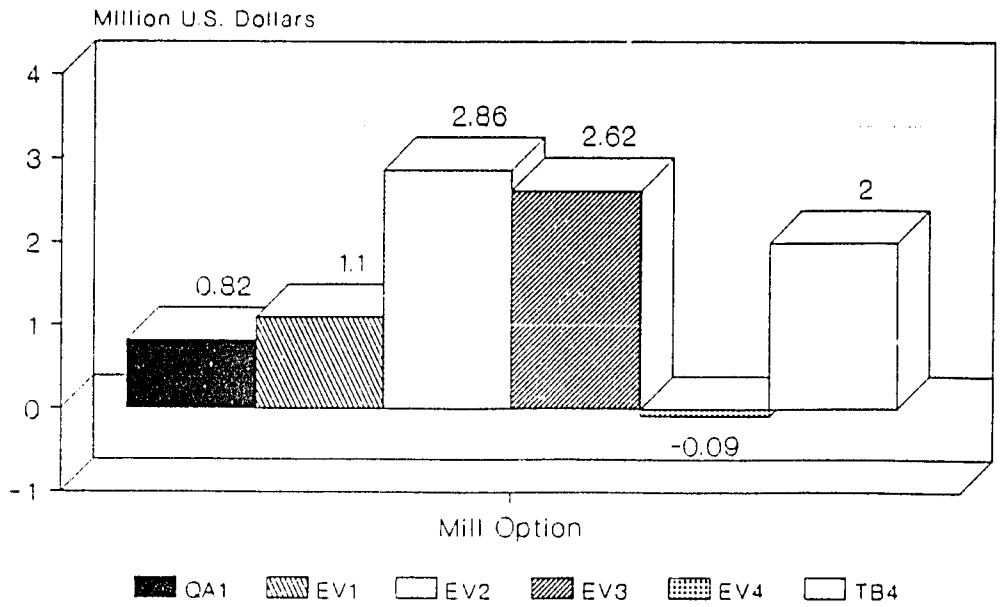


Figure 3.3b
Economic Net Present Value Analysis
Base Case

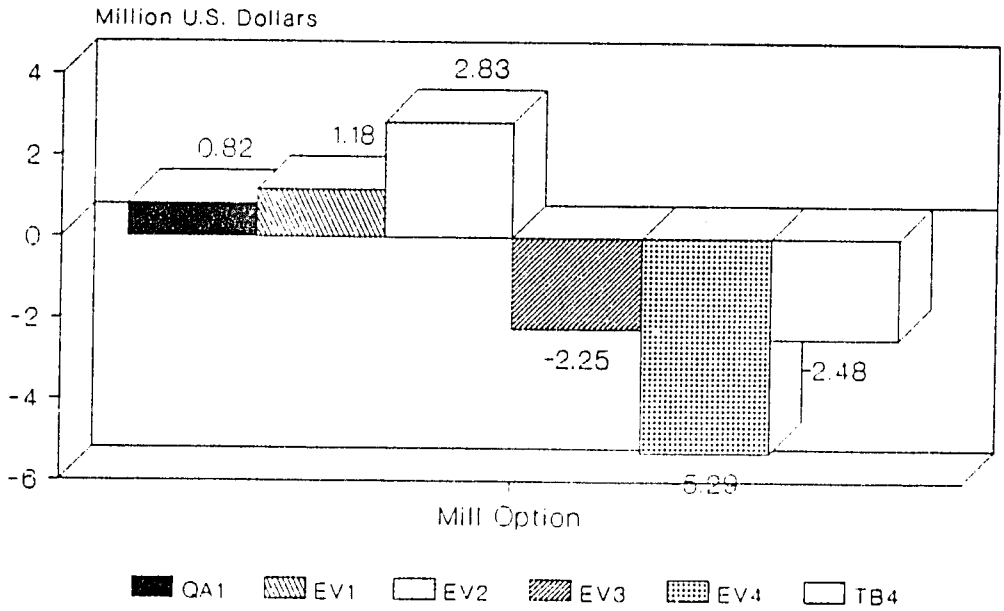


Figure 3.4a
Financial NPV and Capital Requirements

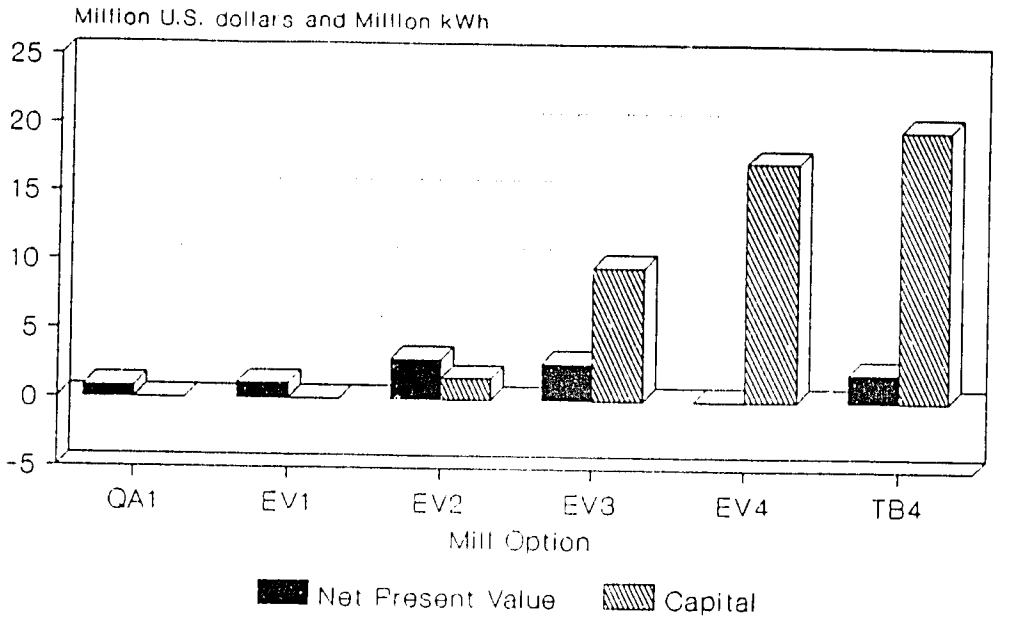
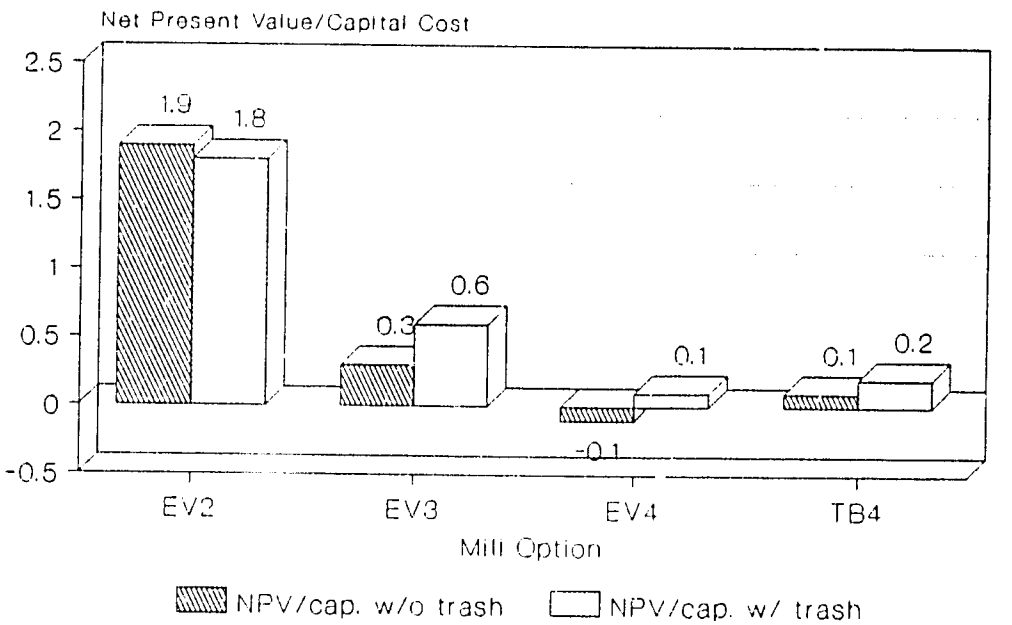


Figure 3.4b
Ratio of Financial Net Present Value to Capital With and Without Trash



Net Present Value is before taxes

Table 3.6

Direct Financial Benefits and Characteristics
of Cane Power Systems
(1988)

Mill	NPV* (M US$)	Capital (M US$)	Foreign** Exchange (M US$)	Power Export (M kWh/yr)
Level 1				
QA 1	0.82	0.00	0.00	2.5
EV 1	1.10	0.00	0.08	1.6
Level 2				
EV 2	2.86	1.54	-0.33	9.6
Level 3				
EV 3	2.62	9.59	-6.70	91.9
Level 4				
EV 4	-0.09	17.31	-8.71	101.6
TB 4	2.00	19.77	-8.23	104.0

* Financial NPV without taxes.

** Foreign exchange represents the total direct net foreign exchange requirements (without shadow valuing) of the investment option, i.e. the total foreign exchange saved from the displaced petroleum at a mill minus the foreign exchange needs for capital and operating expenditures. Negative values indicate net outflows to the country from an investment option. Note, however, this value does not include the indirect foreign exchange savings to the country from cane electricity replacing diesel-based electricity generation by the utility. See Table 3.7 for the inclusion of such benefits.

Sensitivity Analysis

Best, Base and Worst Case Scenarios

Electric power generation from mills is a new alternative for Costa Rica. Mill owners and utility executives have no experience to guide them in estimating system costs and reliability. High uncertainty exists on pivotal variables like electricity purchase prices, interest rates, and future fuel prices. To clarify the risks involved, best and worst case scenarios are compared to the base cases for all options (price assumptions are given in Appendix C). Clearly if, as in the best case, the utility pays high electricity prices and fuel prices, and interest rates remain low, these systems could increase their net returns by as much as ten-fold (Figure 3.5 and B.2). Conversely, if the worst case is realized all systems except for those at Level 1 could experience significant losses.

A wide variability in returns exists between the best and worst cases, with the greatest risk being for high power scenarios. This suggests that if high output options are chosen, then firm agreements must be reached by the mills on all negotiable variables, notably electricity prices and interest rates, to reduce investment risk wherever possible. One primary area where financial risk may be reduced is substituting cane trash or coal for oil during the off-season, as discussed below.

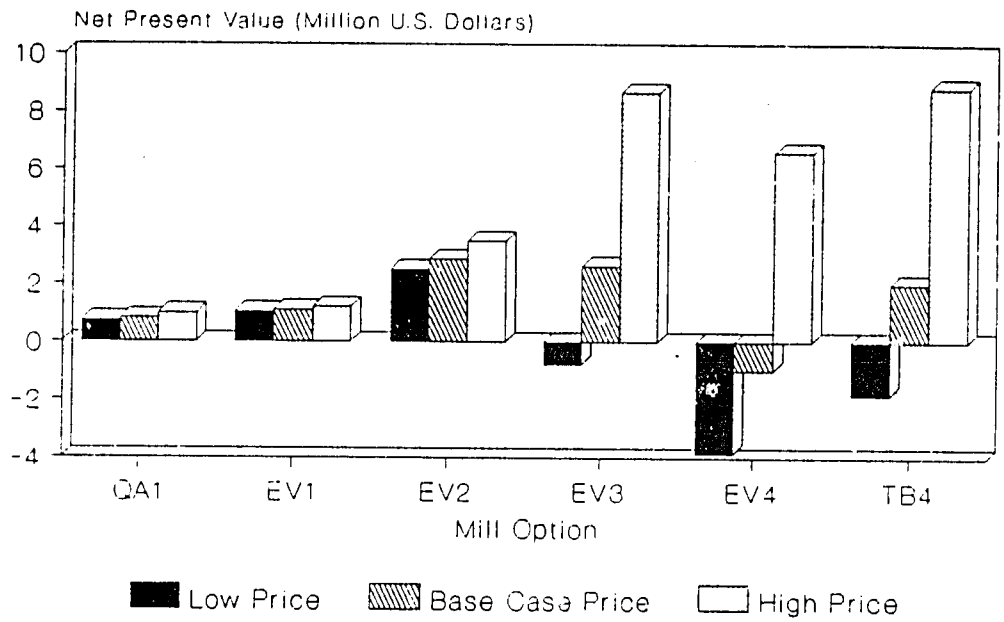
Effects of Changing Electricity Prices

A key variable to the mills is the electricity purchase price, which they will negotiate with ICE. Given the lack of precedents, this rate is uncertain at present. ICE officials have suggested that they may be willing to pay a premium above ICE's long term avoided costs in the short term (1-5 years) due to the immediate need for additional capacity and the potential for the mills to act quickly to contribute to ICE's seasonal demand.

It is clear from a sensitivity analysis of electricity prices (Figure 3.6 and Table B.3) that these rates are of extreme importance to the profitability of the power systems. All assumed rate structures (5/3.0, 5/3.7, and 5.8/4.2 CRc/kWh for years 1-5/6-20) show positive financial NPV's, with the exception of EV3, EV4 and TB4 at low prices. The degree of variability between the low and high scenarios widens exponentially as the power output of the options increases. At Levels 1 and 2, the NPV's jump up anywhere from 16 to 40% going from low to high price scenarios. This spread increases by factors of 3 to 12 times low price scenarios at Levels 3 and 4 when 11 to 13 MW are exported.

The results underscore the importance for mills and ICE of carefully designed purchase price agreements. As the Hawaiian sugar industry and electric utilities have learned, such arrangements need to benefit all parties, including the customer. Consideration needs to be given to a number of issues in order to protect the utility, mill operators and consumers from problems caused by unexpected events. A range of methods are used by the Hawaiian sugar industry to protect against such uncertainty, for example indexing electricity prices, setting floor prices, and including escalators.

Figure 3.6
Electricity Price Sensitivity
Financial Analysis



Effects of Oil Price Changes and Petroleum Savings

The volatility of fuel prices, particularly petroleum prices, over the past two decades has meant that industries must plan to reduce their vulnerability to changing fuel costs. In this study, three fuel prices affect cane power returns, those for oil, trash and coal. As evidenced in Figure 3.7a and 3.7b, oil costs are most important with high power outputs (Levels 3 and 4).

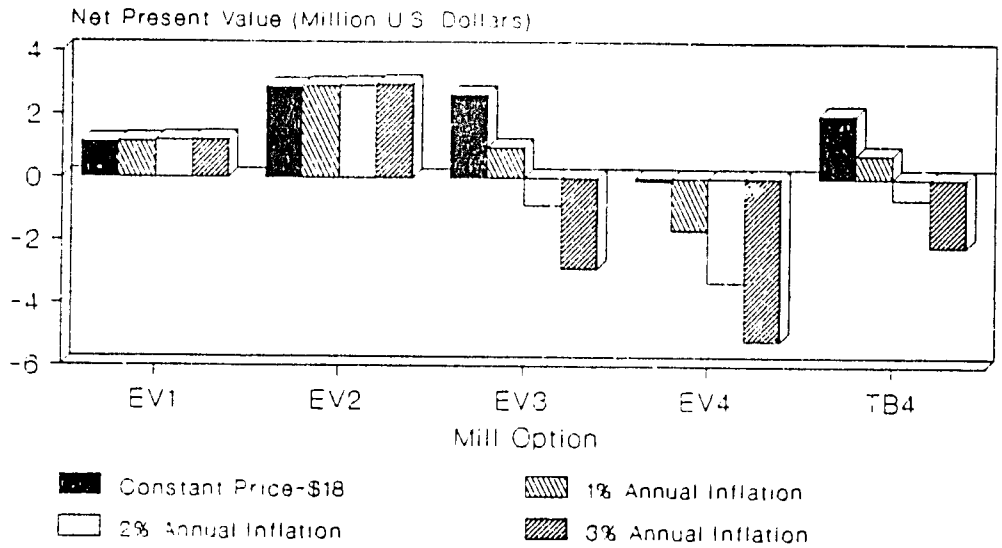
To account for possible escalation or fall in oil costs, a sensitivity analysis of varying inflation factors and two base prices ($14/bbl and $18/bbl) was applied to all base cases. The results, shown in Figure 3.7a, suggest that if oil prices increase constantly at or over 2% per year then all base case investments at Levels 1 and 2 are still profitable but Levels 3 and 4 lose money. As seen below, substituting trash for oil mitigates this effect to some degree. Since oil prices are not expected to increase up to 2% per year until the mid-1990's, a variable inflation scenario using low (US$ 14/bbl) and base case (US$ 18/bbl) oil prices shows the high power scenarios are more resilient to oil price changes. As they recently have, residual fuel oil prices could fall. To account for this, a low price scenario (US$ 14/bbl) demonstrates that such a drop, if it remained with an annual 2% inflation in real terms after year five, could significantly raise financial NPV's of the cane power systems (Figure 3.7b and Table B.4).

Beyond the benefits to specific mills, the country reaps important foreign exchange savings through petroluem displacement from cane power production. Benefits occur from the (1) displacement of previous electricity and direct petroleum use at the mill and (2) displacement of central station diesel use from the portion of exported cane power based on bagasse use. Net annual savings to the mills in this study range from $123,000 to $2.2 million per year, which over a twenty year life amount to significant foreign exchange savings to Costa Rica (Figure 3.7c). Generalizing from these findings to the broader potential for cane power in the country gives annual petroleum import savings of as much a $7 million per year (Table 3.7).

Effects of Substituting Cane Trash for Oil

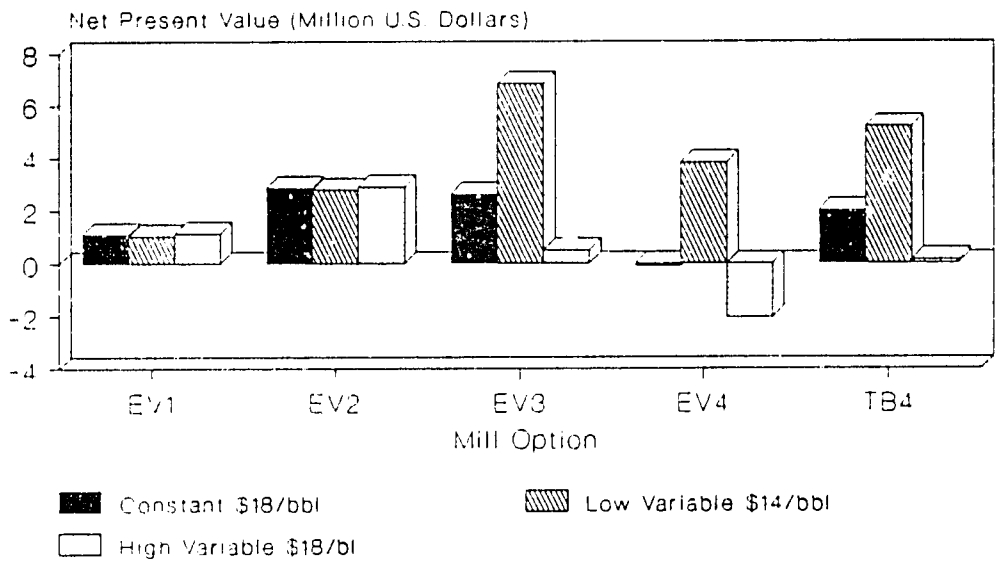
Cane trash collection is an experimental but potentially exciting option by which mills can supplement their biomass supply and displace oil use during the off-season. Experiments with cane trash by sugar companies in the Dominican Republic and Philippines (Gowen, ed. 1987) as well as on-going tests in Thailand and Jamaica by A.I.D.'s Office of Energy Bioenergy Systems and Technology Project are proving the technical feasibility of trash collection. Since trash collection is not commercially proven in Costa Rica, trash costs used in the models are still hypothetical.

Figure 3.7a
Oil Price Sensitivity
Financial Analysis



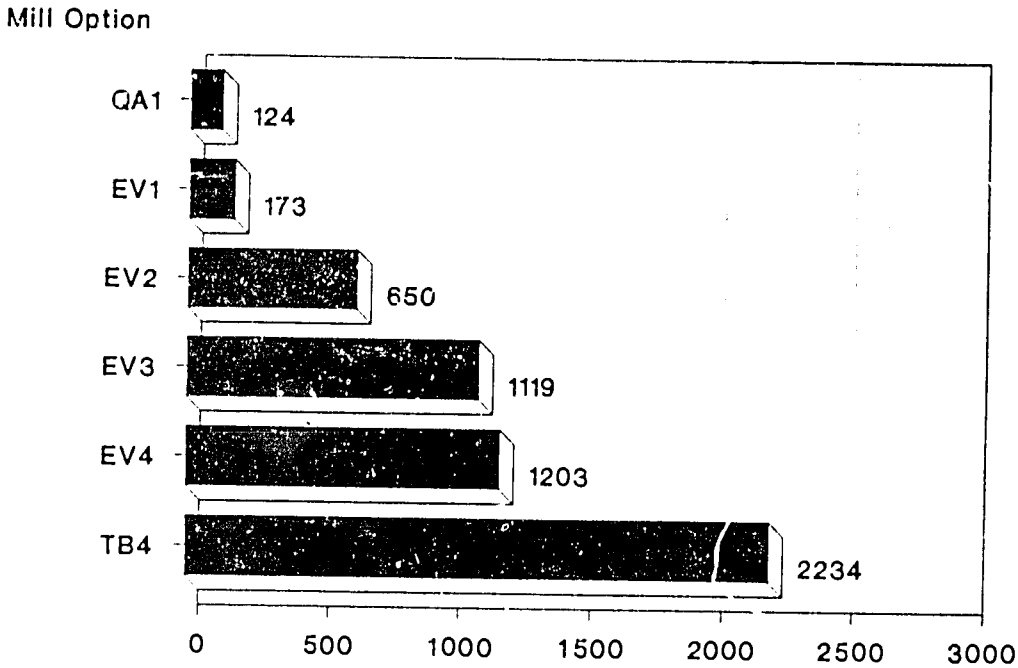
Assumes $18/bbl and indicated oil price inflation in real terms over all project years

Figure 3.7b
Oil Price Sensitivity
Financial Analysis-Variable Prices



Variable scenario assumes annual 2% oil price inflation after yr 5, constant has no inflation in real terms over project

Figure 3.7c
Annual Petroleum Savings by Mill
(Thousand U.S. Dollars Per Year)



Assumes $18/bbl.

Table 3.7

Potential Petroleum Savings from Cane Power in Costa Rica

Power Production	Mills (No.)	Net Petroleum Savings (M US$/yr)
Surplus	15	1.88
All-Year	5	5.00

Assumes 5 large mills at $1 million savings per mill producing power all year and 15 mills have $125,000 savings per mill for surplus power production.

A sensitivity analysis of trash prices shows that NPV's fall as prices increase (Figure 3.8). However, the NPV's are relatively inelastic to trash price increases, since trash costs are a small portion of total costs. Increasing trash costs 50% from $10/ton to $15/ton, reduced NPV's by only 30% in options EV2, EV3, EV4 and TB4. Substituting trash for petroleum for some 42 days a year in options EV1-4 and TB4 increases net returns by 4% to 18% (Figure 3.9 and Table 3.8). In EV1, net returns decrease with the addition of trash since trash does not substitute for oil as in the other options. In all other cases, three important benefits are being realized. First, mills earn more money if they use trash. Second, the country is saving foreign exchange by using trash rather than petroleum, and third, it is employing more rural workers. The most dramatic impact of trash fuel is on the Level 3 option, which becomes the most attractive of all and far less vulnerable to changes in oil prices.

