

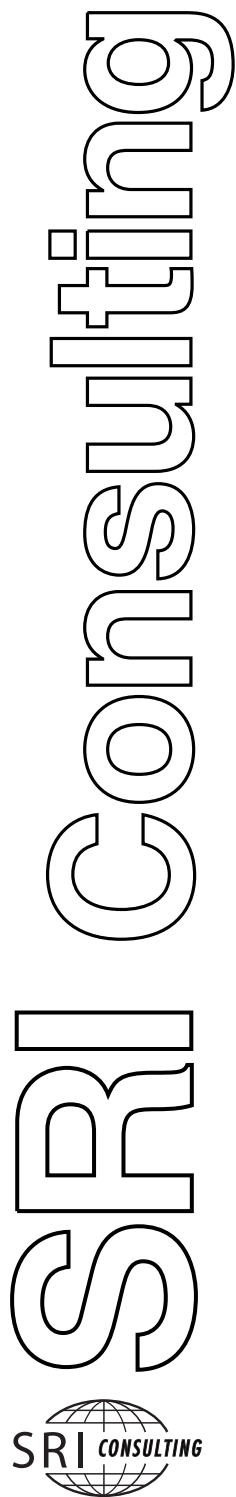
Abstract
Process Economics Program Report 149A
ETHANOL PRODUCTION IN BRAZIL
(October 2006)

World ethanol production is undergoing spectacular growth. Brazil, the world's leading fuel ethanol producer until 2005, is continuing to expand production. Domestic consumption of the renewable fuel continues to rise and important export markets are being developed in Asia, Europe and North America. Brazilian ethanol production is based on sugarcane as feedstock. Cane farmers increasingly believe that world oil prices have broken out of old pricing models and that current high prices are here to stay, leaving fuel ethanol more attractive than ever as an outlet for sugarcane.

In 2005, the United States overcame Brazil as the world's largest ethanol producer. Many of the fuel consumption trends that began in Brazil are now developing in the United States. The largest difference in the two regions is the feedstock source: corn in the United States versus sugarcane in Brazil. Each crop has its pros and cons as a feedstock for ethanol production. A question that often arises is how the process economics compare.

In this report, PEP presents process designs and associated cost estimates for producing ethanol in Brazil and the United States. Three economic models are provided: ethanol from a sugarcane mill, ethanol from a corn dry mill and ethanol from sugarcane bagasse. Sugarcane mill economics are evaluated both on a Brazilian location basis and also a U.S. Gulf Coast basis. The general conclusions are summarized below:

- The most important factor in Brazil's growing ethanol industry is the country's large cultivation of sugarcane. No other country has been able to match Brazil's sugarcane cost structure. Development of an economically sustainable milling industry has also played a large role. Integration of sugar and ethanol production from sugarcane enables very competitive process economics. Future developments that could further enhance economics include bagasse processing to produce ethanol, although this technology is at least several years from successful commercialization in Brazil.
- Brazil's favorable position relative to U.S. corn dry milling has eroded somewhat over the past year (2005 to 2006). This is primarily due to the rising value of the Brazilian real and also the rising cost of sugarcane in Brazil. Never the less, large sugarcane mills in Brazil still enjoy lower production costs than even the largest corn dry mills in the United States.



Report No. 149A

ETHANOL PRODUCTION IN BRAZIL

by GREGORY M. BOHLMANN
and
MARCOS A. CESAR

October 2006

A private report by the
PROCESS ECONOMICS PROGRAM

Menlo Park, California 94025

SRIC agrees to assign professionally qualified personnel to the preparation of the Process Economics Program's reports and will perform the work in conformance with generally accepted professional standards. No other warranties expressed or implied are made. Because the reports are of an advisory nature, neither SRIC nor its employees will assume any liability for the special or consequential damages arising from the Client's use of the results contained in the reports. The Client agrees to indemnify, defend, and hold SRIC, its officers, and employees harmless from any liability to any third party resulting directly or indirectly from the Client's use of the reports or other deliverables produced by SRIC pursuant to this agreement

For detailed marketing data and information, the reader is referred to one of the SRI Consulting programs specializing in marketing research. THE CHEMICAL ECONOMICS HANDBOOK Program covers most major chemicals and chemical products produced in the United States and the WORLD PETROCHEMICALS PROGRAM covers major hydrocarbons and their derivatives on a worldwide basis. In addition the SRIC DIRECTORY OF CHEMICAL PRODUCERS services provide detailed lists of chemical producers by company, product, and plant for the United States, Western Europe, Canada, and East Asia, South America and Mexico.