Figure 3.8
Trash Price Sensitivity
Financial Analysis

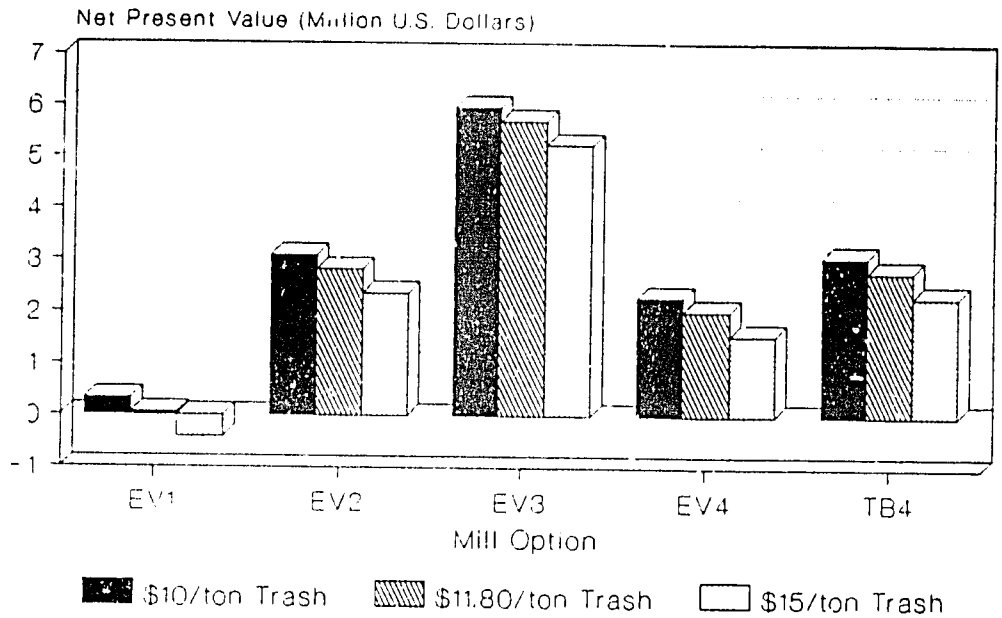


Figure 3.9
Financial NPV With and Without Trash

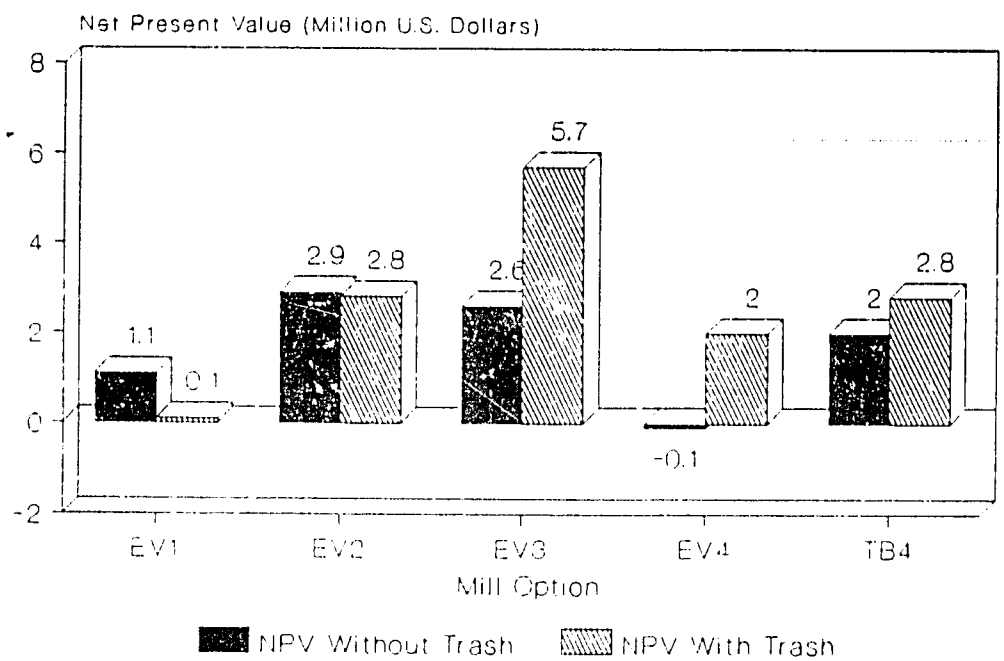


Table 3.8

Direct Financial Benefits and Characteristics
of Cane Power Systems With Trash
(1988)

Mill*	NPV (M US$)	Capital (M US$)	Foreign Exchange (M US$)	Power Export (M kWh/yr)
Level 1				
QA 1	0.82	0.00	0.00	2.5
EV 1	1.10	0.00	0.08	1.6
EV 1T	0.05	0.00	0.08	3.5
Level 2				
EV 2	2.86	1.54	-0.33	9.6
EV 2T	2.82	1.54	-0.33	13.8
Level 3				
EV 3	2.62	9.59	-6.70	91.9
EV 3T	5.70	9.73	-5.94	91.9
Level 4				
EV 4	-0.09	17.31	-8.71	101.6
EV 4T	0.02	18.04	-8.17	101.6
TB 4	2.00	19.77	-8.23	104.0
TB 4T	3.00	19.77	-7.68	102.0

* Mill options followed by a "T" are ones utilizing cane field residues (trash) as fuel.

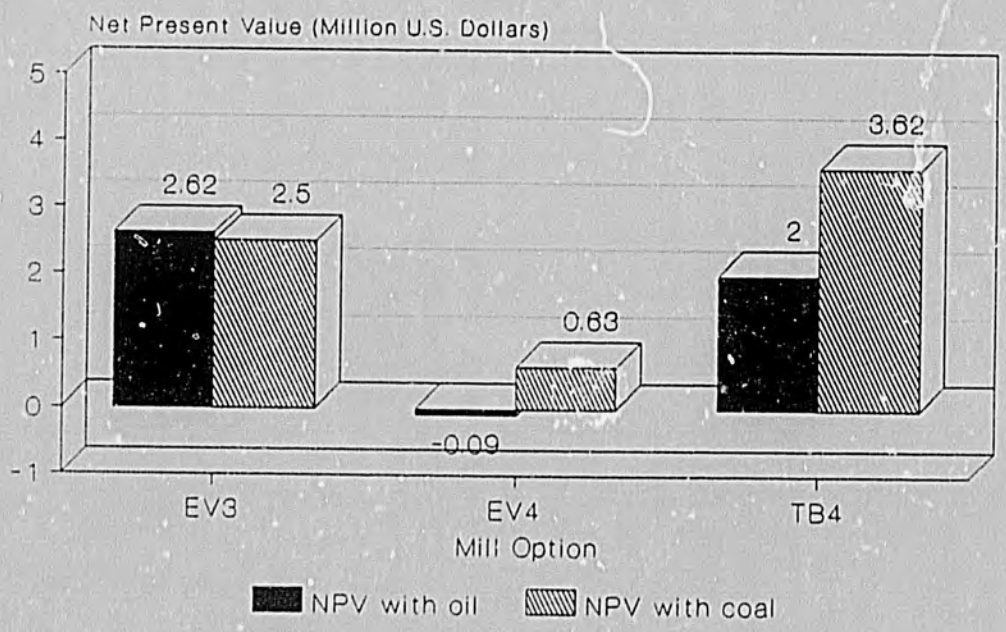
** Foreign exchange represents the total direct net foreign exchange requirements (without shadow valuing) of the investment option, i.e. the total foreign exchange saved from the displaced petroleum at a mill minus the foreign exchange needs for capital and operating expenditures. Negative values indicate net outflows to the country from an investment option. Note, however, this value does not include the indirect foreign exchange savings to the country from cane electricity replacing diesel-based electricity generation by the utility. See Table 3.7 for the inclusion of such benefits.

Effects of Substituting Coal for Oil

Costa Rican mills are unfamiliar with the use of coal as a supplemental fuel and the "base case" analysis assumes that they will turn to fuel oil as the first supplemental fuel when they run out of bagasse. The penalty paid for fuel oil use is high, however, and the poor returns on the larger investments (Level 3 and 4) reflect this fact. A review of the coal resources that might be used reveals that imported coal is significantly less expensive than domestic coal on a delivered-Btu basis (see Appendix E), and may even be less expensive than imported oil at the base case chosen (US$ 18/bb).

A sensitivity analysis using the lowest price coal available to El Viejo mill (12,825 Btu coal from Chile) reveals that this less expensive fuel would significantly raise the returns for the Level 4 investments--in the case of TB4 from US$ 2 million to US$ 3.62 million (Figure 3.10). These findings, plus those from the trash sensitivity, suggest that mills able to secure a supply of both field residues and inexpensive coal would be advised to consider replacing their boiler systems entirely. They would remain, however, vulnerable to changes in the price of these fuels.

Figure 3.10
Coal vs. Oil Substitution Sensitivity
Financial Analysis



Sugarcane Electricity versus Alternative Utility Options

Costa Rica's utility faces serious economic and timing issues in developing its generation expansion plan. ICE needs to select a least-cost expansion strategy that will keep its rates down. However, the most attractive least-cost options, such as geothermal or hydro, have long lead times and ICE is under pressure to invest immediately in additional baseload capacity. The utility is paying dearly for its reliance on expensive gas turbine and diesel power generation, while the country is in jeopardy of losing its competitive edge in attracting new export industries since local and foreign companies cannot be assured reliable and sufficient electricity by the utility.

Implicit in the preceding fuel price sensitivity analyses for cane power systems is a comparison to ICE's planned least-cost options. Currently, ICE must rely on diesel and gas turbine units throughout the dry season for meeting its peak and off-peak demand, and in the wet season diesel for peak hours but a mix of hydro and fuel oil for off-peak hours. The only systems ICE can develop in the short term are diesels or gas turbines. ICE pays 7 US¢/kWh based on its existing diesel/gas systems. Note that this is an average cost, it is not the cost of new or rehabilitated diesel units, i.e. not the short term avoided (marginal) cost. Full avoided costs for diesel thermal units are given in Table 3.3.

Long run marginal costs reflect the integration of geothermal units into the grid. ICE's long term plans are to bring on sufficient geothermal, and possibly coal, to substitute for much of its diesel/gas turbine use. Due to quite recent delays in ICE's geothermal plans, such options are not expected to come on line until the mid, not early, 1990's. Because of these delays, the high electricity price scenario presented in Figure 3.6 appears to represent the most realistic estimate of sugarcane power investment returns. Appendix C presents the data and assumptions on which the analysis is based.

In the short term, sugarcane power investments at all proposed levels are the least cost option for the country. Further, unlike other options, they appear to be the only realistic indigenous fuel alternatives available to Costa Rica in the short term. When combined with the results presented in Figure 3.7c that show annual petroleum savings for each mill, power from sugarcane residues becomes even more attractive to the country as a serious generation option.

Effects of Changing Loan Rates

Mills recognize that the rate charged for loans is key to their ability to invest in electricity production for sale to the grid. Base cases assume concessional loans at 11% in nominal terms are available, terms tied to borrowing and repaying in foreign currency. An analysis of different nominal interest rates borrowing in colones (Figure 3.11 and Table B.5) demonstrates that Level 2 has the widest flexibility in terms of acceptable rates (note Level 1 assumes zero capital costs). Although still positive, even returns for Level 2 fall by 30% if a private bank rate is necessary. Moderate investments begin to lose money at "national" rates, unless, as shown later, trash can be substituted for oil. High investments go negative once national or private rates are charged.

Figure 3.11
Loan Rate Sensitivity
Financial Analysis

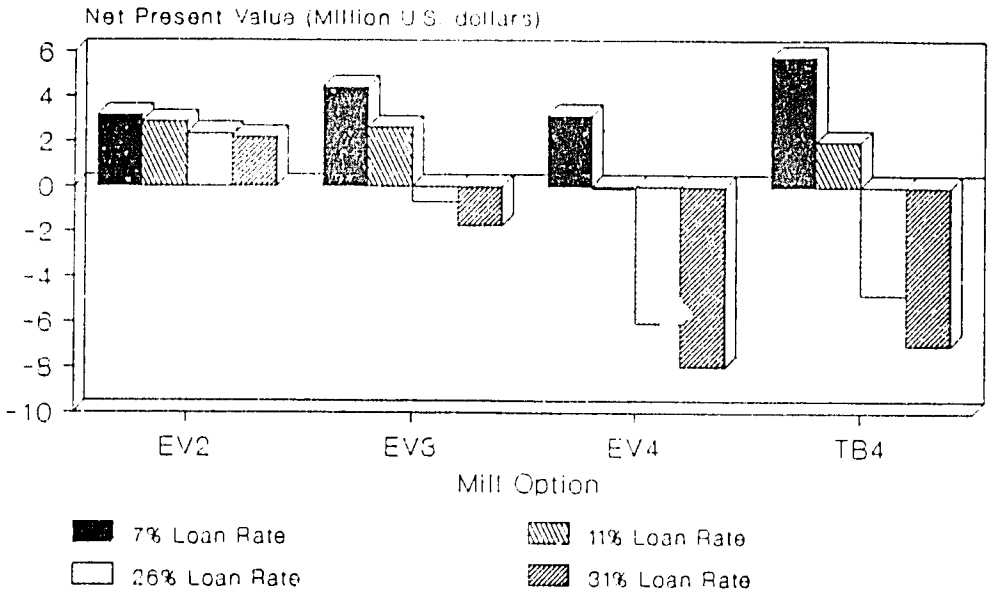
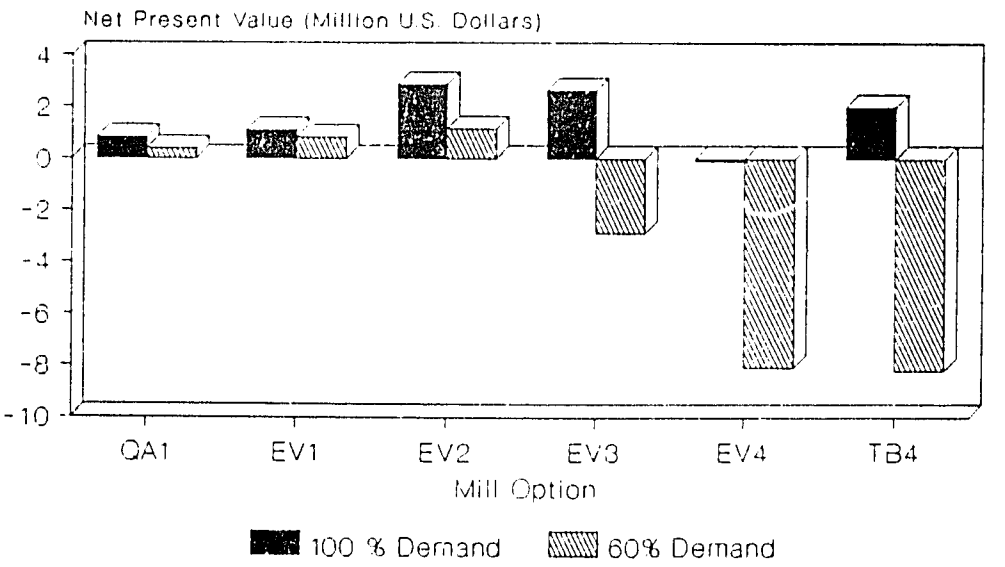


Figure 3.12
Utility Dispatch Factor Sensitivity
Financial Analysis



Factor refers to daily utility power dispatch from mill as percenatage of available power

These results indicate that moderate and high capital investments, which produce the most power, are extremely vulnerable to high interest rates. If it is important to Costa Rica to generate the maximum power from mills in the short term, mills may require access to the kinds of concessional rate now available to ICE.

Effects of Utility Dispatch Factor

As seen in Figure 3.12, the present values of cane power systems are highly dependent upon selling all of their exportable power to the grid, i.e., achieving high dispatch factors. Low dispatch factors (below 75%) result in underutilization of power plant capital. Note that mills anticipating dispatch factor significantly lower than 90-100% may find alternative technical configurations more efficient to increase generation flexibility.

Effects of Changing Discount Rates

Discount rates appear to have less importance for the net returns than other factors in the analysis. Several rates are used in the analysis, a low economic rate (10%), the current rate employed by national and international organizations (12%), and two higher rates (15% and 25%) that are closer in line with current nominal interest rates in the country.

As shown in Table 3.9, lower rates increase the net present values, except in the case for EV4. However, at 25% discount rate, the NPVs still remain positive, indicating that even if businesses or the country assign a high opportunity cost to the value of money, investments in cane power systems look attractive.

Potential Benefits, Risks and Policy Needs

Cane power systems make economic sense to the sugar industry and the country under a variety of conditions. The medium surplus power scenarios with moderate capital and technical changes at the mill produce the highest total net returns unless field trash is available, at which time the Level 3 all-year power production option becomes the most attractive. A conservative approach would be for the mills to begin by supplying ICE with in-crop surplus power, which requires no capital investment and always insures positive returns. Once their ability to provide firm power is established, mills might then add equipment (e.g. topping turbine) to boost sales. Finally, if trash collection proves successful, further investments would decrease the country's dependence on imported oil or coal.

Electricity production from mills for most options also provides critical benefits to the country. New economic activities and jobs are created in rural areas, areas that have few economic alternatives. Low power scenarios that involve no capital commitments are the least risky and provide attractive returns. They make available only small amounts of electricity to the grid. In contrast, higher power

Table 3.9

NPV's for Discount Rate Sensitivities
(Million US$)

Mill	Discount Rates (%)			
	10	12	15	25
Level 1				
QA	0.92	0.82	0.70	0.47
EL Viejo				
EV1	1.25	1.10	0.93	0.61
EVT	0.04	0.05	0.06	0.08
Level 2				
EV2	3.24	2.86	2.42	1.55
EV2T	3.17	2.82	2.41	1.59
Level 3				
EV3	2.67	2.62	2.50	2.03
EV3T	6.19	5.70	5.08	3.66
Level 4				
EV4	-0.03	-0.09	0.10	0.23
EV4T	2.12	2.02	1.85	1.30
Taboga				
TB4	2.12	2.00	1.18	1.21
TB4T	3.04	2.79	2.46	1.60

scenarios provide more electricity to the utility but have different capital and foreign exchange implications. Additional electricity is available to the country in high power scenarios without incurring public sector debt, rather drawing upon the private sector's ability to produce a new product efficiently at lower long run costs. Foreign exchange is required but probably less per unit energy delivered from cane power systems than under ICE's short term expansion plans.

In terms of total electricity supplied to the grid, high power scenarios are the most attractive for Costa Rica. Important, but certainly controllable, risks are associated with such options. In descending order, the greatest project risks identified by this study surround electricity purchase and other fuel prices, loan rates, and daily power scheduling. All such risks can be minimized prior to project implementation through adequate contractual agreements between the mills and utility, and by clear policies regarding private power production in the country.

Investments in cane power systems will require cooperation between the government and mills to ensure that both sides realize their highest potential. Specific areas that will require cooperation include:

- agreement on electricity prices that reflect ICE's long term electricity generation costs, i.e., full avoided costs. Contracts may want to have prices indexed to alternative fuel prices (oil, coal) and consumer price index with escalators and floors to ensure equitable returns to the mills and fair rates to the consumers;

- special consideration by the government regarding interest rates, import duties, and taxes for private sector electricity production for national use that reflects similar policies towards the national utility;

- financing options involving ICE, multi-national funding agencies, the national sugar association, and the mills. Innovative schemes--such as third party financing, Build Operate and Transfer (BOT), debt/equity swaps, or ICE ownership--could make such investments attractive to the mills and country;

- reliability and dispatching schedules that allow the mills to remain solvent in producing energy to the grid; and

- research and development in alternative boiler fuels for extending cane power production year round to displace fuel oil demand, such as trash collection, wood plantations, and other indigenous fuels that pump fuel revenues into the local economy.

Such cooperation will require high level support from the government as well as the active involvement of mill operators. If this can be achieved, all parties will benefit. At present, these positive economic and financial results indicate that the next step is to conduct in-depth investment analyses at particular mills.

Appendix A

Efficient Steam Production and Use for Electricity Generation at Costa Rican Sugar Mills

Introduction

The Costa Rican sugar industry can currently produce more power than needed for factory operations during the milling season; however, the industry could extend its ability to produce surplus power without major capital investment by improving the efficiency of steam production and use in the factory. Specifically, mills could:

a. Maximize the amount of steam produced per ton of bagasse through improved equipment or management. At the simplest level, the cost for increasing efficiency cannot exceed the additional revenues produced by the sale of the surplus electricity generated with the incremental steam.

b. Adopt practical and cost effective methods for storing and handling bagasse to permit operation of the power generation equipment after the factory has stopped crushing.

c. Reduce steam used for sugar production by changing management practices and upgrading or replacing process equipment.

The Costa Rican sugar industry could produce electricity throughout the year if a sufficiently inexpensive fuel could be found to be used in factory boilers after bagasse runs out. How much the sugar industry could afford to pay for fuel of course depends on the price they receive for electricity and the efficiency with which their existing equipment can convert the fuel to electricity. Most factories will need to install more efficient combustion and generation equipment in order to profitably generate electricity after bagasse runs out given the cost of other available fuels and the likely price for electricity.

For small factories, the potential improvement in efficiency of conversion will not likely be large enough to justify investment in new equipment. If located relatively near large factories small factories may find it most profitable to sell any surplus bagasse they can produce to larger, more efficient factories rather than producing surplus electricity themselves.

This Appendix discusses a number of factors affecting the efficiency of steam production and use in sugar factories. Generally, a modern sugar mill can be designed to operate on much reduced steam inputs per ton of cane. For raw sugar factories, process steam demand can range from 34.0% on cane, where maximized power production is a byproduct revenue objective, to 50% on cane where minimizing surplus bagasse production is the objective. Sulfitation plantation white sugar factories will use 5% to 10% more steam than the raw sugar factories, the percentage varying with the type of pan floor sugar boiling system used and the efficiency of water use in the pans and wash-syrup application and separation at the centrifugals.

Factors Affecting Efficient Steam Production

Production of Low Moisture Bagasse

As is well known, lower moisture content bagasse has a higher net calorific value and better burning characteristics in furnaces. Good cane preparation followed by good milling control and maceration distribution can consistently provide bagasse in the 46.0% to 50.0% moisture range. The net heat release in BTU per pound of dry bagasse will range from 6510 at 50% moisture content bagasse up to 6680 at 46 percent. Figure A.1 shows how lower bagasse moistures affect boiler performance; as bagasse moisture decreases (1) power consumed by the fans decrease, (2) required combustion air decreases, (3) calorific value of the bagasse increases and, (4) boiler efficiency increases.

Furnace combustion temperatures increase when lower moisture content bagasse is burned. For example, at 50% moisture content the furnace temperature will be 1800-1900°F; at 35% the temperature will be 2100-2200°F; and at 20% the range is 2600-2800°F. High combustion temperatures have been known to cause furnace slagging and refractory problems.

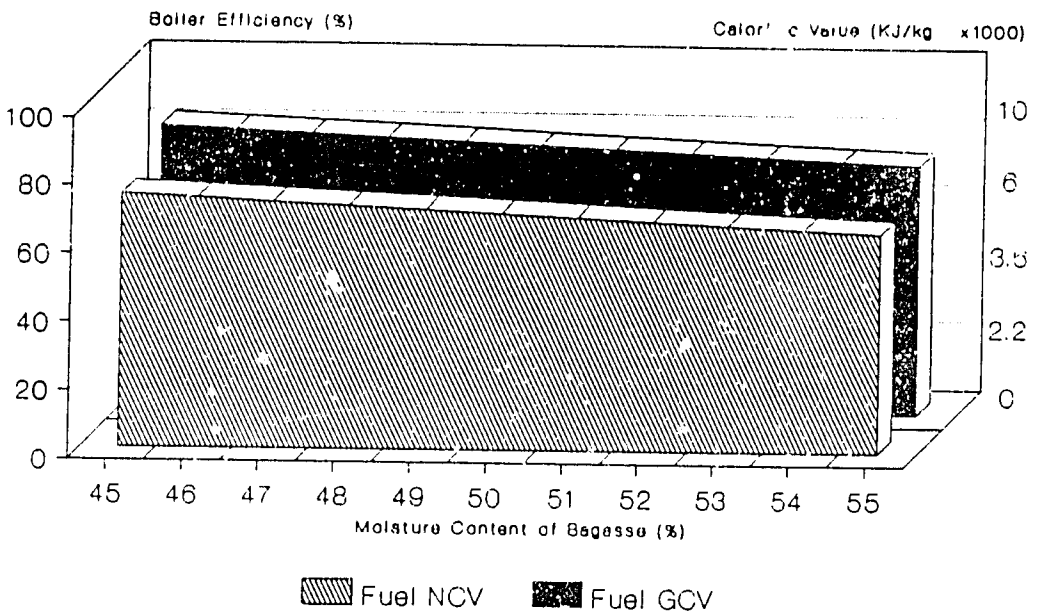
Air leakage into the boiler setting, boiler shell and flue gas ducts should be kept to a minimum. Excess combustion air should be just sufficient to provide adequate mixing in the furnace and provide sufficient combustion air. Insulation should be adequate.

Heat Recovery Equipment

Airheaters operating on boiler flue gasses are now in common use in Costa Rican sugar factories; whether they are heating the combustion air sufficiently high is not known. Heat contained in the boiler flue gasses that would normally be lost out the stack is used to preheat combustion air. Heating combustion air before it enters the boiler improves bagasse combustion and boiler efficiency. A temperature of 410°F to 500°F is suggested as the upper limit for combustion air to the furnace with the actual limit depending on the furnace design. Also, to avoid corrosion, minimum metal temperatures at 80% MCR boiler load should not be less than 260°F when firing bagasse alone. When firing high sulfur fuels the metal temperature must be higher; for example, 3% sulfur in fuel would call for a metal temperature above 290°F.

Economizers like air preheaters provide double benefits. Apart from recovering waste heat from the flue gasses, they also heat up the boiler feedwater to a temperature approaching that of the water in the boiler feed drum. The economizer heated water should not, however, approach within 50°F of the boiler feed drum water temperature to avoid water hammer in the economizer. Boiler feedwater heaters are often used to raise boiler feedwater temperature, sometimes Increasing the feedwater temperature reduces the heat transfer load on the boiler making it more efficient.

Figure A.1
Boiler Efficiency Changes in Response to Moisture Content of Bagasse



NCV=Net Calorific Value
GCV=Gross Calorific Value

To maximize recovery of waste heat from flue gases, it is necessary to use an economizer followed by an airheater. Normally, this will reduce flue gas temperature from about 600°F to 300°F. A number of Hawaiian mills have installed two-pass Rader flue gas rotary drum dryers to dry their bagasse from 45% moisture content down to 35 to 40 percent. These units are installed following the economizer and airheater. If the exit flue gas temperature drops below the dew point, corrosion problems occur in mild steel components.

Boiler Blowdown

Blowdown should be kept in the 3.0% to 5.0% range preferably on a continuous blowdown basis. Installation of flash tanks in the blowdown system will recover 60% to 70% of the blowdown heat for use as exhaust steam. The condensate from the flash tank can be recovered for use as boiler feedwater makeup.

Deaerating Boiler Feedwater Heater

Deaerating boiler feedwater heaters are used to scavenge oxygen from the boiler feedwater and heat the boiler feedwater up to 250°F with blowdown flash vapor or exhaust steam. Increasing the feedwater temperature reduces the heat transfer load on the boiler.

Bagasse Quality Effect on Boiler Heat Losses

The following table shows the adverse effect of poor quality bagasse fuel in terms of moisture content and high ash. If high ash fuel is burned, then as a counter-acting measure the moisture content should be low, preferably below 35%. The ignition characteristic and the so called "burnability" is improved and unburned carbon in the furnace ash is materially reduced as more bagasse is burned in suspension.

Effect of Bagasse and Field Residue Quality on Boiler Heat Losses

During normal operations at sugar factories, ash and moisture content of bagasse can vary significantly depending on weather during harvest and on how frequently milling stops because of breakdowns or lack of cane. Fluctuations in bagasse quality are relatively unimportant for low pressure boilers and do not seriously affect sugar operations. Although boiler efficiency will decrease, most factories have plenty of surplus bagasse.

As boiler temperatures and pressures increase, the impact of fluctuations in fuel quality on boiler performance increases. Changes in ignition characteristics and "burnability" of bagasse due to unexpected charges of wet bagasse or bagasse high in ash content will increase the amount of unburned carbon in the furnace and fly ash decreasing boiler efficiency. Excess air requirements will fluctuate making it difficult to maintain stable boiler conditions.

Switching among or blending bagasse, cane tops and leaves, oil, coal, and other biomass residues will further complicate boiler operation. To operate at maximum efficiency, each of these fuels or blends of fuels will require different boiler settings.

Factors Affecting Efficient Steam Usage

Because they are primarily interested in producing sugar, most conventional sugar mills try to balance production of exhaust steam from all prime movers and back-pressure turbogenerators with the consumption of exhaust steam in the factory. The driving forces behind factory operations are the demand for steam to process sugar and the desire to minimize bagasse disposal problems.

When electricity can be sold, factories use extracting and condensing turbogenerators and try to pass as much steam as possible through the turbogenerators to maximize electricity production while still meeting the factory's demand for steam to process sugar. Saving steam in the factory means increased electricity sales. During periods of time when there is no demand for steam to process sugar, all steam will be sent to the condensors and used to produce electricity.

Given the potential to generate revenues from sales of electricity, most factories will be able to significantly reduce steam consumption in sugar factory operations with minimal investments.

Milling Rate

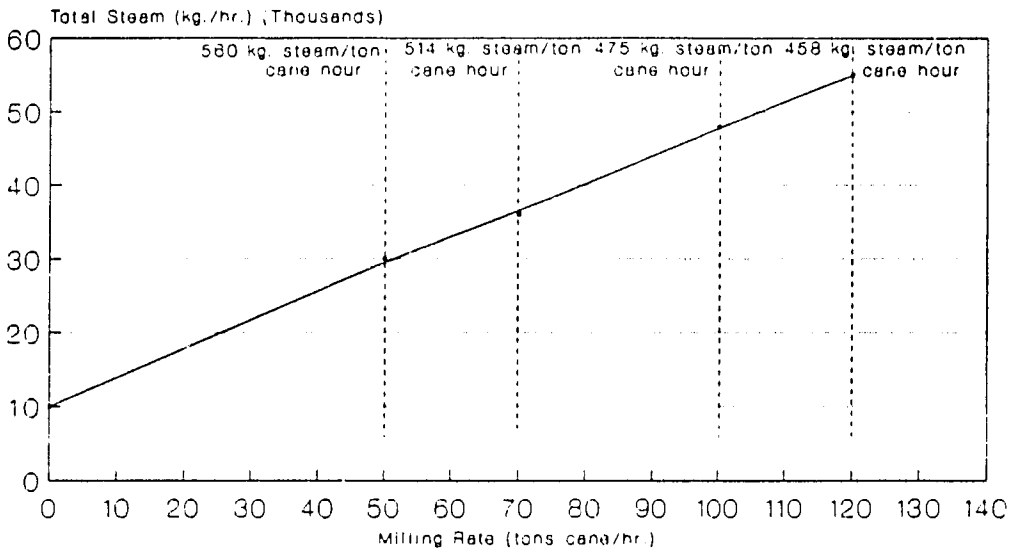
Milling rate directly affects the efficiency of steam use. Figure A.2 depicts the variation in steam usage per ton cane hour (TCH) in a factory designed to mill 100 TCH. Assuming all other factors are unchanged, an increase in the milling rate decreases the per unit steam consumption and a decrease increases the per unit steam consumption. To maximize the efficiency of steam use in milling, the curve indicates it is better to shutdown factory milling and processing operations for periods when cane supply is inadequate rather than mill at one-half or three-quarters speed.

Note that operating the mills requires about 10,000 kilograms of steam per hour even if no cane is milled. Radiation from pipes and equipment and a small percentage due to so called "no load" power consumption make up the greatest proportion of base steam consumption. Insulation on pipes and equipment keeps base steam consumption to a minimum.

Evaporator-Pan Floor Operations

In areas where surplus bagasse disposal has been a problem, emphasis has not been directed toward steam economy in the boiling house. However, for factories using steam pressure in excess of 400 psig and condensing turbogenerators, each 10 to 16 pounds of steam saved in the mills or processing can mean one additional saleable kilowatt hour.

Figure A.2
Proportional and Non-Proportional
Steam Consumption



Most of the Costa Rican mills use evaporator vapors for juice heating and/or vacuum pan heating. The evaporator station is the best steam saving opportunity in the sugar factory, particularly when vapors are bled off for vacuum pans and juice heaters. Tables A.1, A.2 and A.3 indicate the steam economy advantages of more extensive use of vapor heating for both quadruple and quintuple effect evaporators. Table A.1 shows a 1.9% steam saving, by more vapor heating, between Items A and B.

A comparison of Table A.2, Items C and D with Table A.3, Items E and F indicates the steam economy advantage of the quintuple effects over the quadruple effects; the steam usage reduction being on the order of 11.1% (Items C vs. E) and 17.5% (Items D vs. F). Steam demand ranges from 34.8% to 42.6% on cane with the higher pressure exhaust steam arrangement requiring substantially less heating surface. Extraction of higher pressure exhaust steam will, of course, reduce the amount of power generated per pound of steam flowing to the turbogenerator throttle valve.

The vacuum pans in Tables A.1 to A.3 indicate a 13.9% steam usage on cane. This is low and is attributable to high syrup densities, good pan vacuum and supersaturation control, good grain uniformity and minimum water usage in the vacuum pans, and molasses feed to the pans as well as in the centrifugals. Many mills, including some sulfitation mills, operate in the 15% to 20% range. The steam usage reduction between these two percentages is 10.7%, other conditions being the same.

Steam Traps and Condensate Usage

Practices in the Hawaiian sugar industry suggest all first cell condensate from exhaust steam should be returned to the boiler feedwater system. Boiler feedwater makeup should be taken from the third and fourth evaporator cells. Use hot condensate for maceration; however, temperature should not be above 160°F to prevent or minimize mill feed slippage. Condensate from steam traps should be returned to the boiler feedwater system and all steam leaks, should be eliminated. Testing of condensates for sugar should be a standard laboratory practice. Evaporator station should have condensate flash pots to flash condensate to the immediately following cell.

Steam Turbine Mechanical Drives

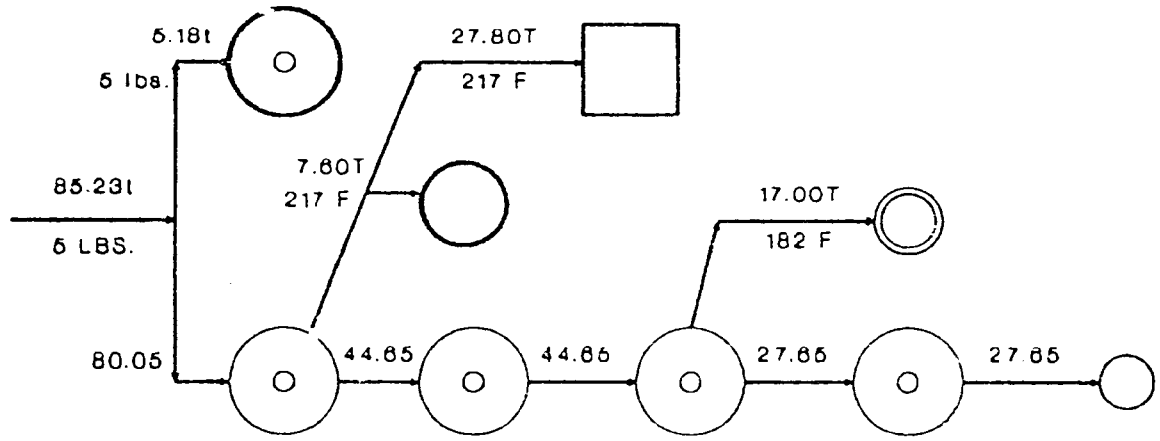
Steam turbines have become a standard for mill drives and many knife and shredder drives. Many of the earlier turbines had poor steam rates, generally in the 30.0 to 40.0 lbs. per hp.-hr. range. New multistage turbines operating at 160 to 200 psig and exhausting at 15 psig have steam rates in the 23.0 to 28.0 lbs. per hp.-hr. range. A 5.0 lb. difference on an 800 hp turbine is 4,000 pounds per hour of 160 or 200 psig steam. The amount of steam saved can be extracted if necessary to meet 15 psig exhaust steam requirements in the factory or passed through the turbine and condensed, in either case generating more kilowatts hours.

If the process equipment has adequate heating surface in the heat exchange equipment, then it is better to operate 160 psig mechanical drive turbines. In the case of a 15,000 kW 850 psig, 825°FTT double extraction and condensing turbine, the difference between extracting at 160 and 200 psig, all other conditions being the same, is about 2,000 kW when extracting 138,000 lbs. per hour of 160/200 psig steam.

Table A.1a

Evaporator Performance Based on 200 TCH
Quadruple Effect

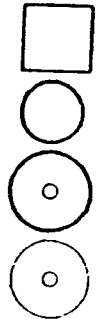
Item A: Vapors from 3rd effect for heating, and from 1st for boiling and heating to 212°F.



Cell	I	II	III	IV
Evaporation, Tons/hr	80.05	44.65	44.65	27.65
Allowable, lbs./Sq.Ft.	8.50	8.50	8.50	8.50
Sq. Ft. Required	18,850	10,500	10,500	6,500

Heating (1st stage):-	198 x (175-90)/988	=	17.00T	vapor from 3rd effect
Heating (2nd stage):-	198 x (212-175)/967	=	7.60T	vapor from 1st effect
Boiling:-		=	27.80T	vapor from 1st effect
Reheating:-		=	5.18T	steam at 5 lbs. effect
Evaporation:-	[197-3 (17.00)-7.60-27.80]/4	=	27.65T	steam at 5 lbs. gauge
	Total	=	85.23T	steam at 5 lbs. gauge

KEY



Boiling

Heating

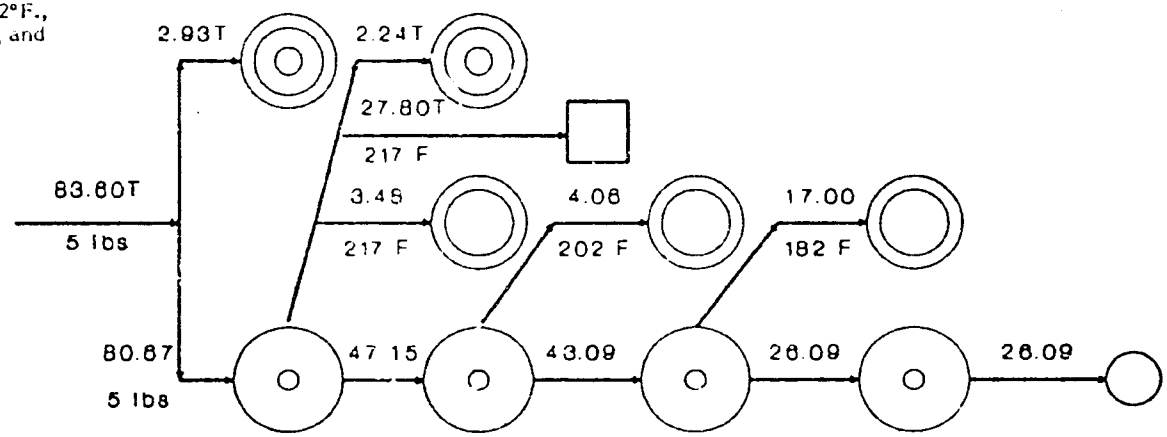
Reheating

Evaporation

Table A.1b

Evaporator Performance Based on 200 TCH
Quadruple Effect

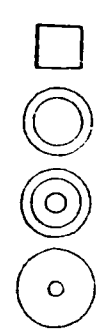
Item B: Vapors from 1st and 3rd cells for heating to 212°F., from 1st effect for boiling and reheating to 212°F.



Cell	I	II	III	IV
Evaporation, Tons/hr	80.67	47.15	43.09	26.09
Allowable, lbs./Sq.Ft.	8.50	8.50	8.50	8.50
Sq. Ft. Required	19,000	11,100	10,150	6,150

Heating (1st stage):-	198 x	(175-90)/985	= 17.00T	vapor from 3rd effect
Heating (2nd stage):-	198 x	(195-175)/976	= 4.06T	vapor from 2nd effect
Heating (3rd stage):-	198 x	(212-195)/967	= 3.48T	vapor from 1st effect
Reheating (1st stage):-	216 x	(212-202)/967	= 2.24T	vapor from 1st effect
Boiling: -			= 27.80T	vapor from 1st effect
Reheating (2nd Stage):-	216 x	(225-212)/960	= 2.93T	steam at 5 lbs. gauge
Evaporation:-	[197-3 (17.00)-2(4.06-3.48 -2.23-27.80]/4		= 27.65T	steam at 5 lbs. gauge
			= 26.09T	steam at 5 lbs. gauge
		Total	= 83.60T	steam at 5 lbs. gauge

KEY



Boiling

Heating

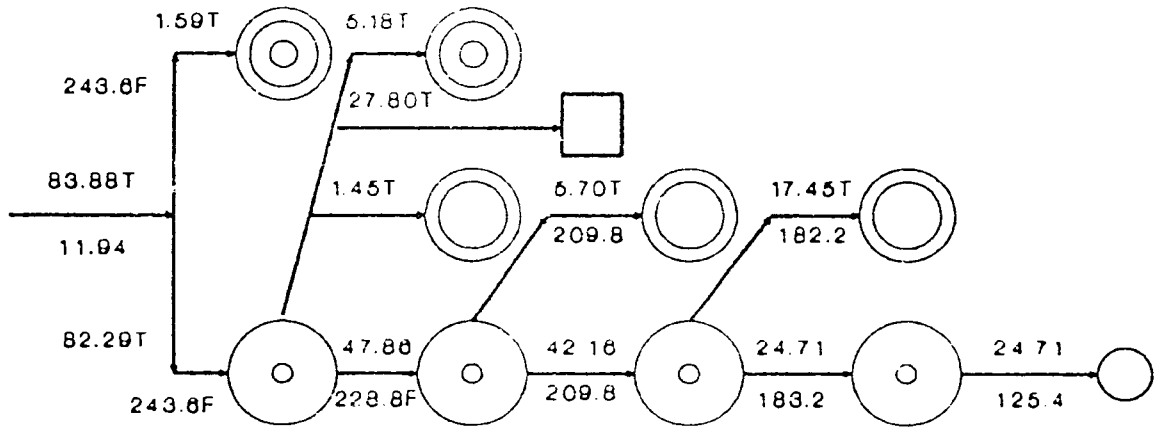
Reheating

Evaporation

Table A.2a

Evaporator Performance Based on 200 TCH
Quadruple Effect
Varying Pressures in Calandria of First Effect
26" HG. Vacuum in Vapor Space of Last Effect

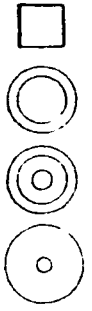
Item C: - Calandria pressure
- 11.94 lbs. gauge



Cell	I	II	III	IV
Evaporation, Tons/hr	82.29	47.86	42.16	24.71
Allowable, lbs./Sq.Ft.	12.85	12.85	12.85	8.5
Sq. Ft. Required	12,800	7,440	6,560	5,820

Heating (1st stage):-	198 x	(177-90)/988	= 17.45T	vapor from 3rd effect
Heating (2nd stage):-	198 x	(205-177)/972	= 5.70T	vapor from 2nd effect
Heating (3rd stage):-	198 x	(212-205)/960	= 1.45T	vapor from 1st effect
Boiling:-			= 27.80T	vapor from 1st effect
Reheating (1st stage):-	216 x	(225-202)/960	= 5.18T	vapor from 1st effect
Reheating (2nd stage):-	216 x	(232-225)/950	= 1.59T	steam at 11.94 lbs. gauge
Evaporation:-	[197-3 (17.45)-2(5.70)-1.45-27.80 -5.18]/4		= 24.71T	steam at 11.94 lbs. gauge
		Total	= 83.88T	steam at 11.94 lbs. gauge

KEY



Boiling

Heating

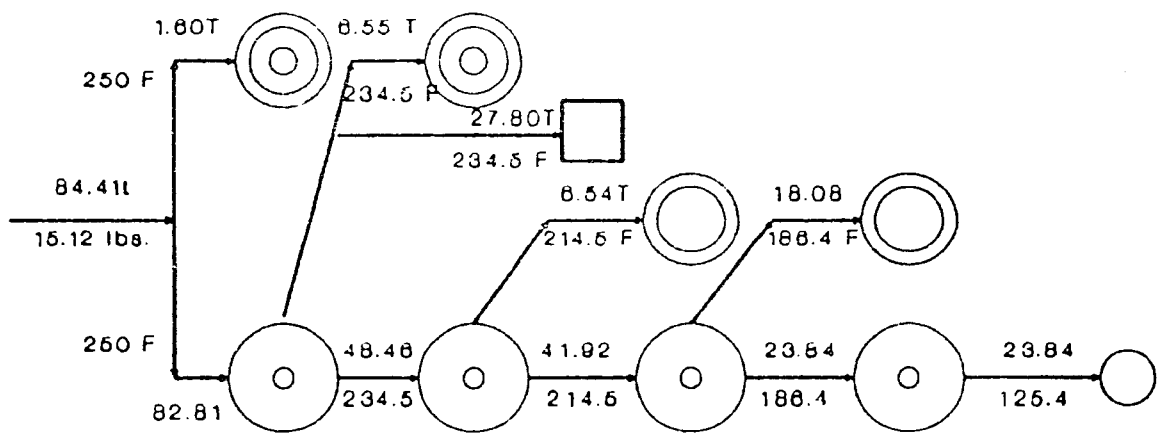
Reheating

Evaporation

Table A.2b

Evaporator Performance Based on 200 TCH
Quadruple Effect
Varying Pressures in Calandria of First Effect
26" HG. Vacuum in Vapor Space of Last Effect

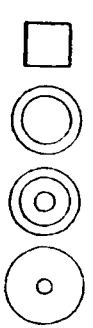
Item D: - Calandria Pressure
- 15.12 lbs. gauge



Cell	I	II	III	IV
Evaporation, Tons/hr	82.81	48.46	41.92	23.84
Allowable, lbs./Sq.Ft.	15.0	15.0	15.0	8.5
Sq. Ft. Required	11,030	6,460	5,590	5,610

Heating (1st stage):-	198 x	(180-90)/986	=	18.08T	vapor from 3rd effect
Heating (2nd stage):-	198 x	(212-180)/969	=	6.54T	vapor from 2nd effect
Boiling: -			=	27.80T	vapor from 1st effect
Reheating (1st stage):-	216 x	(231-202)/956	=	6.55T	vapor from 1st effect
Reheating (2nd Stage):-	216 x	(238-231)/945	=	1.60T	steam at 15.12 lbs. gauge
Evaporation:-	[197-3 (18.08)-2(6.54)-27.80-6.55]/4		=	23.84T	steam at 15.12 lbs. gauge
		Total	=	84.41T	steam at 15.12 lbs. gauge

KEY



Boiling

Heating

Reheating

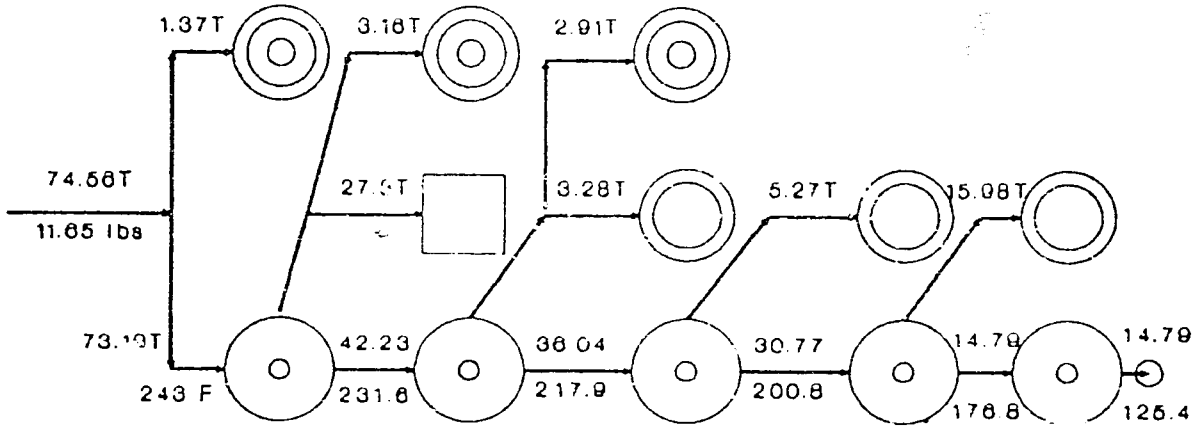
Evaporation

Table A.3a

Evaporator Performance - Quintuple Effect
Based on 200 TCH

Varying Pressures in Calandria of First Effect
26" HG Vacuum Vapor Space of Last Effect
Quadruple Effect

Item E: - Calandria pressure
- 11.65 lbs. gauge



Cell	I	II	III	IV	V
Evaporation, Tons/hr	73.19	42.23	36.04	30.77	14.79
Allowable, lbs./Sq.Ft.	10.4	10.4	10.4	10.4	6.75
Sq. Ft. Required	14,070	8,130	6,935	5,915	4,380

Heating (1st stage):-	198 x	(170-90)/992	= 15.98T	vapor from 4th effect
Heating (2nd stage):-	198 x	(196-170)/977	= 5.27T	vapor from 3rd effect
Heating (3rd stage):-	198 x	(212-196)/967	= 3.28T	vapor from 2nd effect
Reheating (1st stage):-	216 x	(215-202)/967	= 2.91T	vapor from 2nd effect
Reheating (2nd stage):-	216 x	(229-215)/958	= 3.16T	vapor from 1st effect
Boiling:-			= 27.80T	vapor from 1st effect
Reheating: (3rd stage):-	216 x	(235-229)/950	= 1.37T	steam at 11.65 lbs. gauge
Evaporation: {197-4 (15.98)-3(5.27)-2(3.28)-2(2.91) -3/16-27.80}/5			= 14.79T	steam at 11.65 lbs. gauge
		Total	= 74.56T	steam at 11.65 lbs. gauge

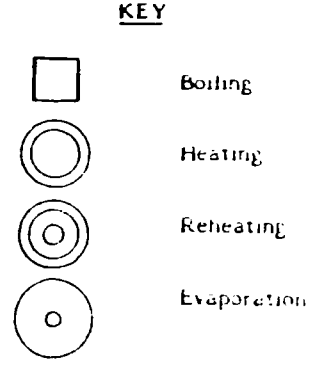
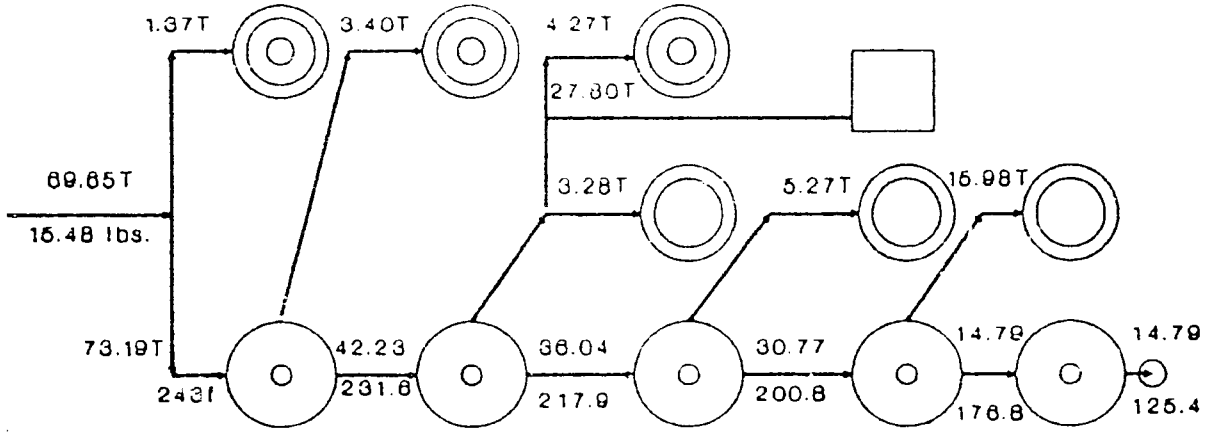


Table A.3b

Evaporator Performance - Quintuple Effect
Based on 200 TCH

Varying Pressures in Calandria of First Effect
26" HG Vacuum Vapor Space of Last Effect
Quadruple Effect

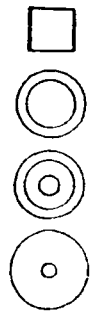
Item F: - Calandria Pressure
- 15.12 lbs. gauge



Cell	I	II	III	IV	V
Evaporation, Tons/hr	68.28	64.88	30.54	25.05	8.25
Allowable, lbs./Sq.Ft.	12.5	12.5	12.5	12.5	6.75
Sq. Ft. Required	10,920	10,380	4,890	4,010	2,445

Heating (1st stage):-	198 x	(174-90)/990	=	16.80T	vapor from 4th effect
Heating (2nd stage):-	198 x	(201-174)/974	=	5.49T	vapor from 3rd effect
Heating (3rd stage):-	198 x	(212-201)/962	=	2.27T	vapor from 2nd effect
Boiling: -			=	27.80T	vapor from 2nd effect
Reheating (1st stage):-	216 x	(221-202)/962	=	4.27T	vapor from 2nd effect
Reheating (2nd stage):-	216 x	(236-221)/953	=	3.40T	vapor from 1st effect
Reheating (3rd stage):-	216 x	(242-236)/945	=	1.37T	steam at 11.65 lbs gauge
Evaporation:-	[197-4 (16.08)-3(5.49)-2(2.27)-2(27.80) -2(4.27)-3.40]/5		=	8.25T	steam at 11.65 lbs. gauge
		Total	=	69.65T	steam at 11.65 lbs. gauge

KEY



Boiling

Heating

Reheating

Evaporation

APPENDIX B

Financial and Economic Models and Data

Table B.1

FINANCIAL AND ECONOMIC ANALYSIS OF
ELECTRICITY PRODUCTION FROM COSTA RICAN SUGAR MILLS
CANEPRO MODEL VERSION 1

Revised: 7-2-88

MILL: EL VIEJO
OPTION: 3 BASE

SUMMARY OF RESULTS

Project: El Viejo 3 BASE — Date: 7-2-88
Season: All Year Electricity Production, Bagasse and Oil
System: New Topping Turbine and Three Condensing Turbines

Total kWh product./yr.	99,669,553	NPV, financial (M CRc)	191.45
Total kWh export/yr.	91,942,949	[M US$]	2.62
Power export (MW)	11.4	NPV, after tax (M CRc)	95.73
Tot. invest.(M CRc)	702	[M US$]	1.31
[M US$]	9.59	NPV, economic (M CRc)	(164.61)
Av. elec. cost (CRc/kWh)	4.01	[M US$]	(2.25)
[US$/kWh]	0.05	Discounted net Forex [M US$]	(5.68)
Av. cost supplement. -trash	NA	Discounted net Forex--SER [M US$]	(6.70)
fuel [US$/kWh] -oil	0.05	IRR	NA
-coal	NA	Percentage equity financing	20%
Net power employment (days/yr.)	10,050	Loan interest rate	11%

TECHNICAL ASSUMPTIONS

Sugar Mill and Fuel Characteristics

Total Cane Milled (MT/y)	300,000	Boiler Fuels	
Mill Size (MT/d)	2,941	In-crop Bagasse used	78,977
Bagasse to Boiler (MT/y)	97,020		
Bagasse Moisture (%mcwb)	50.0%	Supplemental Fuels	
Trash-25%mcwb GCV (BTU/lb)	6,053	Surplus Mill Bag.-50%mcwb (MT/y)	18,043
Bag. GCV (BTU/lb)	4,007	Purchased Bag.-50%mcwb (MT/y)	0
Fuel Oil GCV (BTU/lb.)	18,230		
Coal GCV (BTU/MT)	11,200	Cane Trash-25%mcwb (MT/y)	0
Exported kWh/MT Bagasse	180	Coal (MT/y)	0
ExportedkWh/MT Cane Trash	0	Petroleum (gal/y)	8,393,191
Exported kWh/MT Coal	0	Wood (MT/y)	0
Exported kWh/gal. Fuel Oil	9	Displaced Fuel	
		Electricity (kWh/y)	341,496
		Petroleum (gal/y)	147,000

Power Plant Characteristics

Boiler Configuration	
Lb/hr (x1000)	200
Psig,deg	455, 660 FFT
Tot. Generator Cap. (kW)	3 Cond. Turb. & 3 [illegible]

Annual Power Distribution			Total
Total Power In-Crop (kWh)	13,397,464	Total Power Off-Crop (kWh)	86,272,039
Sugar Factory (kWh)	2,399,904	Sugar Factory (kWh)	2,055,688
Power Plant (kWh)	199,932	Power Plant (kWh)	659,046
Outside Load (kWh)	599,976	Outside Load (kWh)	1,812,053
Exportable (kWh)	10,197,652	Exportable (kWh)	81,745,297
Daily Load Factor	100%	Daily Load Factor	100%
Days of Export (d/y)	83	Days of Export (d/y)	252
Exported (kWh)	10,197,652	Exported (kWh)	81,745,297
Tot. Annual Export (kWh)	91,942,949	Exported (MW)	11.44

FINANCIAL AND ECONOMIC ASSUMPTIONS

Project Life (years)	20		
Rates			
Discount Rate	12%	Marginal Tax Rate	50%
Private Bank Interest Rate	31%	Exchange Rate (CRc=1 US$)	73.20
National Bank Interest Rate	26%	Shadow Exchange Factor	16%
Concessionary Interest Rate	11%	Shadoow Exchange Rate (SER):	61.49
Import Duty	0%	Shadow Wage Factor (enter 1 if no change)	1.00
Capital Investment Options (0=no, 1=yes)		Fuel Prices	
Full Equity	0	Surplus Bag.-50%mcwb (CRc/MT)	0
Debt/Equity		35%mcwb (CRc/MT)	NA
Private Bank	0	Purchased Bag. (CRc/MT)	143
National Bank	0	Cane Trash-35%mcwb (CRc/MT)	867
Concessional	1	25%mcwb (CRc/MT)	867
		Imported Coal	4,392
Percentage Equity	20%	[US$/MT] $60 Inflation(%/yr)	0%
		Oil [M US$/gal] $18 Inflation(%/yr)	0%
Capital Invest. for Improved/New Power Systems		Wood (CRc/MT)	0
Imported Equip. (M CRc)	505.67	Electricity Purchase Price (CRc/kWh)	
Foreign Ex.-Fin. [M US$]	6.91	Financial-Interim In-Crop (yrs 1-5)	5.0
ForEx-SER [M US$]	8.01	Off-Crop (yrs 1-5)	5.0
		Negotiated In-Crop (yrs 6-20)	3.7
Local Equip. Costs (M CRc)	196.54	Off-Crop (yrs 6-20)	3.7
[M US$]	2.69	Economic-Avoided In-Crop (yrs 1-5)	5.0
		Off-Crop (yrs 1-5)	5.0
Installation (% capex)	0%	In-Crop (yrs 6-20)	3.7
		Off-Crop (yrs 6-20)	3.7
Install. Costs (15% capex)	0.00	Electricity Tariff (Displaced Fuel)	4.7
ForEx-Fin. [M US$	0.00	Power Inflation Factor (%/yr)	0%
ForEx-SER [M US$	0.00	In-Crop Labor Wage (CRc/hr)	84
		Laborers/day	10
		Hours/day	24
Tot. Cap. Invest. (M CRc)	702.21		
Tot. Cap. Invest. [M US$]	9.59	Off-Crop Labor Wage (CRc/hr)	84
Percentage Foreign/Tot Cap.	72%	Laborers/day	10
Maintenance (% Cap.Invest.)	3%	Hours/day	24
% Foreign Ex.	25%	Trash Labor	

BENEFIT-COST ANALYSIS: Financial and Economic Analysis
(colones x1000)

PROJECT YEARS:		1	2	3	4
BENEFITS					
Electricity Revenues (Total)		459,715	459,715	459,715	459,715
Interim Price (Years 1-5)					
In-Crop	5.0 CRc/kWh	50,988	50,988	50,988	50,988
Off-Crop	5.0 CRc/kWh	408,726	408,726	408,726	408,726
Negotiated Price (Years 6-20)					
In-Crop	3.7 CRc/kWh	0	0	0	0
Off-Crop	3.7 CRc/kWh	0	0	0	0
Displaced Fuel Costs (Total)		6,217	6,217	6,217	6,217
Electricity	4.7 CRc/kWh	1,605	1,605	1,605	1,605
Petroleum	31 CRc/gal	4,612	4,612	4,612	4,612
ForEx-Fin. [M US$]		0.06	0.06	0.06	0.06
ForEx-SER [M US$]		0.08	0.08	0.08	0.08
Total Benefits		465,931	465,931	465,931	465,931
Per kWh-(Undiscounted) CRc/kwh		5.07	5.07	5.07	5.07
Per Kwh (Undiscounted) USc/kWh		6.92	6.92	6.92	6.92
ForEx-Fin. [M US$]		0.06	0.06	0.06	0.06
ForEx-SER [M US$]		0.08	0.08	0.08	0.08
COSTS					
Capital Investment					
Full Equity	0	0	0	0	0
Debt/Equity					
Private Bank	0	0	0	0	0
National Bank	0	0	0	0	0
Concessional	1	210,986	70,544	70,544	70,544
Total Capital Investment		210,986	70,544	70,544	70,544
Tot. ForEx-Fin. [M US$]		2.08	0.69	0.69	0.69
Tot. ForEx-SER [M US$]		2.41	0.81	0.81	0.81
Operations and Maintenance		21,066	21,066	21,066	21,066
ForEx-Fin. [M US$]		0.07	0.07	0.07	0.07
ForEx-SER [M US$]		0.09	0.09	0.09	0.09
Labor					
In-Crop		1,680	1,680	1,680	1,680
Off-Crop		5,074	5,074	5,074	5,074
Total Labor		6,754	6,754	6,754	6,754

Financial and Economic Models and Results

Fuel					
Surplus Bag.	0 CRc/MT 50%mcwb	0	0	0	0
Purchased Bag.	143 CRc/MT 50%mcwb	0	0	0	0
Cane Trash	867 CRc/MT 35%mcwb	0	0	0	0
	867 CRc/MT 25%mcwb	0	0	0	0
Coal (Imported)	4,392 CRc/MT	0	0	0	0
ForEx-Fin.	[M US$]	0.00	0.00	0.00	0.00
ForEx-SER	[M US$]	0.00	0.00	0.00	0.00
Petroleum	31 CRc/gal	263,306	263,306	263,306	263,306
ForEx-Fin.	[M US$]	3.60	3.60	3.60	3.60
ForEx-SER	[M US$]	4.28	4.28	4.28	4.28
Wood	0 CRc/MT __%mcwb	0	0	0	0
Total Fuel		263,306	263,306	263,306	263,306
Total Costs		502,112	361,670	361,670	361,670
Average per kWh-(Undiscounted) CRc/kWh		4.0			
Average per kWh-(Undiscounted) US$/kWh		$0.05			
ForEx-Fin. [M US$]		5.74	4.36	4.36	4.36
ForEx-SER [M US$]		6.78	5.17	5.17	5.17
ANNUAL NET BENEFITS		(36,180)	104,261	104,261	104,261
(Net Profits before Taxes)					
Annual Net Foreign Exchange-Fin		(5.68)	(4.30)	(4.30)	(4.30)
Annual Net Foreign Exchange-SER		(6.70)	(5.10)	(5.10)	(5.10)

FINANCIAL ANALYSIS RESULTS

NPV (Financial)	191,450.02
[M US$]	2.62
IRR	-5%
(Guess %) 0%	

ECONOMIC ANALYSIS RESULTS

NPV (Economic)	(164,608.34)			
[M US$]	(2.25)			
Annual Net Imported Oil Displacement [M US$]	(4.21)	(4.21)	(4.21)	(4.21)
NPV ForEx [M US$]	(33.35)			
NPV ForEx--SER [M US$]	(17.59)			
Public Capital Invest. Displaced [M US$]	9.59			
Net Employment (days/yr.)	10,050.00			

Table B.2

Financial NPV's for Best, Base and Worst Cases
(Million US$)

Mill	Best	Base	Worst
Level 1			
QA	1.11	0.82	0.44
EV1	1.37	1.10	0.45
Level 2			
EV2	4.28	2.86	-0.62
Level 3			
EV3	11.48	2.62	-9.99
Level 4			
EV4	10.86	-0.09	-8.62
TB4	14.22	2.21	-20.92

Table B.3

NPV's for Electricity Price Sensitivity Analysis
(Million US$)

Mill	Financial NPV			Economic NPV		
	Low	Medium	High	Low	Medium	High
Level 1						
QA	0.73	0.82	0.99	0.73	0.82	0.99
EV1	1.04	1.10	1.21	1.12	1.18	1.29
Level 2						
EV2	2.51	2.86	3.49	2.48	2.83	3.47
Level 3						
EV3	-0.78	2.62	8.66	-5.65	-2.25	3.80
Level 4						
EV4	-3.85	-0.09	6.59	-9.04	-5.29	1.39
TB4	-1.85	2.00	8.84	-6.33	-2.48	4.36

Table B.4

NPV's for Oil Price Sensitivities
(Million US$)

Mill	Constant Inflation*				Variable**	
	0%	1%	2%	3%	2% $14/bbl	2% $18/bbl
Level 1						
QA	NA	NA	NA	NA	NA	NA
EV1	1.10	1.13	1.17	1.20	1.03	1.14
Level 2						
EV2	2.86	2.89	2.92	2.96	2.79	2.90
Level 3						
EV3	2.62	0.95	-0.88	-2.90	6.84	0.50
Level 4						
EV4	-0.09	-1.64	-3.33	-5.20	3.82	-2.05
TB4	2.21				5.19	0.14

* Rates apply from year 1 to 20.
** Rates apply from year 5 to 20.

Table B.5

NPV's for Loan Rate Sensitivities
(Million US$)

Mill	Loan Rates (%) 7%	11%	26%	31%
Level 2*				
EV2	3.15	2.86	2.33	2.16
EV2T	3.11	2.82	2.29	2.12
Level 3				
EV3	4.40	2.62	-0.68	-1.76
EV3T	7.51	5.70	2.35	1.26
Level 4				
EV4	3.13	-0.09	-6.05	-7.99
EV4T	5.38	2.02	-4.19	-6.12
Taboga				
TB4	5.78	2.00	-4.80	-7.02
TB4T	6.48	2.79	-4.01	-6.23

* No Capital investments are made in QA, EV1 and EV1T.

Table B.6

NPV's for Daily Load Factor Sensitivities
(Million US$)

	Daily Load Factors	
	100%	60%
Level 1		
QA	0.82	0.38
EV1	1.10	0.82
EVT	0.05	-0.57
Level 2		
EV2	2.86	1.16
EV2T	2.82	0.38
Level 3		
EV3	2.62	-2.88
EV3T	5.70	-1.09
Level 4		
EV4	-0.09	-8.06
EV4T	2.02	-7.13
TB4	2.00	-8.19
TB4T	2.79	-7.72

Table B.7
Mill Options Estimated
Installed Capital Costs
(M US$)

	Level 2	Level 3	Level 4	
	El Viejo EV-2	El Viejo EV-3	El Viejo EV-4	Taboga TB-4
Equipment Type	3750 KW Back Pressure (Topping) Turbine 455 psig Inlet and 200 psig Exhaust Pressures	EV-2 Back Pressure (Topping) Turbine Plus 3 Condensing Turbines 3750 KW Each, 200 psig Inlet Pressure and Condensing at 3" Hb Abs Also Improvements in Factory Steam Balance	850 psig 850°FTT Boiler and Double Extraction and Condensing 15,625 KW Turbogenerator. Also Factory Steam Balance Improvements	
			Boiler 215,000 lbs. Steam/hr Bagasse and Fuel Oil Firing	Boiler 250,000 lbs. Steam/hr. Bagasse, Fuel Oil and Coal Firing
Cost Item				
1. Factory Improvements				
(a) 5th Effect evaporator cell, condensate flash recovery equipment, condensate testing and storage tanks		0.48	0.65	0.71
(b) Juice heaters and piping		0.36	0.36	0.39
(c) Steam and vapor piping and insulation		0.24	0.44	0.51
(d) Bagasse baler, bale breaker, conveyors and storage		0.16	0.46	0.80
2. Boiler and/or Boiler Improvements				
(a) Boiler and accessories			6.74	7.05
(b) Piping and insulation	0.13	0.29	0.77	0.80
(c) Fuel oil and/or coal burning equipment		0.36	0.42	0.98
		0.15	0.15	0.18
				0.85
3. Turbogenerator and Electrical Equipment				
(a) Turbogenerator foundations, building modifications	0.87*	4.32*	4.17**	4.81**
(b) Condensers and pumps		0.44	0.60	0.63
(c) Switchgear, instrumentation, transformers and power factory improvement equipment	0.54	2.80	2.01	2.06
TOTAL ESTIMATED COST	1.54	9.60	17.31	19.77

* 4,160 VAC to 13,800 VAC
** 13,800 VAC to 4,160 and 69,000 VAC
Total costs include installation and engineering costs.

Appendix C

Economic Analysis Methods and Assumptions

Economic analysis assumes the national perspective in assessing the attractiveness of an investment. As contrasted with financial analysis, which determines private market incentives, economic assessment shows a project's contribution to, or drain on, national welfare. Key benefits and costs are shadow valued where market interventions--such as taxes, externalities, subsidies, undervalued currency, etc.--distort market prices.* In addition to shadow valuing particular benefits or costs, all transfers within the economy such as taxes, import duties and interest charges are excluded in an economic analysis.

Critical variables that are significant to the net benefits streams of the cane power systems considered for Costa Rica whose financial prices do not reflect their social value include:

- electricity purchase prices, which should be based on the avoided costs to ICE of displacing their peaking fuels;
- all foreign exchange used in purchasing fuel (oil and imported coal), capital, and recurring operational costs; and
- discount rates that are based on social versus current market rates.

Establishing purchase prices that account for the long run marginal costs of electricity generation in Costa Rica is based on an avoided cost methodology described in detail below. Foreign exchange is needed for capital, a portion of the operations and maintenance, and imported fuel expenditures. According to A.I.D. Mission economists, the appropriate shadow exchange rate is 1.16 since the colon is currently overvalued. Several discount rates are used in the analyses to assess the effect on net returns of varying the time value of money.

---

* Shadow pricing individual benefit or cost streams raises some theoretical and practical problems. Arguments against shadow valuing are eloquently stated by Lipsey and Lancaster (1957) in their "second best" theory. According to that theory, changing specific prices will affect relative price adjustments within an economy. Thus, shadow pricing cannot be justified in a project where high interdependence exists in the project variables to the economy. Practically, two counter arguments can be made. First, many financial prices are already distorted by serious market interventions--taxes, subsidies, quotas, and trade agreements; thus the primacy of market prices is not completely justified, although it is clear price adjustments can occur. Second, sensitivity analyses using shadow prices for key factors tell what would occur if these price relationships prevailed, rather than implying that only these shadow values are acceptable.

Wages are not shadow priced in the analyses since there reportedly is a seasonal shortage of skilled and unskilled labor around the mills, with some operators paying for workers' transport costs or providing transport to the mills. At present, no attempt is made at shadow pricing trash prices for inclusion of environmental costs (nutrient removal) or field owner benefits (reducing trash disposal costs). On-going experiments on cane trash collection and impacts by A.I.D.'s Office of Energy will provide better data on actual costs or benefits. The above variables are shadow priced in the economic, best versus worst case, and sensitivity analyses. Data used in these analyses are presented in Tables C.1, C.2, and C.3.

A Suggested Method for Computing Avoided Costs*

In order to deliver "firm" power to the ICE grid, a sugar mill will need to produce with a high degree of reliability. This reliability will, in turn, affect the price that ICE is willing to pay for output.

The two types of costs that a sugar mill can save for the utility are energy costs and capacity costs. Avoided Energy Costs (AEC) are those variable costs that a utility saves by purchasing power from a sugar mill. Typically, these include fuel and variable operation and maintenance costs.

Avoided Capacity Costs (ACC) are those capital charges that the utility may avoid by not purchasing a given increment to its capacity. To determine ACC, it is first necessary to calculate the reliability of the power supplied by the sugar mill. Such reliability is a system concept. That is, reliability cannot be determined just by the operation of one facility. Rather, it needs to be related to the characteristics of the utility's load, the size and outage rates of the utility's own units, and the sequence in which the units are operated. From ICE's viewpoint, the important question is not the reliability of the sugar mill units alone. Rather, they must know how reliable their system will be if they purchase power from a sugar mill or a group of mills.

Using the accepted Loss of Load Probability (LOLP) as the main measure of system reliability, a Reliability Ratio (RR) can be calculated for the proposed facility. To compute RR, one must first determine the Effective Load Carrying Capacity (ELCC) of the proposed facility; i.e. how much can the system peak increase with the new facility. The computation of ELCC requires that the utility hold the LOLP constant or at an acceptable level.

---

*Source: Excerpted from Flaim (1985) in A.I.D. September 1986. "Electric Power From Cane Residues in Thailand: A Technical and Economic Analysis", Appendix C. Produced by RONCO Consulting Corporation for the Office of Energy, Bureau for Science and Technology, U.S. Agency for International Development.

Table C.1

Economic versus Financial Analysis
Assumptions for Key Variables

Data	Financial	Economic
Discount Rate	Market rate (12%)	Social rate (10%)
Benefits		
Purchase Elec. Price	Suggested negotiated prices: °5 CRc/kWh(yrs 1-5) °3.7 CRc/kWh (yrs 6-20)	Avoided costs: Low: °5 CRc/kWh (yrs 1-5) °3 CRc/kWh (yrs 6-20) High: °5.8 CRc/kWh (yrs 1-5) °4.2 CRc/kWh (yrs 6-20)
Displaced Fuel Oil	Market price ($18 or $14/bbl)	Foreign exchange shadow value (16% above market price)
Costs		
Capital	Market value Includes interest at varying rates Debt financed, payments spread over loan period	Foreign component shadow valued No interest charge Paid in year 1
O & M	Local and foreign component not differentiated	Foreign component shadow valued
Labor	Market wage rate	Not shadow valued due to labor constraints in sugar industry
Fuel Oil	Market Price ($18 or $14 bbl)	Foreign exchange shadow value (16% above market price)

Table C.2

Data Assumptions for Sensitivity Analysis

Variable	Base	Range
Electricity Purchase Price	5 CRc/kWh (yrs 1-5) 3.7 CRc/kWh (yrs 6-20)	Low: 5.0 CRc/kWh (yrs 1-5) 3.0 CRc/kWh (yrs 6-20) High: 5.8 CRc/kWh (yrs 1-5) 4.2 CRc/kWh (yrs 6-20)
Bank Loan Rates	11%	Concessionary: 7, 11% National: 26% Private: 31%
Daily Load Factor	100%	60-100%
Fuel Oil Prices and and Inflation Rates	$18/bbl	Low price: $14/bbl Annual inflation rates Constant: 0, 1, 2, 3% Variable: 2% in Yrs 5-20
Trash Price	$11.80/MT	Low: $10/MT High: $15/MT
Discount Rates	12%	10%, 12%, 15%, 25%

Table C.3

Data Assumptions for Best, Base, and Worst Cases

Variable	Best	Base	Worst
Daily Load Factory (%)	100	100	60
Discount Rate (%)	10	12	25
Loan Rate (%)	7	11	31
Imported Duty (%)	0	0	30
Fuel Prices			
Fuel Oil inflation (%/yr) (at $18/bbl)	0	0	2
Trash Prices ($/MT)	10.00	11.80	15.00
Elec. Purchase Price (CRc/kWh)			
yrs 1-5	5.8	5.0	5.0
yrs 6-20	4.2	3.7	3.0

ICE can calculate LOLP with and without the proposed sugar mill facilities. From this computation, they can give an ELCC for that facility. The Reliability Ratio, then, is simply the ratio of the ELCC to the facility's nameplate capacity.

i.e.

$$RR = \frac{ELCC}{Capacity} \qquad (1)$$

A value of RR close to 1 (it is always less than 1) means that the system's peak load can increase by a factor close to the nameplate capacity of the proposed facility. A high RR value is important if sugar mills are to receive maximum credit for their electricity production, and therefore, maximum payment.

The capacity savings for the system will come in the form of retired or deferred plants. To determine these values, ICE will need to calculate the weighted Average Avoided Cost (AAC). This calculation starts with an estimation of avoided costs by time period. That is, the utility will calculate the impacts of the sugarmill on the daily and seasonal generating cycles of its system and on the energy costs for the two alternatives. Such a calculation will give the value of the ELCC; i.e. how much the new facility can increase the system peak throughout the daily demand cycle. The Avoided Capital Cost in a given period, then, is the uniform capital cost associated with a reduction in system load during that period. Step Two is the reliability analysis outlined above. Calculation of ELCC from Step One provides the needed input for determining the value of RR. Step Three is to combine the data on AEC and ACC to give an overall Average Avoided Cost. Symbolically, this may be represented as an equation:

$$AAC = \frac{[(AECi)(kWhi) + (ACCi)(kWhi)(RR)]}{kWhi} \qquad (2)$$

This formula computes the weighted average of the energy costs and the capital costs in period i avoided by the investment in the facility. The calculation must be done for each period of the utility's load to determine the change in ELCC for each configuration of power plants and power demand.

An example may be instructive at this stage. Assume that ICE has just two energy sources, gas and oil. Suppose that AEC for gas is $0.03/kWh at all times and that the AEC for oil is $0.04/kWh at all times. Now suppose that the proposed facility has a reliability ratio of RR=0.95, i.e. 95%. Suppose further that the Avoided Capital Cost per kW is $1,220 (leading to a capital cost per kWh of $0.03 under 10 year amortization of a 10% loan). Finally, assume that the current generating mix is gas: 60%, oil= 40%. For simplicity's sake, assume that the power generated

during the period in question is 1000 kWh. Using equation (2), we would get an AAC of:

$$AAC = \frac{[0.03 \times 600 + 0.04 \times 400] + [0.03 \times 1000 \times 0.95]}{1000}$$

$$= \$0.06/kWh$$

That is, in our hypothetical example, each kWh of power from the proposed facility would save ICE $0.06/kWh.

Such calculations need to be made with real data from the ICE system. However, the method is sound and can be understood easily by all of the parties to the agreement.

In Costa Rica, one of the major considerations for sugar mills and ICE would be the importance of the power produced during the off season. Suppose, for example, that the system peak were to occur during the sugar milling season and that the ELCC was increased only slightly if at all during that period. Under those circumstances, RR would be small (low ELCC) and the main credit to the sugar mill would come in the form of an energy credit. However, if the system peak occurred during the sugar milling off season and the ELCC was increased by almost the full amount of the capacity of the plant then the mill would be due a capacity payment by ICE. In all likelihood, the sugar mill would help ICE with part of its April load, thereby earning some capacity credit. However, the calculation would need to be done carefully for various system configurations.

ICE may not be willing to pay the entire value of AAC to the sugar mill. However, the value of AAC should be considered as a maximum figure. Regardless of the specific figure negotiated by ICE and the sugar mills, the calculated value of AAC shows the value to Costa Rica of such a power supply. As long as the price paid by ICE to the sugar mill is less than AAC, such production gives a net benefit to the Costa Rica.

Note: Much of the material in this Appendix is Drawn from the excellent article by Theresa Flaim, "Avoided Costs for Solar Facilities," Energy Policy, June, 1985, 267-282. The thrust of this article was aimed at intermittent electricity providers. Nevertheless, it provides a useful summary of the concepts needed to compute the relevant avoided cost figures.

Appendix D

Trash Harvesting for Costa Rican Sugar Mills

The cost estimates for trash (cane residue) harvesting in Costa Rica are summarized in Table D.1. The approach recommended by the study team is based on an examination of experience in the Dominican Republic, the Philippines, Jamaica, Puerto Rico, Hawaii and Texas. Papers reviewing trash harvesting activities around the world can be found in the published results of A.I.D.'s special workshop on the subject, held in Hawaii in April, 1987.[1]

Procedure

Cane field residues can be harvested in a variety of ways, depending on the site-specific circumstances of the sugar operation involved. In Hawaii, in most locations, whole cane is harvested in one operation. In the Dominican Republic, cane residues (called barbojo) are raked into windrows, chopped with a regular forage chopper, and blown into specially designed wagons. The wagons are transported by ox and tractor to an extensive network of cane rail loading points, and transported to the mill by the mill-owned rail system.

Based on recent A.I.D.-sponsored experiments carried out in Hawaii by the Hawaiian Sugar Planter's Association, the study team recommends that the Costa Rican industry use standard, commercially available, rectangular balers to bale residues that have been either raked into windrows by tractor-drawn rakes (the "base case" for cost estimates) or either hand-raked or thrown into windrows during the harvest process itself. The bales, which can be varied in size to permit manual loading, would then be transported to the mill by the same means as cane. Since the trash will be used in the "off" season, the bales can be stacked in piles near the fields or at decentralized depots until cane hauling equipment is free to bring the material to the mill. The latter approach would permit the designation of a smaller area for storage and handing at the mill itself. Once at the mill, the trash would be stored until needed, at which time it would be fed to a tub grinder for shredding and introduced to the boilers using the same fuel feeders employed for bagasse.

---

[1]See M. Gowen, Rapporteur and Editor, "Cane Energy Symposium," Vol. II (Washington, D.C.: A.I.D., 1987).

Moisture

Research in a variety of locations suggests that hand-harvested field residues of unburned cane would, after a period of field drying, have a moisture of some 25-35 percent. In Costa Rica the cane is currently burned before harvest, and the study team has assumed that this would continue to be the procedure. Burning removes the dryest parts of the cane, especially attached desiccated leaves, leaving the green tops to be removed during harvest. The green tops have a greater moisture, but the team has assumed that the burning dries these, leaving approximately the same moisture as unburned material. A period of field drying would quickly bring these to the 20-25% moisture assumed in the technical analysis presented here. Storage piles at the mill and at field depots should be covered with plastic or thatch to prevent the absorbtion of moisture during rainy periods. If this is done, the moisture will remain the same or actually decline.

Harvesting Unburned Cane

The study team strongly recommends that Costa Rican mills choosing to sell electric power conduct experiments to determine the costs and benefits of harvesting unburned cane. Although this would increase the cost of hand harvesting, it might produce enough increased revenues--especially where the trash harvested would displace imported oil or coal--to justify its adoption as a standard agricultural practice. Because the benefits would be industry wide, LAICA itself might undertake some factory/field experiments to collect information of this kind.

Costs

The cost estimates for trash harvest, transport, storage, and preparation are based on data collected for El Viejo Mill. As noted in the text of Chapter 2, the quantities that would be available. even after burning, appear to be much greater than the amounts proposed for use by the study team. The mill analyses assume that 19,636 tons would be burned. In order to present a more realistic cost estimate, the cost analysis here assumes a larger number, 32,727 tons, allowing the capital costs to be spread over a larger tonnage.[2]

---

[2]The cost of the harvest of only 19,636 metric tons, using the same capital equipment, would be US$ 12.60 ton.

Table D.1

Trash Cost Estimates for Costa Rican Mills
Based on Data from El Viejo Mill
(metric tons and colones)

Financial Assumptions	
interest rate	0.26
loan period (yrs)	5
import duty	30%
Technical Assumptions, Mill	
mill cane (mt/y)	300,000
mill grind rate (mt/hr)	150
days of grinding/yr	102
in-crop	102
out-of-crop-	0
Technical Assumptions, Field	
cane % mill alnd	65%
mill harv. cane (mt/y)	195,000
mill harv. trash (mt/y)	21,273
prod. harv. cane (mt/y)	105,000
prod. harv. trash (mt/y)	11,455
total trash available	32,727
av. moisture (%)	25%
Cost Assumptions	
harvest equip set (e)	
harvest capital cost/set	1,142,454
[cost in U.S.$]	$15,586
Duty	342,736
total capital cost	1,485,190
annual capital cost/per set	563,624
tons/harvest equip. set/yr	10,167
harvest capital cost/ton	55
materials cost/ton	53

Fuel Processing	
mill capital cost/hrly ton	219,900
[cost in U.S.$]	$3,000
duty	65,970
Total capital cost	285,870
hourly tons fuel use	25
total mill capital cost	7,075,283
mill capital cost	2,685,045
total fuel tons/yr	32,727
processing capital cost/ton	82
mill labor cost/ton	17
field labor cost/ton	60
transport cost/ton	150
tractor/driver cost/ton	400
farmer payment/ton	73
benefit (no re-burn)/ton	73
Total trash cost/ton	867
[in U.S.$]	$11.8
Economic Attributes	
for. exch. cost/ton [US$]	$1.9
Total for. exch. cost [US$]	$18,586
field employment (days/ton)	0.02
field employment (days)	6545
other employment (days/ton)	0.014
other employment (days)	409
total employ (days)	6,955

The cost estimates presented in Table D.1, below, are based on the following assumptions:

1. The quantity of trash is estimated at 12 MT for each 110 MT of cane.

2. Harvest equipment is a set of two machines, a Ford-New Holland side delivery rake (model 258, $3,458 delivered), and a Ford-New Holland standard baler (model 26, $11,928, delivered), totalling $15,366. To these prices we have added $200 for internal delivery in Costa Rica. Prices as quoted by Ford-New Holland, 6-9-88.

3. The equipment is assumed to produce 100 tons of bales per set per day.

4. Materials cost is for baling twine.

5. Fuel processing cost is higher than it would be if a larger amount of field residues could be collected. The amount collected here is sufficient for only 55 days of off-crop operation.

6. Mill labor costs per ton assume two full-time skilled laborers managing a boiler feed rate of 25 tons per hour. The rate includes 10 colonos per ton (fuel cost and depreciation) for the use of the front-end loader used during the season for bagasse handling.

7. Field labor cost assumes an unskilled worker loads one ton per hour, or 20 to 25 square bales. Cost is the same as that for one ton of cane.

8. Transport cost is double the average cost of transporting one ton of cane to the mill.

9. Tractor cost assumes that one half hour of tractor/driver time is required to harvest each ton of cane. Lease of tractor/driver cost 800 colonos per hour.

10. To reflect the higher cost of trash harvested from lands and other than those controlled by the mill, 73 colonos has been included as payment to farmers.

11. Benefit for no burning is a credit to the mill for costs now incurred to dispose of trash.

Appendix E

Domestic and Imported Coal Resources for Electricity Production at Costa Rican Sugar Mills

Costa Rican Coal

In 1978 the Instituto Costarricense de Electricidad (ICE) started a program to investigate the economic potential of the coals of the Baja Talamanca region of Costa Rica. Subsequent studies completed in 1980 established the presence of numerous coal outcrops in the Rio Carbon Volio drainage basin. In 1981 A.I.D. funded a brief reconnaissance of this region by Miller and Landis of the U.S. Geological Survey. This was the beginning of cooperative studies between the USGS and several Costa Rican organizations.

In 1982 a preliminary study of 144 square kilometers of the Baja Talamanca region (including the Rio Carbon Volio area) was undertaken by Malavassi and Bolanos of ICE, with assistance of the Japanese International Cooperation Agency. Later in 1982 this entire program was transferred to Refinadora Costarricense de Petroleo (RECOPE) under the direction of O. Ramirez. To date, geologic mapping and chemical analyses have been undertaken (or are being undertaken in the areas of Zent, Volio (Utsai), and Venada. Very preliminary information is also being gathered from some of the other coal fields of Costa Rica (eg. San Carlos, Puriscal, etc.).

Locations of Coal Deposits and Candidate Sugar Mills

Preliminary estimations of the quantity, quality, and accessibility of the known coal deposits in Costa Rica suggest that two of these areas (Zent and Uatsi) have the greatest potential for use in the near future for industrial purposes. The Venado depostis might also be developed in the future if needed.

Approximate distances of transport from Zent, Uatsi, and Venado coal fields to these mills are shown in Table E.1. Transport costs by roads in Costa Rica are estimated to be 5.25 colones per metric ton per kilometer (equivalent to US$ 0.07 per metric ton per kilometer).

Quantity and Quality of Domestic Coal Resources

Table E.2 shows the rank of the coals and projected reserves for each of the three major exploitable coal fields in Costa Rica. Note that the Venado field, which is closest to the candidate mills, has the smallest reserves and is lowest in heating value of the three fields.

Table E.1

Distances by Road from Coal Fields to Candidate Sugar Mills
(kilometers)

Sugar Mills	Coal Fields		
	Venado	Zent	Uatsi
Taboga	85	309	424
El Viejo	125	34	454
Quebrada Azul	45	180	265

Table E.2

Total Reserves of Costa Rica Coal (Dec. 1986)
(million metric tons)

Coal Field	Resource Type	Proven Res.	Probable Res.	Possible Res.	Total Reserves
Uatsi	Subbit. A & B	19.3	9.1	4.1	32.5
Zent	Subbit. B & C	5.6	5.4	3.8	14.8
Venado	Lignite A & Subbit. C	2.0	-	-	2.0

The average chemical composition and energy content of coals from the three fields are shown in Table E.3. The Uatsi coals are highest n rank (avg. 10,500 But/lb dry),. followed by the Zent coals (avg. 8,500/lb dry, and by the Venado coals (av. 6,000 But/lb dry). The Uatsi coals also have the lowest ash content and highest fixed carbon content.

Lead Times Required to Develop Domestic Coal Deposits

According to RECOPE, the exploitation of the Zent deposit is scheduled to begin sometime in mid-1988, with about 1,000 metric tons being mined for initial tests and about 10,000 metric tons being mined for commercial purposes. This coal is scheduled to be used in the Costa Rican cement industry. RECOPE has also indicated that it has plans to develop both the Uatsi and Venado fields in the near future (3 to 4 years from now), depending upon future demand for coal. If this schedule for development proves to be correct then any of these three deposits would be available for use in this cane energy project.

Table E.3

Geochemical and Energy Characteristics of Costa Rican Coals
(Avg. Value)

	Uatsi		Zent		Venado	
Calorific Value	Wet	Dry	Wet	Dry	Wet	Dry
Kcal/Kgr	4000	5724	3221	4699	2000	3500
Btu/lb	7200	10300	5800	8500	3600	6300
Moisture (% wt.)	33.59	-	27.09	-	35.00	-
Ash (% wt.)	13.85	17.04	22.55	29.74	28.00	-
Vol. Mat. (% wt.)	29.71	44.72	30.04	41.89	15.00	-
Fixed C (% wt.)	25.41	38.24	20.67	28.68	10.00	-
Total S (% wt.)	1.0	1.5	1.0	1.4	1.0	-

Imported Coals

Table E.4 shows published chemical and energy characteristics for export coals from Colombia and Chile provided by three exporting companies. These values indicate that the Colombian and Chilean coals are significantly higher in quality than the domestic Costa Rican coals. Note the higher calorific values and lower ash, sulfur, and mositure contents (as received).

Table E.4

Published Quality of Colombian and Chilean Coals (As Received)

Company	Calorific Value	Ash (%)	Sulfur (%)	Moist. (%)
Proceso (Colombia)	6,500 kcal/kgr 11,700 Btu/lb	10	0.85	10
Carbones (Colombia)	7,500 kcal/kgr 13,500 Btu/lb	8.5	0.75	7
Evacar (Chile)	7,124 kcal/kgr 12,825 Btu/lb	13	2.9	9
Evacar (Chile)	5,750 kcal/kgr 10,350 Btu/lb	17	2.9	11

Relative Costs of Imported and Domestic Coals

Table E.5 shows the estimated costs for imported coals and Table E.6 shows the costs for domestic coals. It is expected that, if coals are imported for use in the sugar mills, they will be unloaded at the Pacific port of Caldera. Thus, costs were determined for transportation to this port.

In preparing Table E.5, the FOB and shipping costs were obtained from the exporting companies and the storage and handling costs were provided by RECOPE. Ground transportation costs were obtained by multiplying the map distances (most direct route by road) by a transportation rate of 5.25 colones per metric ton per kilometer (provided by RECOPE).

Table E.5

Estimated Costs per Metric Ton of Colombian and Chilean Coals
(Costs Provided by RECOPE)

Coal Field	Destination	Embarking Port/MT	Ship Cost	Storage & Handl	Ground Transport To Mill/MT			Tot. Costs Deliv. To Mill/MT		
					Taboga	El Vie.	Que	Taboga	El Vie.	Que
Colombia	Caldera	$45	$16	$3.65	47.00	$8.75	$9.80	$72	$73	$74
Chile (12825 Btu)	Caldera	$37	$16	$3.65	$7.00	$8.75	$9.80	$64	$65	$66
Chile (10350 Btu)	Caldera	$35	416	$3.65	$7.00	$8.75	$9.80	$62	$63	$64

For Table E.6, a base price of $27 per metric ton (at the mine) was utilized. This is the price that RECOPE has recently announced for coal from the El Indio Mine at Zent, which will begin production within the next few months. Transportation costs were calculated in the same manner as for the imported coals.

As these tables indicate, the total costs per metric ton of coal delivered to each of the mills are considerably higher for the imported coals ($58 to $74) than for the domestic coals ($30 to $57). However, the Colombian and Chilean coals have much higher heating values that the Costa rican coals. Thus, a greater amount of Costa Rican coals would be needed to produce an equal amount of heat as that which can be produced by a metric ton of the imported coal.

Table E.6
Estimated Costs per Metric Ton for Costa Rican Coals

Coal Fields		Sugar Mills	
	Taboga	El Viejo	Quebrada Azul
Venado			
Cost (FOB) Mine	$27	$27	$27
Trans. Cost	6	8	3
Tot. Cost @ Mill	$33	$35	$30
Zent			
Cost (FOB) Mine	$27	$27	$27
Trans. Cost	21	23	13
Tot. Cost @ Mill	$48	$50	$40
Uatsi			
Cost (FOB) Mine	$27	$27	$27
Trans. Cost	28	30	17
Tot. Cost @ Mill	$55	$57	$44

A better comparison of the costs of using imported versus domestic coals is indicated in Table E.7. This table shows the relative costs of the coals in terms of equal units of heating value (cost per million Btu's). Using this comparison, it is evident that the costs of Costa Rican coal would be significantly higher and that these would probably not be economical to use.

Table E.7
Costs of Imported and Domestic Coals per Million Btu

	Cost in $ per MT Delivered to Mill			Cost per Million Btu @ Mill*		
	Taboga	El Viejo	Quebrada Azul	Taboga	El Viejo	Quebrada Azul
Imported						
Colombia (11700Btu)	72	73	74	3.30	3.34	3.39
Colombia (13500Btu)	72	73	74	2.86	2.90	2.94
Chile (12825Btu)	64	65	66	2.68	2.72	2.76
Chile (10350Btu)	62	63	64	3.21	3.26	3.31
Domestic						
Venado (3600Btu)	33	35	30	4.91	5.21	4.47
Zent (5800Btu)	48	50	39	4.44	4.62	3.60
Datsi (7200Btu)	55	57	44	4.09	4.24	3.28

*Btu values reduced to reflect 85% boiler efficiency.

Appendix F

Biomass-Fired Steam-Injected Gas-Turbine Cogeneration for the Cane Sugar Industry

Abstract

Considerable amounts of power could be produced at cane-sugar factories for export to the utility grid (while meeting on-site energy needs) by adopting more energy-efficient cogeneration and sugar-processing technologies. With off-season operation of the power plant using an auxiliary fuel (e.g. stored cane tops and leaves), still larger quantities of electricity could be exported. Modern condensing extraction steam turbines have been installed in several factories worldwide. By comparison to these, steam-injected gas turbines fired with gasified biomass, which could become commercially available within a few years, offer higher thermodynamic efficiencies, lower unit capital costs, and weaker scale economies. A case study based on the Jamaican Monymusk factory indicates attractive rates of return on gas turbine investments, compared to those for steam turbines. Gas turbines have the potential to provide some 1000 GWh per year of electricity using the presently produced cane residues in Jamaica. Globally, over 50,000 MW of gas turbine capacity could be supported with the 1985 level of cane-residue production. The costs of producing this electricity would be lower than the estimated costs for power from most central station alternatives including hydro.

Introduction

This study was undertaken to assess the prospects for increasing the production of exportable electricity from sugar factories by the use of gas-turbine cogeneration systems, with residues from the cane as the primary fuel. [1] Gas turbines at sugar factories would represent a fundamental technological change, involving some risks, so their expected technical and economic performance must be far better than that of the commercially established steam turbine before they could be considered for the sugar industry. To compare advanced gas-turbine and modern steam turbine cogeneration, a case study based on the Jamaican Monymusk factory was undertaken, with data drawn in large part from a study exploring the feasibility of installing a large condensing extraction steam turbine (CEST) cogeneration system at Monymusk. [2]

Exporting Electricity from Sugar Factories

Bagasse-fired cogeneration is familiar to the world's sugar industry, but few sugar factories generate excess electricity for export to national utility grids. A typical factory cogeneration system would product some 20 kWh of electricity per tonne of cane crushed (kWh/tc)--just enough to meet on-site demand. Such a system would also meet on-site steam demands and leave no excess bagasse. A modern, large condensing extraction steam turbine (CEST) cogeneration system, similar to that being considered for Monymusk and to those already installed at a few factories (e.g. in Hawaii [3] and Reunion [4], could export in excess of 100 kWh/tc, while meeting on-site energy demands. If steam-conserving process technologies widely used in oil-dependent industries like beet-sugar and dairy (e.g. condensate juice heaters, falling film evaporators, and continuous vacuum pans) were adopted at cane sugar factories, still more electricity (perhaps 25% more) could be exported to the grid. Furthermore, if an auxiliary fuel were used for power production in the off-season, the total electricity generation would be still higher--some 240 kWh/tc (Figure F.1).[1]

The biomass-gasifier steam-injected gas turbine (biomass-GSTIG) cogeneration system considered in the present study, if operated year-round at a "steam-conserving" factory would produce about 460 kWh/tc, or about double that for a CEST and 23 times as much as that produced at a typical sugar factory today (Figure F.1).

GSTIG Technology

The biomass-GSTIG system (Figure F.2) would operate by converting the biomass feedstock into a combustible gas in a pressurized gasifier, which would be coupled to an aircraft-derivative steam-injected gas turbine. Some of the air from the gas turbine compressor would be used in the gasifier, and the combustible gas would be cleaned of particulates before burning it in a combustor with the balance of the compressor air. The hot turbine exhaust gases would raise steam in a heat recovery steam generator (HRSG), some of which would be required to operate the gasifier and the rest of which could be used for process needs or for injection into the combustor. The injection of steam into the combustor leads to an increase in both power output and electrical efficiency.[2]

---

[1] Note that in all cases in Figure F.1, for ease of comparison, the electricity production is referenced to the cane processed during the milling season.

[2] With steam injection, the higher mass flow through the turbine expander increases power output. Higher efficiency is achieved largely because only a negligible amount of additional work input is required to pump the boiler feed water to boiler pressure, avoiding the large amount of work required to compress a gaseous working fluid. Aircraft-derivative gas turbines are chosen for steam injection, because they are designed to accommodate turbine flows considerably in excess of their normal ratings. [5]

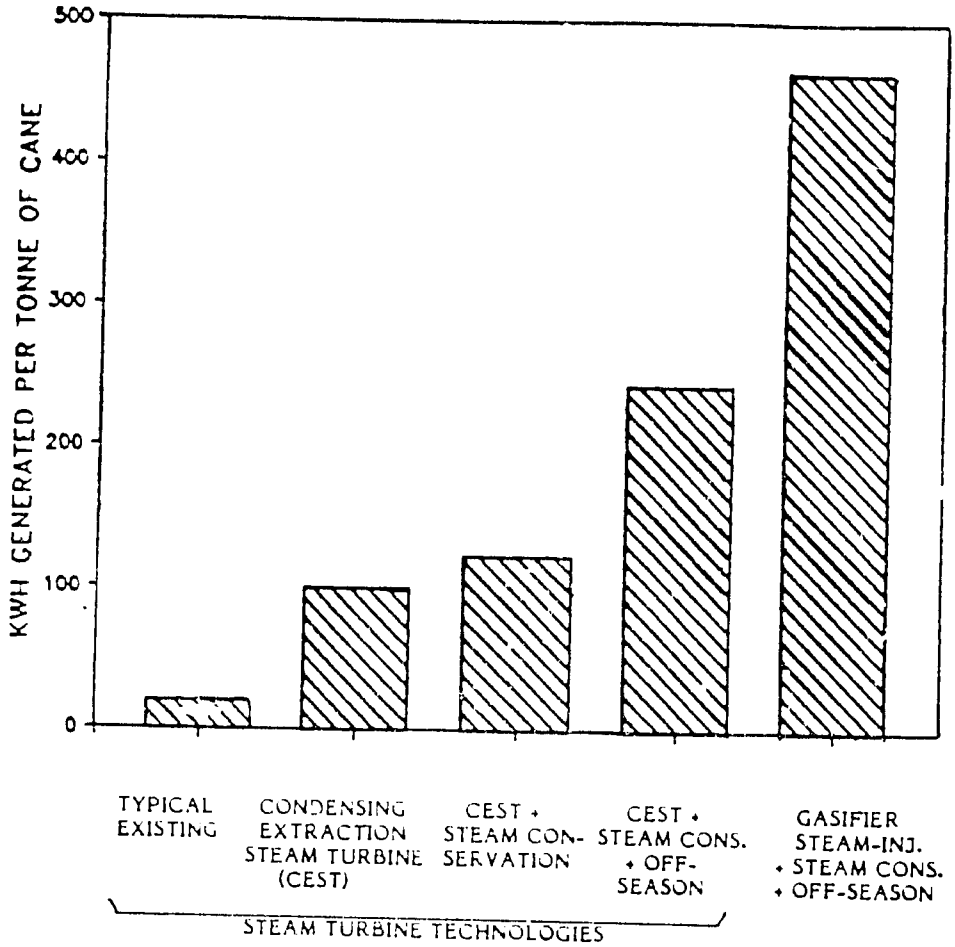


Figure F.1: Electricity generating potential of cane-residue-fired condensing extraction steam turbine and gasifier steam-injected gas turbine cogeneration systems. The two right-most bars include the effects of reduced process steam demand and off-season operation with an auxiliary fuel. [1]

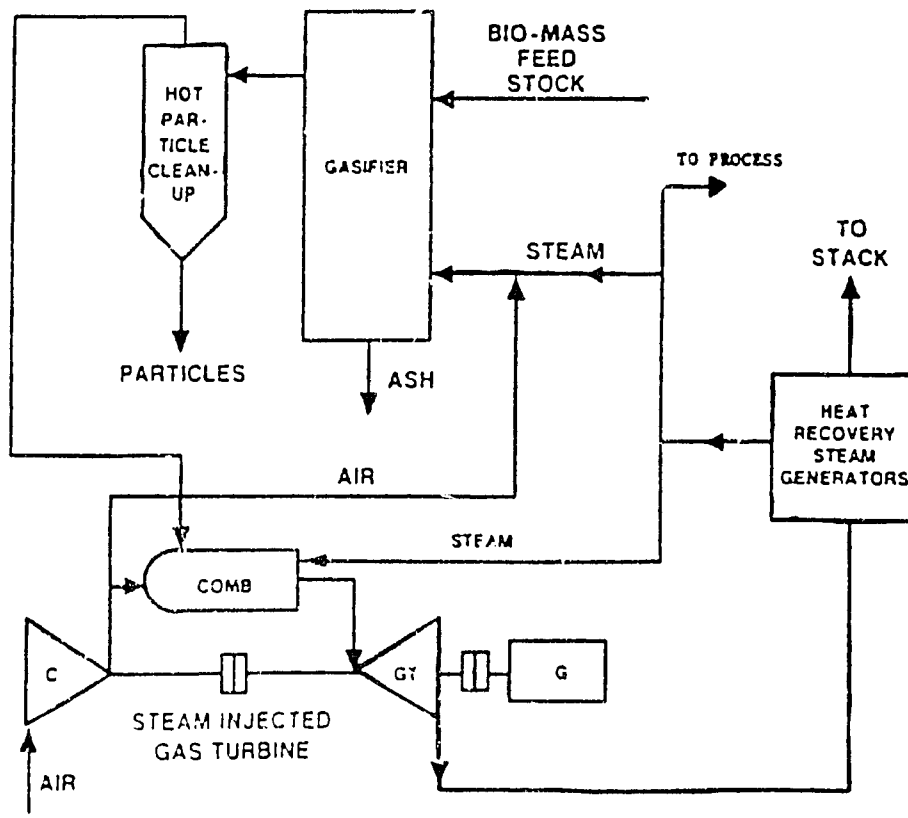


Figure F.2: Schematic representation of a biomass-gasifier steam-injected gas turbine (biomass-GSTIG) cogeneration cycle.

Steam-injected gas turbines fired with natural gas have been operating commercially in the United States for several years in cogeneration applications. This technology is attractive for cogeneration applications, because steam not needed for process can be injected to produce more power; under provisions of the Public Utilities Regulatory Policies Act (PURPA) in the U.S., the extra electricity can be sold to the utility at a reasonable price,[3] thus extending the financial viability of gas turbine cogeneration to a wide range of variable steam-load applications. [5]

Steam-injected gas turbines fired with gasified coal has been under development by the General Electric Company (GE) in the U.S., with support from the Department of Energy (USDOE), [6] following the successful commercial demonstration of a gas turbine-steam turbine combined cycle[4] operating on gas derived from sulfur-bearing coal at the 100-MW Cool Water central station power plant in California. [7] As of the time of this writing, however, an agreement between the USDOE and GE to continue this $156 million "clean coal" program had not been reached. A key goal of the coal-GSTIG program is the development of a system for removing sulfur from the hot combustible gas, which would considerably improve the system's efficiency compared to the cold-scrubbing system used at Cool Water. Should the clean coal program proceed, GE indicates that a commercial-scale demonstration of the hot-gas sulfur-removal technology would be undertaken within one year, followed within three years by the startup of a 5-MW coal-GSTIG pilot plant and within six years by the startup of a 50-MW commercial demonstration plant. [8]

The coal-GSTIG technology is largely transferable to systems based on biomass. In fact, the higher reactivity of biomass makes it inherently easier to gasify than coal. [9] Furthermore, most biomass contains no sulfur, obviating the need for, and additional cost of, the sulfur removal equipment. Thus, no new technology must be proven to use biomass in GSTIG systems. [8] In fact, by "piggy-backing" onto the ongoing work on coal-GSTIGs, the commercialization of the biomass-GSTIG technology could be accomplished in about 3 years. [8]

---

[3] PURPA requires electric utilities to purchase cogenerated electricity at a price equal to the cost the utility could avoid by not having to otherwise supply that electricity.

[4] In a gas-turbine steam-turbine combined cycle power plant, the hot exhaust from a simply-cycle gas turbine is used to raise steam in a HRSG, which in turn is used to drive a condensing steam turbine, which augments the power production of the gas turbine. Industrial (not aircraft-derivative) gas turbines are used in combined cycles.

Performance and Cost Estimates of Biomass-Cogeneration Technologies

Performance

Fueled by bagasse during the milling season, both CEST and GSTIG cogeneration systems could produce variable amounts of electricity and process steam, as the simplified representation in Figure F.3 indicates. To increase electricity production in a CEST, a greater fraction of the steam would be condensed rather than extracted. In a GSTIG, a greater fraction of the steam produced in the HRSG would be injected into the combustor. At any level of process steam production, the GSTIG units would produce roughly twice as much electricity per tonne of cane as the CEST (Figure F.3). However, the maximum level of process-steam production for the GSTIG systems considered here is about 300 kg/tc,[5] while the CEST could produce in excess of 400 kg/tc. Matching the available process steam with the steam demands at a sugar factory is discussed below.

Costs

Capital: Installed unit capital costs have been estimated for several sizes of CEST and GSTIG systems[6] (Figure F.4). [1] Unit costs are higher for CEST systems, and they have stronger associated scale economies. Unit costs for the GSTIG would be lower because of their substantially higher energy efficiency and reduced material requirements (e.g. no condenser or cooling tower). In addition, scale economies would be weaker than for the CEST systems, since even in the larger sizes it is expected that shop fabrication, rather than field assembly, could be used extensively.

Also shown for comparison in Figure F.4 is a cost estimate for a new 61-MW coal-fired central station power plant, which is discussed below. This was previously identified in a report for the Jamaica Public Service Company (JPS) [11--hereafter refered to as the MONENCO report] at a least-cost expansion option.

---

[5] The total steam produced in the HRSG of a GSTIG would be in excess of 300 kg/tc. It is estimated, however, that the Lurgi-type gasifier considered here would require (primarily for cooling the bed) about 20% of the total steam production, which is based on the steam requirements when gasifying coal in this type of gasifier. [6] The gasification steam required with biomass may actually be lower, although sufficient testing with biomass has not been carried out to determine this. An alternative gasifier, e.g. a pressurized fluidized-bed unit such as the Rheinbraun High-Temperature Winkler unit, may require virtually no steam, since its normal operating temperature without steam would be relatively low. [11]

[6] The United States' GNP deflator has been used to express all costs in this report in constant 1985 U.S. dollars.

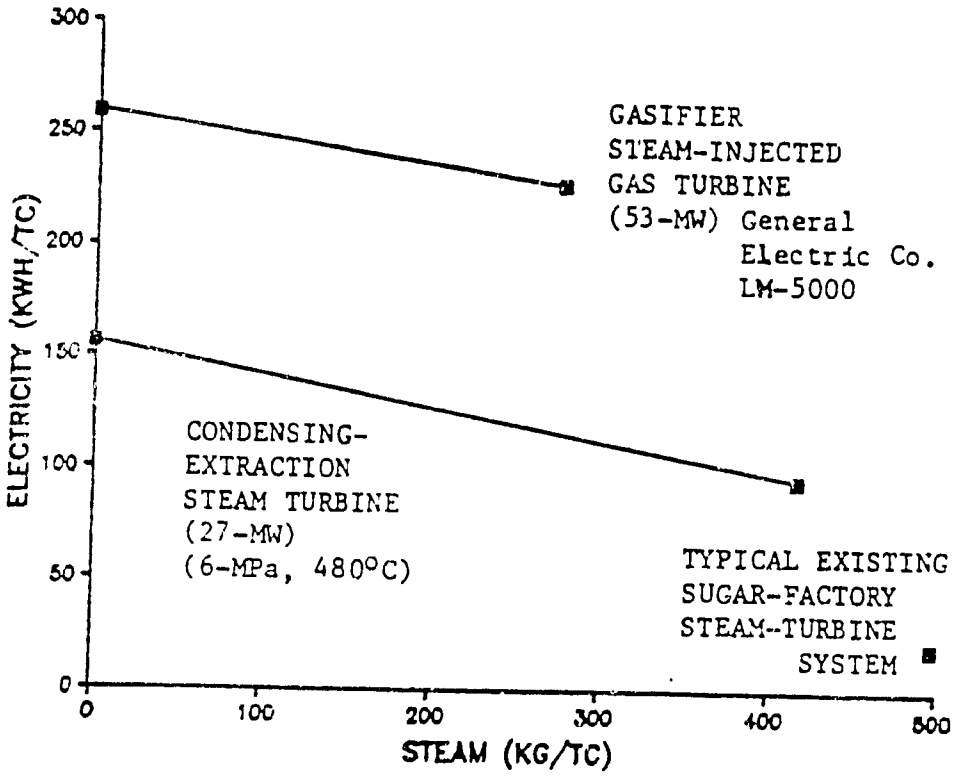


Figure F.3: Steam and electricity production estimates for CEST and GSTIG cogeneration systems operating at sugar factories during the milling season with bagasse as fuel. [1]

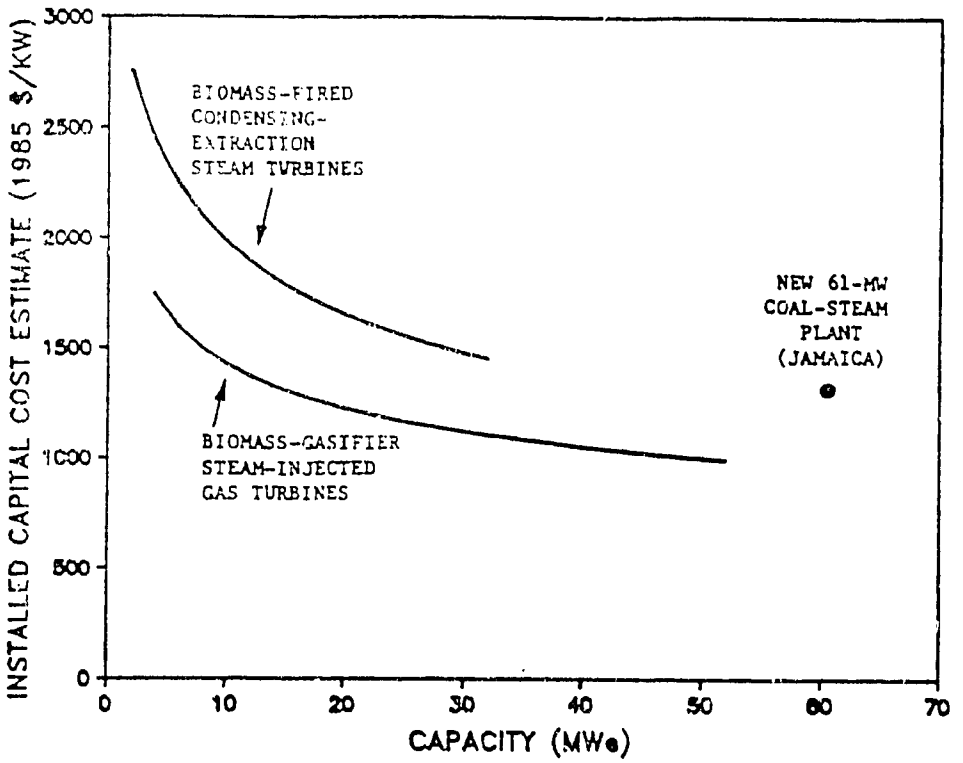


Figure F.4: Estimated unit capital costs for biomass-fired CEST and GSTIG cogeneration system, [1] and estimated capital cost for a new 61-MW central station coal-steam plant in Jamaica. [11]

Maintenance: Maintenance costs are a key consideration for gas turbines. They are believed to be relatively high, based primarily on the electric utility experience with peaking gas turbines. Indeed, with low capacity factors and repeated starts and stops, such units often have high per-kWh maintenance costs. [12] However, with the proper maintenance programs that accompany most gas turbines operating in baseload applications, the costs can be quite modest.[7]

Minor maintenance of aircraft-derivative gas turbines, upon which GSTIG systems would be based (see footnote 2), is facilitated by the modular design of the machines originally developed to minimize down time for aircraft. Major maintenance is typically done off-site, while a replacement engine continues to produce power. The replacement engines are often leased or purchased from manufacturers as part of a service agreement. In other cases, manufacturers provide innovative service contracts which guarantee delivery (anywhere in the world) in installation of a replacement engine within a specified period of a major engine failure (e.g. 48 hours), which is made possible by the very compact nature of aero-derivative machines.

With relatively low maintenance costs, stationery gas turbines, including many aircraft-derivative units, are operating in industrial applications worldwide (See Figure F.5).

Table F.1 provides a summary of the cost assumptions used in the financial analysis discussed in the next section. Maintenance cost estimates were based on previous studies and discussions with industry experts. [1] The operating labor estimates are based on employment data for power plants operated by JPS as a function of plant capacity. [11]

Table F.1
Cogeneration Costs Assumed for the Financial Analysis[a]

Cogeneration System =====>	CEST	GSTIG
Capacity (MW)	27	53
Unit Cost ($/kW)	1560	990
Total Installed Cost (10^6\$)[b]	42	53
Fixed Maintenance (10^3\$/yr)	660	1300
Variable Maintenance ($/kWh)	0.003	0.001
Number of operating employees	24	55
Labor cost (10^3\$/yr)	130	300

a From [1]
b If steam conservation retrofits are made at the factory, the capital cost would increase by $3.1 million (see Table F.2).

7 For example, the Dow Chemical Company has operated several natural-gas-fired Pratt and Whitney FT-4 aircraft-derivative gas turbines (15-20 MW each) in cogeneration plants in the San Francisco area for some 20 years, with total maintenance costs averaging $0.002-$0.003/kWh. [12]

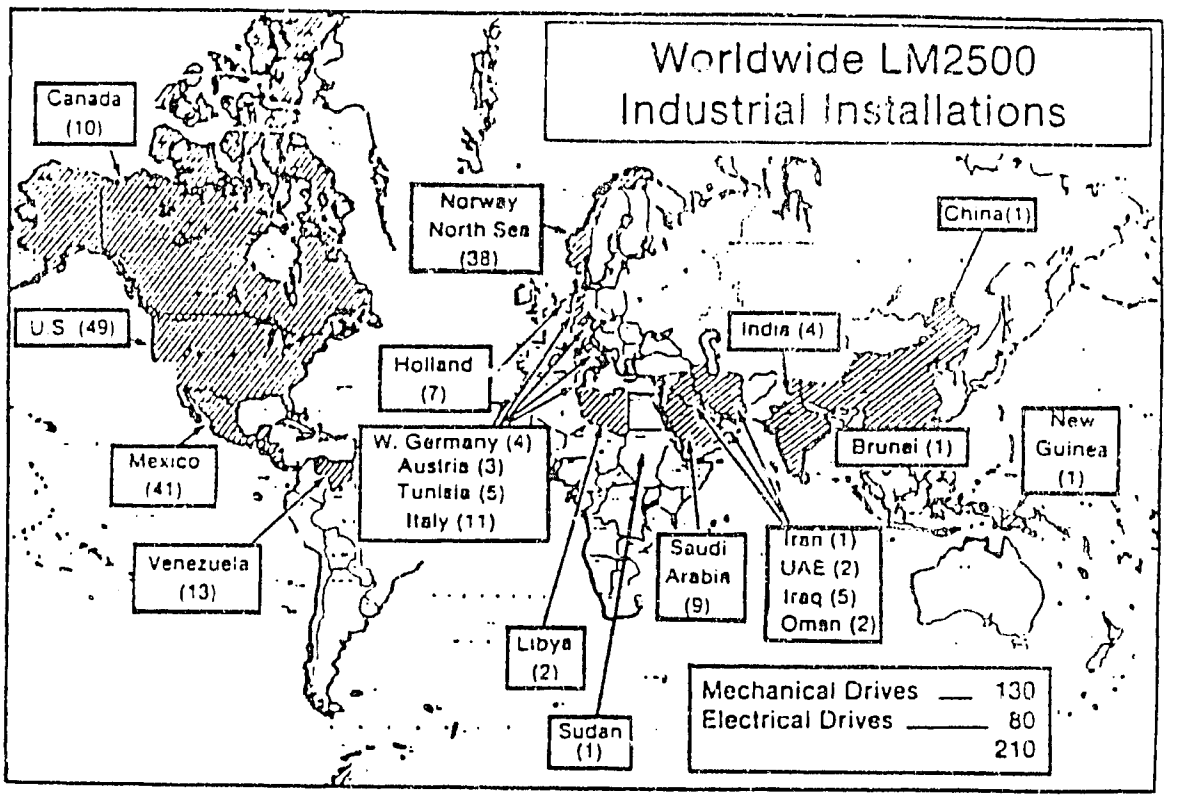


Figure F.5: Current worldwide industrial installations of the General Electric LM-2500 aircraft-derivative gas turbine. (Supplied by the General Electric Company, Cincinnati, Ohio, USA.)

CASE STUDY: A Sugar Producer's Perspective

To explore the financial feasibility of exporting electricity, internal rates of return have been calculated for CEST and GSTIG cogeneration plants installed at hypothetical raw-sugar factories.

Assumptions

Factory Operation: The operation of the Monymusk Factory, processing a nominal 175 tc/hr during a 206 day season, was chosen as the basis for developing the hypothetical factory energy demands. Monymusk has operated for the last several years with an average cane throughput of 150-160 tc/hr, which is below its rated capacity of over 200 tc/hr, because of inadequate cane supplies and deteriorating factory equipment. [13] With World-Bank supported rehabilitations to field irrigation systems, as well as the processing plant, plans are to raise the throughput to 200 tc/hr, or a total of over 755,000 tonnes per season, by 1990.

Two levels of sugar-factory energy demands considered in this study are summarized in Table F.2 and discussed in detail elsewhere. [1,14] The total steam requirement of 374 kg/tc for the "conventional" sugar factory is based on the performance of existing equipment at Monymusk. To utilize a GSTIG cogeneration system, which would produce a maximum of about 300 kg/tc of process steam (see Figure F.3 and footnote 5), equipment retrofits would be required at a typical factory to reduce steam demand. Decreasing steam demand would also permit a greater amount of electricity to be exported from the CEST. A "steam-conserving" factory considered here would utilize condensate juice heating, falling film evaporators, and continuous vacuum pans to reduce the exhaust steam demand to 209 kg/tc, or that available from the mill turbines (Table F.2).

Exported-Electricity Price: In principle, the price a utility pays a cogenerator for electricity should reflect the cost the utility avoids by not having to supply that electricity itself, e.g. by building new capacity or operating existing plants. The lowest cost of new electricity supplies (including capital, fuel, and O & M charges) in Jamaica is estimated to be 5.0-5.8¢/kWh for a new 61 MW coal-steam plant.[8,9] The cost of operating existing oil-fired plants (O & M and fuel only) in Jamaica is estimated to be 4.5-6.1¢/kWh.[10]

---

[8] Assuming an installed cost of $1316/kW (which includes a proportion of the costs of building a national coal-handling system), a heat rate of 12,030 kJ/kWh, a 66% annual capcity factor, an annual labor cost of $358,000, maintenance costs of $0.002/kWh, a discount rate of 12%, and a 30-year economic life. [11] Assumed coal costs are given in Table F.3.

[9] Generating costs estimated elsewhere [2] for Jamaica are: 8.3¢/kWh for a new coal-fired steam-electric plant, 6.6¢/kWh for a new oil-fired steam-electric plant, and 8.7¢/kWh for a new oil-fired gas turbine plant.

[10] Assuming a heat rate of 14,500 kJ/kWh and an O & M cost of $0.003/kWh. [11] The assumed costs of residual fuel oil are given in Table F.3.

Table F.2

Summary of Factory End-use Scenarios[a]

Factory Type Equipment Retrofits	Cost Thousand 1985 US$	Factory Energy Use Steam (kg/tc)[b,c] [Live]	 [Exhaust]	 Electricity[d] (kWh/tc)
"Conventional" No Retrofits	0	209	374	13.0
"Steam Conserving"		209	209	13.0
Plate/Gasket Juice Heater	100			
5-Effect Falling Film Evap.	2,400			
Continuous Vacuum Pan	600			
TOTAL	3,100			

a From [1]. See also [14]

b Steam conditions are 1.4 MPa, 250°C for live steam and 120°C, saturated for exhaust steam.

c For the analysis of the conventional plant, it is assumed that the existing turbo-alternators are operated to produce all on-site electricity, in which case all of the cogenerated power would be exported, and all steam (374 kg/tc) would be supplied to the factory as live steam. For the steam-conserving factory, the turbo-generators existing in the plant would be retired, and the cogeneration plant would supply on-site electricity needs.

d With a new cogeneration system installed, the previously-existing boiler system (including fans, pumps, and other electrical ancilliaries), which accounts for approximately 1/3 of the electricity demand at a typical factory [15], would be shut down. The electricity demands shown here are with a new cogeneration system. Note that elsewhere in this paper, the electrical output of the CEST and GSTIG systems are specified as net of the cogeneration plant.

Bagasse Costs: During the milling season, a CEST unit would burn unprocessed (50% moisture content) bagasse, for which no cost is charged. For the GSTIG systems it is currently unknown what level of processing of the bagasse will be required for gasification. Five levels that are considered here, and their associated costs, are shown in Table F.3.

Costs of Off-Season Fuel: Since a cogenerator would need to operate year-round to earn an avoided cost that includes a capacity credit, several off-season scenarios are considered here.

Barbojo, the tops and leaves of the cane, is assumed to be the off-season fuel for the base case, cost estimates for which are given in Table F.3. The harvesting and storage of barbojo for energy has not been done on a large commercial scale. However, field trials or small-scale operations have been conducted in Puerto Rico [18], the Dominican Republic [19], Mauritius [20], The Philippines [21], Thailand [22], and Florida [23], and tests are underway in Jamaica. In Puerto Rico, where extensive field trials with three varieties of cane have been carried out, an average of 660 kg of 50% moisture content barbojo were produced with each tonne of cane. (Left on the field after cutting, the barbojo dried from about 50% to 35% moisture with 6 days). One approach being pursued in Jamaica [24] has been to focus on developing cane varieties that will retain most of their leaves through harvesting, with the whole cane being transported to a central location where the barbojo and millable cane would be separated.

Initial trials indicate that increased weed growth and decreased soil moisture retention associated with barbojo removal are not serious problems in some cane-growing regions. Of greater concern appears to be potential damage to an emerging crop and soil compaction (particularly of clay soils, as in Jamaica) on ratooned fields during mechanical collection of barbojo. In any case, while some level of barbojo recovery appears feasible, longer-term studies are required to fully assess the agronomic effects.

Since barbojo has yet to be proven commercially viable, plantation fuelwood is considered as the off-season fuel in a second scenario. Experience in tropical regions indicates that the total costs for establishing fuelwood plantations, harvesting, and chipping is in the range of $1.00 to $1.50/GJ (Table F.3). For the present study, $1.25/GJ is assumed.

Since barbojo recovery is unproven and "energy plantations" would require several years to establish, a third off-season scenario is considered in which oil is burned during the off-season for the first 5 years of operation, followed by a switch to barbojo. The CEST systems would burn residual fuel oil, and the GSTIG would burn distillate fuel oil. The lower oil prices shown in Table F.4 are assumed for operation during this five-year period, since these are the prices currently used in JPS projections to the year 2000. [17]

Table F.3

Levelized Fuel Prices Assumed for The Jamaica Case Study

Fuel	Price (1985$/GJ)
Bagasse	
As delivered from mills, 50% moisture	0.00
Dried to 25% moisture[a]	0.58
Baled, dried to 25% moisture and stored [a]	0.78
Briquetted (12% moisture)[a]	1.16
Pelletized (15% moisture)[a]	2.02
Barbojo	
Baled, dried to 25% moisture, transported and stored[b]	0.97
Briquetted, transported, and stored (12% moisture)[c]	1.35
Pelletized, transported, and stored (15% moisture)[c]	2.21
Plantation Fuelwood	1.00-1.50[d]
Residual fuel Oil	
Low	2.90[e]
High	4.00
Distillate Fuel Oil	
Low	5.40[e]
High	7.50
Imported Coal	
Low	1.43[e]
High	2.08[f]

a From [16].

b Estimated in [2]. The barbojo would dry in the field to roughly 35% moisture, after which it would be baled. It is estimated that it would have a moisture content of about 25% moisture, by the time it is used at the cogeneration plant.

c Calculated as the cost of baled barbojo ($0.97/GJ, which includes transport and storage costs) plus the difference in cost between baling and either briquetting or pelletizing bagasse.

d See Table F.10 in [1].

e Currently used in JPS projections to the year 2000. [17]

f Estimated for Jamaica to the year 2000. [11]

Table F.4: Potential foreign exchange savings to Jamaica with alternative cogeneration systems (based on the 1985 level of cane production) by avoiding construction of new coal-fired capacity or by displacing existing oil-fired capacity.[a]

Generating Technology	Potential New Capacity (MW)	Required Capital Investment (Million $)	Lifecycle Foreign Exchange For Fuel (Million $)[b]	Present Value Of Lifecycle FOREIGN EXCHANGE SAVINGS WITH COGENERATION over Coal/Oil (Million $)	Firing[c] ($/MWh)
1. CEST COGEN[d]	79	132	0		
vs. New Coal-Steam[e]					
Coal @ $1.43/GJ	88	116	70	54	3.54
Coal @ $2.08/GJ	88	116	102	86	5.64
vs. Existing Oil-Steam[f]					
Oil @ $2.9/GJ	0	0	172	not applicable[g]	
Oil @ $3.2/GJ	0	0	190	58	3.81
Oil @ $4.0/GJ	0	0	237	92	6.89
2. GSTIG COGEN[h]	153	160	0		
vs. New Coal-Steam[e]					
Coal @ $1.43/GJ	172	226	138	204	6.84
Coal @ $2.08/GJ	172	226	200	266	8.92
vs. Existing Oil Steam[f]					
Oil @ $2.9/GJ	0	0	337	177	5.94
Oil @ $3.2/GJ	0	0	372	212	7.11
Oil @ $4.0/GJ	0	0	464	304	10.2

a For a cane production of 2.2 million tonnes per year, and CEST and GSTIG export electricity production of 231 and 452 kWh/tc, respectively. Thus, the CEST and GSTIG systems would produce 500 and 1000 GWh/year, respectively.

b For a 12% discount rate and a 30-year lifecycle.

c For this analysis, all of the capital is assumed to be foreign exchange.

d Assuming all of the capacity is installed at a cost of $1671/kW, which includes factory retrofits for a "steam-conserving" factory, and a calculated capacity factor of 73 percent.

e See Footnote 8 for costs of coal-steam electricity.

f See Footnote 10 for costs of oil-steam electricity.

g CEST power would not displace oil-fired power unless the price of oil is at least $3.2/GJ, where the fuel plus operating cost for the oil-fired plants would equal the total generating cost for the CEST ($0.048/kWh).

h Assuming all of the capacity is installed at a cost of $1048/kw, which includes factory retrofits for a "steam-conserving" factory, and a calculated capacity factor of 74 percent.

114

Results

Base-Case: The annual exports of electricity and the estimated financial rate of return (ROR) for alternative cogeneration investments at factories with two levels of process energy demands are shown in Figure F.6. The cogeneration systems considered here are sized for fueling with the bagasse available from the processing of 175 tc/hr: a 27-MW CEST or a 53-MW GSTIG. An investment in the CEST plant at a "conventional" factory estimated to provide a ROR of 13-16%, if barbojo were the off-season fuel. With additional investments in process-equipment required for a "steam-conserving" factory, slightly more electricity could be exported, but the ROR would be virtually unchanged (Figure F.6), since the extra investment costs (Table F.2) would offset the extra electricity revenues.

Investing in the GSTIG system (fueled briquetted bagasse and barbojo[11]) and "steam-conserving" retrofits would provide an estimated ROR of 18-23%, and the exports of electricity would be about double that for the CEST (Figure F.6).[12]

At the "steam-conserving" factory up to $23 of electricity revenue would be generated per tonne of cane crushed, if GSTIG cogeneration were used and if the electricity buy-back rate were 5.0¢/kWh. Sugar revenues would equal electricity revenues for a sugar price of about 23¢/kg. For comparison, electricity revenues with the CEST would equal sugar revenues for a sugar price of about 11¢/kg.

Impact of Alternative Fuels: The "steam-conserving" case is chosen here to illustrate the impact of using alternative fuels.

If less extensive processing than briquetting of bagasse and barbojo were required for the GSTIG, the ROR would increase from a range of 18-23% up to a range of 24-29%, while if pelletizing were required, it would fall to 11.16 percent.

If plantation fuelwood were used as the off-season fuel, the RORs for both CEST and GSTIG would be comparable to those for the base case shown in Figure F.6, since the off-season fuel costs would be comparable. The total fuelwood plantation area required would represent 30-40% of the sugarcane land area,[13] but the GSTIG would export about twice as much electricity per hectare of plantation as the

---

[11] The Lurgi dry-ash gasifier, which is considered for the GSTIG systems analyzed here, was originally designed to gasify chunks of coal. The biomass fuel, therefore, may need to be in a form similar to coal chunks. If an alternative gasifier were considered, e.g. a Rheinbraun High-Temperature Winkler fluidized-bed unit [10], less processing of the bagasse might be required, with dramatic impacts on cost.

[12] The total tonnage of barbojo required for the off-season with the CEST would be about 3/4 of the total bagasse tonnage consumed during the milling season. For the GSTIG, bagasse and barbojo consumption would be comparable.

[13] Assuming a plantation yield of 40 m^3 of wood per hectare per year (a yield readily achievable in Brazil) [1] and the average Jamaican cane yield in 1985 of 62 tonnes per hectare.

115

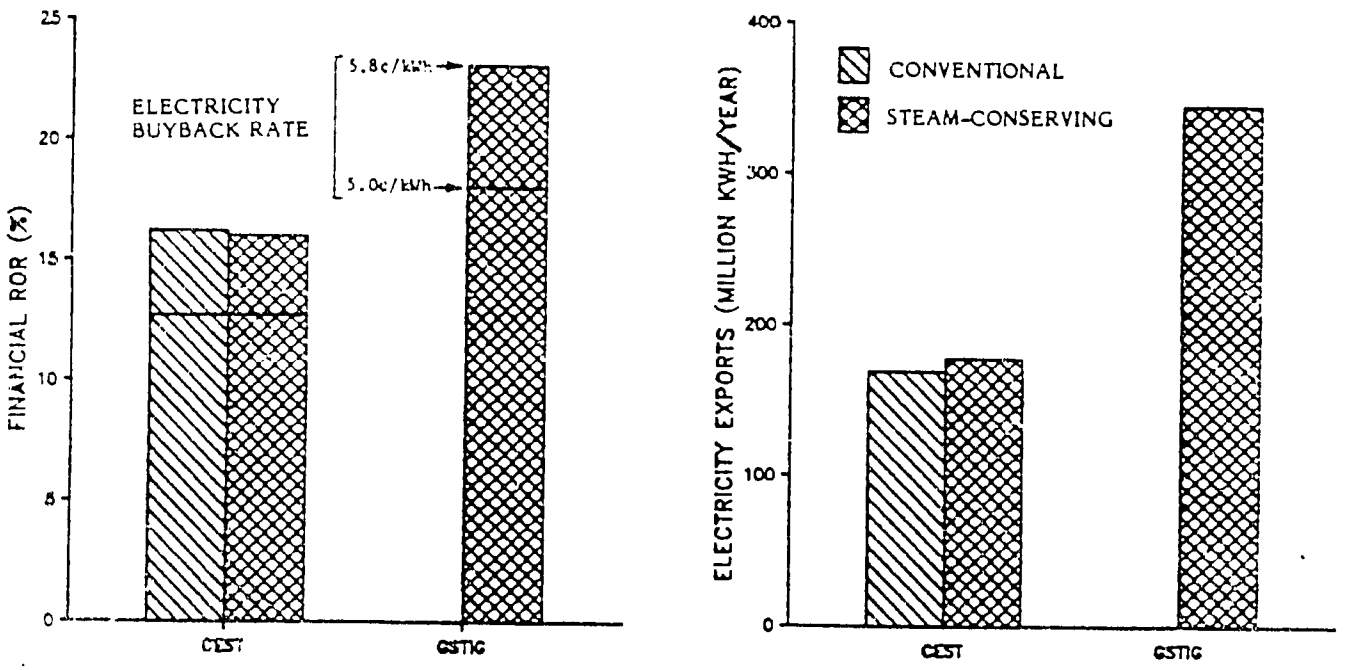


Figure F.6: Financial rates of return and annual electricity exports for cogeneration and process-equipment investments at "conventional" and "steam-conserving" described in Table F.2. Table F.1 gives cost assumptins for the cogeneration facilities. A thirty-year economic life is assumed in all calculations.

116

CEST. New permanent employment associated with maintenance of the plantations would represent about 30% of the estimated direct employment associated with Monymusk today, and a still larger number of temporary jobs would be created in establishing the plantations.

For the scenarios in which oil is burned during the first 5 off-seasons, the ROR for the GSTIG would be 11-13%, while that for the CEST would be 10-12 percent. The ROR for the GSTIG falls relatively further from that for the base case since the GSTIG would burn distillate fuel oil, while the CEST would burn less costly residual fuel oil.[14]

Results for Smaller Installations

The average cane-processing capacity of sugar factories in Jamaica and many other countries is lower that 175 tc/hr. Since there are scale economies associated with both the CEST and GSTIG technologies (see Figure F.4), the ROR would decrease in both cases for cogeneration investments at small factories. However, because of its weaker scale economies, the financial advantage of the GSTIG relative to the CEST would increase with decreasing size. For a "steam-conserving" factory processing about 20 tc/hr, the ROR would be 9-13% for a 5-MW GSTIG unit (fueled by briquetted cane residues) and 3-5% for a 3-MW CEST (using less-processed cane residues). [1]

Case Study: National Perspective

Jamaican Context

While the GSTIG would provide much more attractive rates of return to a sugar producer than would a CEST plant, the capital involved (Table F.1) would be far in excess of investments to which sugar producers are accustomed. In contrast, the investments in a GSTIG unit would typically be less than what an electric utility might invest in building a comparable amount of new central station capacity (Figure F.4). In addition, the capacity increment of a single GSTIG would be smaller than a typical new central station power plant, allowing a utility to better track evolving electricity supply and demand.

---

[14] In a fourth scenario, the cogeneration system could be undersized relative to the in-season fuel supply, and excess bagasse stored for use during the off-season (after processing to permit long-term storage), thus avoiding the use of an auxillary biofuel as well as of oil. In this scenario, about half as much electricity would be produced annually, and the RORs would be 14-18% for the GSTIG (using briquetted bagasse year-round) and 10-13% for the CEST (using baled, dried bagasse during the off-season). [1]

For a utility, cogenerated electricity would be of interest if it cost less than other utility sources. Fueled by briquetted cane residues at a "steam-conserving" factory, the GSTIG would produce exportable electricity for about 4.1¢/kWh, and the CEST would produce about half as much electricity for about 4.8¢/kWh. If plantation fuelwood were the off-season fuel, generating costs would be 4.0¢/kWh for the GSTIG and 5.1¢/kWh for the CEST. In the scenarios involving oil the costs would be about 5.2¢/kWh for the GSTIG and 5.4¢/kWh for the CEST. These cogeneration costs are compared in Figure F.7 to the cost of power from a new 61-MW coal-fired power plant, which is being considered by JPS as a least-cost expansion option. It would produce electricity for an estimated total cost of 5.0-5.8¢/kWh (See note 8). In all cases shown in Figure F.7, the GSTIG plant would provide comparable- or lower-cost electricity than the new coal-fired option, even with a low price for coal.

The cost of cogenerated electricity is also compared in Figure F.7 to the operating cost of existing oil-fired power plants, which would range from 4.5 to 6.1¢/kWh (See Note 10). For the cases where biomass is the sole fuel, the GSTIG facility would produce electricity at a lower cost, even with oil at $2.9/GJ. Under these conditions, it would be economically worthwhile to scrap existing oil-fired plants and replace them with new GSTIG facilities.

If Jamaica's total resource of cane residues were to be exploited for power, some existing oil-fired generating capacity could be retired, new central-station power plant construction could be deferred for many years or perhaps decades, and substantial foreign exchange would be saved. A typical 1980s cane harvest (2.2 million tonnes) would support up to 80 MW of CEST units that could export about 500 million kWh of electricity annually, or over 150 MW of GSTIG units that could export about 1000 million kWh per year. For comparison, JPS generated 1,437 million kWh in 1985. If GSTIG generated power were to displace new coal-fired capacity, up to $270 million dollars of foriegn earnings might be saved over the 30-year life of the plants (Table F.4). If cogenerated power displaced electricity from existing oil-fired units, up to $300 million might be saved (Table F.4). Per kWh generated, the savings with GSTIG would be 50-90% higher than with CEST.

Southeast Brazilian Context

Southeast Brazil, where most of Brazil's sugarcane grows and which includes the heavily industrialized state of Sao Paulo, provides an interesting contrast to Jamaica, because it is a cane-producing region which relies heavily on hydropower, a much less costly electricity source than most alternatives. With electricity demand in Sao Paulo growing at 8-10% per year [25], the installation of new hydro capacity is under consideration. Since all of the economical hydro potential has already been exploited in the South, however, new plants would be build in the Amazon, with transmission lines connecting them to Sao Paulo. [26] Electricity from such facilities is estimated to cost from 3.2 to 5.8¢/kWh, depending primarily on the siting of the facility (Figure F.7).

118

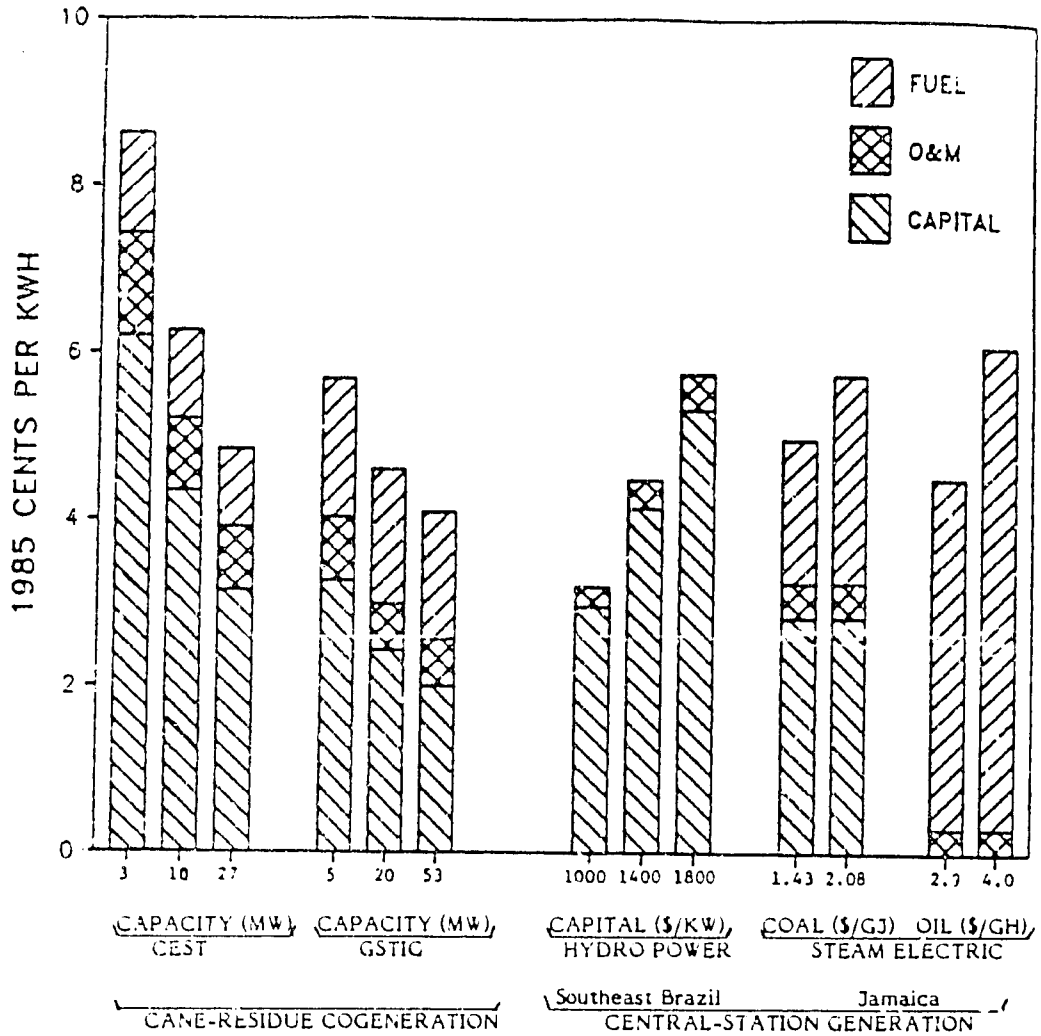


Figure F.7: Estimated levelized cost of generating exportable electricity with CEST and GSTIG cogeneration systems at a "steam-conserving" sugar factory and for three central-station alternatives. [1] Total costs are shown for a new 61-MW coal-steam plant in Jamaica and new hydro plants supplying power to Southeast Brazil. Also shown is the cost of operating existing oil-steam plants in Jamaica. The three cogeneration cases correspond to the scenarios described in the text.

Based on the calculations for the Jamaican case study, large (53 MW) GSTIG cogeneration plants operating year-round on briquetted cane residues at sugar factories in Sao Paulo could supply electricity at a cost in the mid-range of those estimated for new hydro supplies, and small units would be competitive with the higher-cost hydro supplies. By contrast, only the larger CEST units would be competitive and then only with the higher-cost hydro (Figure F.7).

Given the shortage of capital in Brazil (as in many other developing countries, the capital charges alone for electricity may be as important as the total cost of generation, in which case the GSTIGs would have a significant advantage. For example, the capital charges for GSTIG power would be 50 to 80% of those for hydro capacity costing $1400/kW (Figure F.7). For CEST, only a modest capital advantage would be gained, and only with larger units.

Even if GSTIG units were operated only during the milling season, the produced power may be attractive to the electric utilities if hydro and GSTIG options were considered together. Since the cane milling season coincides with the dry season, cogeneration at sugar processing facilities could help fill the hydropower "trough", (Figure F.8), thus making greater use of the installed hydroelectric capacity. Furthermore, since the GSTIGs would have the capability to operate on oil in the off-season, a larger risk of a rain-short year could be designed into new hydro facilities, resulting in still lower capital charges for hydropower.

Implications

The introduction of GSTIG units worldwide could have a significant impact in over 70 countries that grow cane. The amount of cane residues produced globally in 1985 would support over 50,000 MW of GSTIG capacity, most of which would be in developing countries in Asia and Latin America (Table F.5). Based on an extrapolation of the results for Jamaica, some 300 billion (10^9) kWh of electricity could be produced at the 1985 level of cane production (Table F.6). This is more than 1/4 of the electricity generated by utilities in these countries in 1982, and is comparable to the level of electricity generated with oil.

A global transition to GSTIG cogeneration, while attractive, offers challanges for both the sugar and electric utility industries. In the sugar factories, the introduction of steam-conserving process technologies would probably be required, and year-round operation of the cogeneration plant would be beneficial. The development of barbojo recovery systems or "energy plantations" would be desirable to supply fuel for the off-season. Since investments in a cogeneration plant would typically be large compared to traditional investments in the sugar industry, creative financing and ownership arrangements may be desirable, e.g. utility and/or third-party participation.

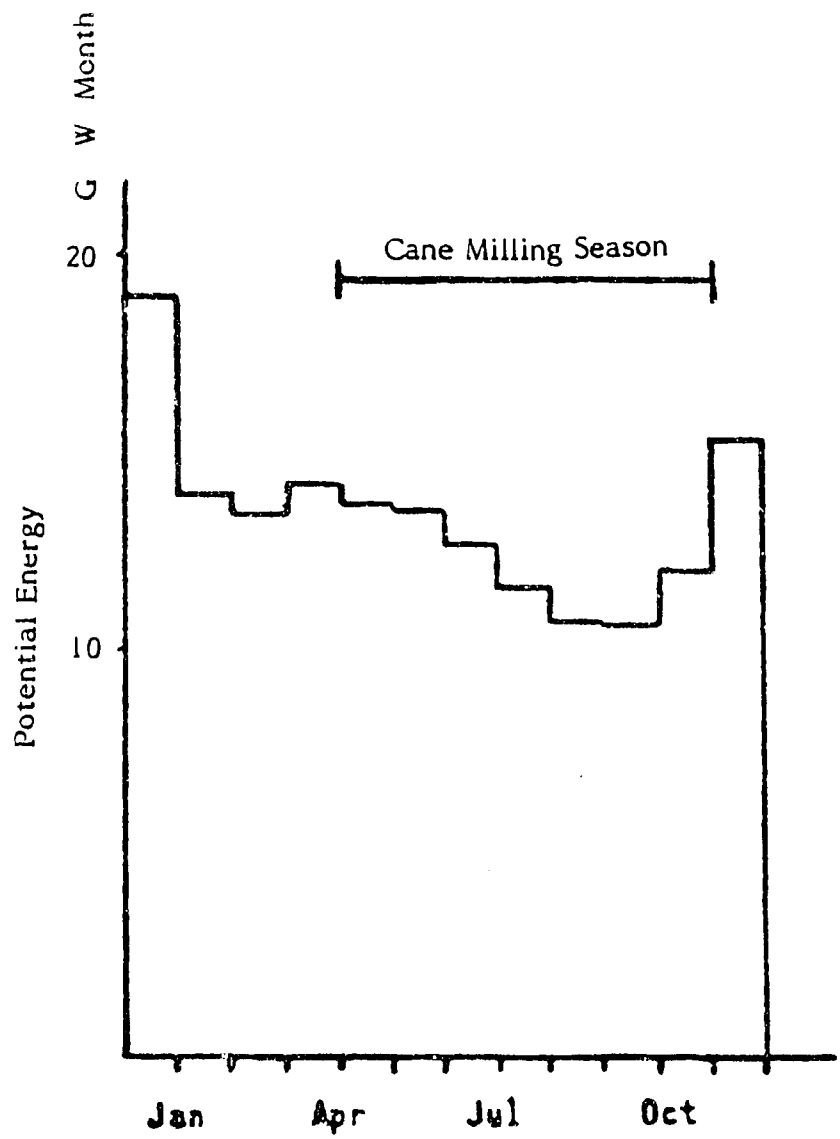


Figure F.8: The current hydro-electricity supply "trough" and the sugar cane milling season in the state of Sao Paulo, Brazil. [1]

Table F.5

Estimated Potential Worldwide GSTIG Generating Capacity at Sugar Factories With the 1985 Level of Sugarcane Production.[a,b]

Region	Potential Electricial Capacity (MW)
South America	17,800 [c]
Asia	14,000
Central America	10,100
Africa	4,900
Oceania	2,700
United States	1,900
Europe	200
Total	51,600

a Sugarcane production, assuming ten tonnes of cane are required to produce one tonne of sugar. Sugar production from [27].

b Assuming a 206 day season, 24 hour/day operation, 90% plant availability, and a GSTIG fuel requirement corresponding to 172 tonnes of cane per hour for a 53 MW unit.

c Includes capacity that would be installed at alcohol production facilities in Brazil.

Table F.6: GSTIG electricity generating potential using the 1985 level of cane production (A) and the actual total electric utility generation in 1982 (B) in developing countries. Number are given in 10^9 kWh[3]

	A	B		A	B	A	B
ASIA						89	599
India	31.6	129.5	Iran	0.90	17.5		
China	19.0	327.7	Vietnam	0.81	1.69		
Thailand	10.8	16.2	Burma	0.45	1.52		
Indonesia	7.6	11.9	Bangladesh	0.42	2.98		
Philippines	7.4	17.4	Malaysia	0.32	11.1		
Pakistan	6.4	14.9	Nepal	0.12	0.284		
Taiwan	3.4	45.0	Sri Lanka	0.07	2.07		
CENTRAL AMERICAN						65	100
Cuba	35.5	10.8	Jamaica	0.94	1.30		
Mexico	15.7	73.2	Panama	0.72	2.71		
Dominican Rep	4.2	2.38	Belize	0.49	0.065		
Guatemala	2.3	1.42	Barbados	0.45	0.339		
El Salvador	1.2	1.45	Trinidad & Tob	0.36	2.30		
Nicaragua	1.1	0.945	Haiti	0.23	0.352		
Honduras	1.0	1.04	St. Chris - Nevis	0.12	na		
Costa Rica	1.0	2.42					
SOUTH AMERICA						117	257
Brazil	95.0	143.6	Guyana	1.1	0.255		
Colombia	6.1	21.3	Bolivia	0.78	1.40		
Argentina	5.5	36.2	Paraguay	0.36	0.569		
Peru	3.3	7.25	Uraguay	0.23	3.47		
Venezuela	2.1	39.0	Suriname	0.05	0.175		
Ecuador	1.3	3.09					
AFRICA						32	167
South Africa	11.4	109.0	Mozambique	0.26	3.25		
Egypt	3.7	17.2	Somalia	0.24	0.075		
Mauritius	3.1	0.320	Nigeria	0.23	7.45		
Zimbabwe	2.1	4.16	Angola	0.23	1.46		
Sudan	2.0	0.910	Uganda	0.15	0.569		
Swaziland	1.8	0.075	Congo	0.11	0.195		
Kenya	1.6	1.73	Mali	0.09	0.080		
Ethiopia	0.87	0.618	Gabon	0.05	0.530		
Malawi	0.69	0.410	Burkina Faso	0.05	0.123		
Zambia	0.64	10.3	Chad	0.04	0.065		
Ivory Coast	0.57	1.94	Guinea	0.02	0.143		
Tanzania	0.47	0.720	Sierra Leone	0.02	0.136		
Madagascar	0.45	0.342	Benin	0.02	0.016		
Cameroon	0.32	2.15	Liberia	0.01	0.389		
Zaire	0.30	1.48	Rwanda	0.01	0.066		
Senegal	0.30	0.631					
OCEANIA						2	1
Fiji	1.6	0.241	Pap. N. Guinea	0.13	0.441		
ALL SUGAR-PRODUCING DEVELOPING COUNTRIES						304	1,124

[a] From [1].

For candidate GSTIG manufacturers, the potential markets appear large enough to justify the development effort that would be required to commercialize the technology, and the projected growth of the sugar industry worldwide--1.5% per year through at least the mid-1900's [28] would insure secure markets in the future. The potential GSTIG market may be still larger if cane-based fuel alcohol comes into wide use. Preliminary calculations indicate that GSTIG cogeneration would be well-suited for the production of electricity at alcohol distilleries. [1] Although the fuel-alcohol industry is developed on a large scale today only in Brazil, this situation may change, if, as expected,[15] oil prices rise considerably in the next 10-15 years. In light of the favorable projected economics of GSTIG cogeneration, a co-product strategy with GSTIG-electricity could make alcohol production economically attractive at lower oil prices than otherwise, [1] a possibility that warrants a detailed assessment.[16]

Conclusions

Steam-injected gas-turbine cogeneration at sugar factories, using gasified cane residues as fuel, would be technically and economically attractive. The modern jet-engine-based technology, on which GSTIG cogeneration would be based, would be appropriate technology for firing with biomass in Jamaica and other countries for a number of reasons:

- The natural, economical scale of the technology is small (5-50 MW), which is well-suited for use with a diffuse energy source like biomass.
- For a utility, GSTIG capacity additions would typically be small in relation to the size of the utility grid in most developing countries, making it easier to keep evolving demand and supply in balance.
- Widespread operation of GSTIG systems could lead to lower average electricity prices in many countries.

---

[15] The U.S. Department of Energy projects rising oil prices in a tightening world market, e.g. residual fuel oil for U.S. utilities is projected to cost $4.3/GJ to $6.4/GJ in the year 2000 compared to $2.27/GJ in 1986. [29]

[16] A multiple-product strategy might involve producing electricity plus a mix of alcohol and sugar that depends on the relative market prices for sugar and oil at any time. This approach would be consistent with the trend toward production of multiple, higher-value products. For example, the Jamaican Sugar Industry Research Institute's Factory Technology Division is testing a small-scale (10 tc/hr) low energy-consuming plant at its Bernard Lodge facility that can produce a mix of higher value-added products in addition to sugar: cane syrup, amorphous sugar, fancy molasses, and charcoal (from cane rind).

124

- Because GSTIGs would be based on aircraft-derivative gas turbines, a sophisticated local maintenance capability is not required as a prerequisite for introducing the technology. Most major repairs would be done off-site, while replacement engines (flown in from centralized facilities) continue to produce power.

- Utilizing indigenous, renewable resources, GSTIG technology could reduce dependence on imported energy supplies, leading to savings in foreign exchange.

- For GSTIG suppliers, potential markets exist which could justify the needed commercialization effort. The global market potential with existing levels of cane production is some 50,000 MW of capacity, and sugar demand is projected to grow 1.5% annually through the mid-1900s.

- GSTIG units may also provide favorable economics at fuel-alcohol distilleries, even with today's oil prices. The cane processing plant of the future may be one which produces electricity from a GSTIG as its primary product, with sugar and/or alcohol as co-products.

- Introduced for initial operation on the biomass already available in the sugar cane-processing industries, GSTIG systems might motivate subsequent wider applications using other biomass forms, including fuelwood from "energy plantations."

- The higher efficiency and lower capital cost of GSTIG relative to CEST would make fuelwood more valuable for power generation than would be the case for existing wood-burning power generating technology, thus making fuelwood plantations a more attractive investment opportunity.

- GSTIG systems would be used largely in rural areas of developing countries, where they might help generate greater employment opportunities by increasing the value of the agricultural products, and hence the level of investment in the agricultural sector.

Acknowledgements

The authors thank the Office of Energy of the United States Agency for International Development (Washington, DC) for financial support in undertaking the research reported here.

In addition, for helpful discussions in Jamaica, the authors would like to thank Roddy Ashby, John Blanchard, Robert Campbell, Emile Finlay, Richard Jones, Jack Keppeler, John Lanigan, Steve Marston, Charles Mathews, and Ian Sangster. Also, contributions are gratefully acknowledged from Angel Abbud-Mardid, Sam Baldwin, Stefano Consonni, Simone Hochgreb, and Robert Soccolow at Princeton University and from Francisco Correa of the Sao Paulo State Energy Company, Sao Paulo, Brazil.

REFERENCES

1. E.D. Larson, J.M. Ogden, and R.H. Williams, "Steam-injected Gas-Turbine Cogeneration for the Cane Sugar Industry; Optimization Through Improvements in Sugar-Processing Efficiencies," PU/CEES Report 217, Center for Energy and Environmental Studies, Princeton University, Princeton, New Jersey, USA, September 1987.

2. RONCO Consulting Corporation and Bechtel National, Inc., "Jamaica Cane/Energy Project Feasibility Study," funded by the U.S. Agency for International Development and the Trade and Development Program, Washington, DC, 1986.

3. Unpublished data supplied by C.M. Kinoshita, Head, Sugar Technology and Engineering Department, Hawaiian Sugar Planter's Association, Aiea, Hawaii, December 1986.

4. Directorate-General of Information and Market Innovation, "24.65 MW bagasse-fired steam power plant demonstration project," EUR 10390 EN/FR, Commission of the European Communities, brussels, 1986.

5. E.D. Larson and R.H. Williams, "Steam-Injected Gas Turbines," ASME Journal of Engineering for Gas Turbines and Power, Vol. 109, No.1, January, 1987.

6. J.C. Corman (Program Manager), "System analysis of simplified IGCC Plants," prepared for the U.S. Department of Energy by the General Electric Company, Schenectady, New York, USA, September 1986.

7. "Cool Water Coal Gasification Program: Fourth Annual Progess Report," Electric Power Research Institute, Report AP-4832, Palo Alto, California, USA, 1986.

8. J.C. Corman in "Report on the (June 19, 1987) Workshop on Biomass-Gasifier Steam-Injected Gas Trubines for the Cane Sugar Industry," E.D. Larson and R.H. Williams (eds) Center for Energy and Environmental Studies, Princeton University, Princeton, New Jersey, USA, forthcoming.

9. M.J. Antal, "Biomass Energy Enhancement: A Report to the President's Council on Environmental Quality," Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey, USA, July 1978.

10. A. Berlin, H-J Scharf, L. Schrader, and H. Tegger, "Application of Rheinbraun-HTS Gasification Process to Biomass Feedstocks," Bioenergy 84, Vol. III, Elsevier, London, 1985 pp. 65-72.

Reference (cont.)

11. Montreal Engineering Company, "Least-Cost Expansion Study," prepared for the Jamaica Public Service Company, Ltd., Kingston, Jamaica, 1985.

12. E.D. Larson and R.H. Williams (eds), "Workshop on steam-injected gas turbines for central staton power generation," New Jersey Energy Conservation Laboratory, Center for Energy and Environmental Studies, Princeton University, Princeton, New Jersey, USA 1986.

13. Tate and Lyle Technical Services, "Jamaica Sugar Holdings, Ltd. Corporate Plan 1984-1989," Vol. III (Monymusk Factory and Estate Technical Report), Bromley, England, December 1984.

14. J.M. Ogden, S. Hochgreb, and M.G. Hylton, "Steam Economy and Cogeneration in Cane Sugar Factories," prepared for Annual Meeting of the Jamaican Association of Sugar Technologists, Ocho Rios, Jamaica, November 5-6, 1987.

15. S. Baldwin and E. Finlay, "Analysis of Electric Motor Driven Systems in the Sugar Industry: I. Electricity Conservation in Boiler Fans and Irrigation Pumps," prepared for the Annual Meeting of the Jamaican Association of Sugar Technologists, Ocho Rios, Jamaica, Nov. 5-6, 1987.

16. Eletrobras, "Aproveitamento Enginertico dos Residuos da Agroindustria da Cana-de-Acucar," Ministry of Industry and Commerce, Brasilia, 1981.

17. R. Ashby, Manager, Center for Special Studies, PCJ Engineering, Kingston, Jamaica, personal communication, April 1987.

18. A.L. Phillips, "Cane Crop Residue for Biomass Fuel," Agricultural Engineering Department, University of Puerto Rico, Mayaguez. (In Appendix 2A, RONCO Consulting Corporaton and Bechtel National).

19. V. Vinas, Central Romana Sugar Factory, Dominican Republic, presentation at the Second Pacific Basin Biofuels Workshop, Kauai Island, Hawaii, April 1987.

20. K. Deepchand, "Economics of Electricity Production from Sugar Cane Tops and Leaves--A Preliminary Study," Int. Sugar J., Vol. 88, 1986, pp. 210-216.

21. V.F. Varua, Vice-President, Jose Cojuangco and Sons, Inc., (Luisita Plantation), Philippines, presentation at the Second Pacific Basin Biofuels Workship, Kauai Island, Hawaii, April 1987.

22. N. Coovattanachai, Faculty of Engineering, Prince of Songkla University, Hatyai Thailand, personal communication, August 1987.

23. B.R. Eiland and J.E. Clyton, "Collection of Sugarcane Crop Residue for Energy," presented at the American Society of Agricultural Engineers Winter Meeting, Chicago, Illinois, USA, December 1982.

127

Reference (cont.)

24. M. Shaw, Director, Field Division, Sugar Industry Research Institute, Mandeville, Jamaica, personal communication, August 1987.

25. Conselho Estadual de Energia, (1986), Balanco Energetico do estado de Sao Paulo 1984, Sao Paulo, Brazil.

26. F. Correa, Project Engineer, Special Projects Groups, State Energy Company of Sao Paulo (CESP), Sao Paulo, Brazil, personal communication. March 1987.

27. International Sugar Organization, Sugar Yearbook 1985, London. 1986.

28. J.G. Brown, "The International Sugar Industry: Development and Prospects," Commodity Working Paper 18, World Bank, 1987.

29. Energy Information Administration, Annual Energy Outlook, U.S. DOE, Washington, DC, February 1987.

174

REFERENCES

A.I.D. Office of Energy. March 1986. "Special Issue: Cane Energy Systems," Prepared by Bioenergy Systems and Technology. U.S. Agency for International Development. Washington, D.C.

A.I.D. Office of Energy. April 1986. "Fuel Alcohol Production in Honduras: A Technical and Economic Analysis." Cane/Energy Assessment Program. Prepared by RONCO Consulting Corporation for the U.S. Agency for International Development. Washington, D.C.

A.I.D. Office of Energy. September 1986. "Jamaica Cane/Energy Project Feasibility Study." Prepared by RONCO Consulting Corporation and Bechtel National Inc. for The U.S. Agency for International Development. Washington, D.C.

A.I.D. Office of Energy. September 1986. "Electric Power from Cane Residues in Thailand: A Technical and Economic Analysis." Cane/Energy Assessment Program. Prepared by RONCO Consulting Corporation for The U.S. Agency for International Development. Washington, D.C.

A.I.D. Office of Energy. December 1986. "The Sugar Industry in the Philippines: An Analysis of Crop Substitute and Market Diversification Opportunities." Cane/Energy Assessment Program. Prepared by RONCO Consulting Corporation for The U.S. Agency for International Development. Washington, D.C.

A.I.D. Office of Energy. December 1987. Non-Utility Power Generation in Costa Rica: Potential Impediments and Policy Issues. Produced by Hagler Bailley for the Office of Energy, Science and Technology, U.S. Agency for International Development. Washington, D.C.

Alexander, Alex. The Energy Cane Alternative. New York: Elsevier. 1985.

Brown, James. March 1987. "The International Sugar Industries: Developments and Prospects." World Bank Staff Commodity Working Papers. No. 18. The World Bank, Washington, D.C.

Eiland, B. R. and J. E. Clayton, "Unburned and Burned Sugarcane Harvesting in Florida," Transaction of the ASAE (Vol. 26, No. 5, 1983).

Gowen, Marcia M. ed. April 1987. "Cane Energy Utilization Symposium; A Report from the 2nd Pacific Basin Biofuels Workshop, Vols. I and II". Prepared by RONCO Consulting Corporation for the U.S. Agency for International Development. Washington, D.C.

Kinoshita, C. M. 1986. "Energy Inventory of Hawaiian Sugar Planters' Association (1982-1985)." Unpublished data. Hawaiian Sugar Planters' Association. Aiea, Hawaii, December.

Larson, Eric D., Joan M. Ogden, Robert W. Williams, and Michael G. Hylton. November 1987. "Biomass-Fired Gas-Turbine Cogeneration at Efficient Cane-Sugar Factories: A Jamaican Case Study." Paper presented at Jamaican Association of Sugar Technologists Meeting, Ocho Rios, Jamaica. November 5-6, 1987. Center for Energy and Environmental Studies. Princeton University, Princeton, New Jersey.

Lipsey, R. G. and R. K. Lancaster. 1957. "The General Theory of the Second Best," Review of Economic Studies, February 1963, No. 77, pp. 93-111.

Phillips, Allan. "Cane Crop Residue for Biomass Fuel." Department of Agricultural Engineering. Unviersity of Puerto Rico. Mayaguez, Puerto Rico.

World Bank. 1986. Costa Rica Country Report. Washington, D.C.