CONTENTS

1	INTRODUCTION	1-1
2	SUMMARY	2-1
	INTRODUCTION	2-1
	Agricultural Resources	2-1
	Economic Sustainability.....	2-2
	Research and Development.....	2-3
	ECONOMIC ASPECTS	2-5
	CONCLUSIONS	2-8
3	INDUSTRY STATUS.....	3-1
	STATUS IN BRAZIL	3-2
	U.S. STATUS.....	3-4
	ETHANOL PRODUCTION	3-6
	GLOBAL TARIFFS AND TRADE	3-12
	ETHANOL PRICES	3-12
4	AGRICULTURAL FEEDSTOCKS	4-1
	CORN	4-1
	SUGARCANE.....	4-5
	BIOMASS AVAILABILITY.....	4-14
5	ETHANOL FROM SUGARCANE MILLS	5-1
	SUGARCANE MILLING PROCESS.....	5-2
	FERMENTATION	5-5
	DISTILLATION.....	5-9
	COGENERATION	5-12
	PROCESS DESCRIPTION	5-14

CONTENTS (Continued)

Cane Milling.....	5-16
Sugar Crystallization.....	5-16
Fermentation.....	5-17
Distillation and Dehydration.....	5-17
PROCESS DISCUSSION.....	5-25
Conventional Sugarcane Mill Design	5-25
Fermentation.....	5-25
On-Stream Factor.....	5-25
Waste Treatment	5-25
CAPITAL AND PRODUCTION COSTS	5-27
BRAZILIAN PROCESS ECONOMICS	5-35
6 ETHANOL FROM BAGASSE.....	6-1
PROCESS REVIEW.....	6-4
Pretreatment/Prehydrolysis	6-4
Fermentation.....	6-10
PROCESS DESCRIPTION	6-11
Pretreatment and Conditioning.....	6-20
Saccharification and Co-Fermentation	6-21
Distillation and Dehydration.....	6-22
Enzyme Preparation	6-22
PROCESS DISCUSSION.....	6-23
Saccharification and Fermentation.....	6-23
Feedstock	6-24
On-Stream Factor.....	6-24
Waste Treatment	6-25
Materials of Construction.....	6-26

CONTENTS (Continued)

	CAPITAL AND PRODUCTION COSTS	6-26
	DISCUSSION OF PRODUCT VALUE	6-27
7	CORN MILLING	7-1
	WET MILLING PROCESS.....	7-2
	Wet Milling Advances	7-4
	DRY MILLING PROCESS.....	7-7
	Dry Milling Advances	7-8
	PROCESS DESCRIPTION	7-13
	Saccharification	7-16
	Anaerobic Fermentation	7-16
	Distillation and Dehydration.....	7-16
	DDGS RECOVERY	7-17
	PROCESS DISCUSSION.....	7-23
	Conventional Dry Mill Design	7-23
	Anaerobic Fermentation	7-23
	On-Stream Factor.....	7-23
	DDGS Quality	7-24
	Waste Treatment.....	7-24
	CAPITAL AND PRODUCTION COSTS	7-25
	DISCUSSION OF PRODUCT VALUE	7-26
8	ECONOMIC FACTORS IN BRAZIL	8-1
	LABOR.....	8-1
	CAPITAL INVESTMENT FACTORS	8-2
	Equipment Manufacturers	8-2
	Location Factor for Sugar Cane Mills.....	8-4
	Financing and Interest Rates	8-5

CONTENTS (Concluded)

LOGISTICS AND TRANSPORTATION	8-7
EXTERNAL FACTORS	8-8
Currency Exchange Rates.....	8-8
Government Policies	8-11
BRAZILIAN GOVERNMENT'S ALTERNATIVE ENERGY PROGRAM (PROINFA)..	8-12
Environmental Aspects.....	8-13
APPENDIX A: PATENT SUMMARY TABLE	A-1
APPENDIX B: DESIGN AND COST BASES	B-1
APPENDIX C: CITED REFERENCES.....	C-1
APPENDIX D: PROCESS FLOW DIAGRAMS	D-1

ILLUSTRATIONS

3.1	Fossil Fuel Price History.....	3-1
3.2	2005 World Ethanol Production by Region	3-6
3.3	Corn Wet Milling and Dry Milling	3-9
3.4	US Ethanol and Gasoline Quotations.....	3-13
3.5	Historical Ethanol and Gasoline Prices	3-14
4.1	Feedstock Price History	4-1
4.2	Declining Cost of Corn with Time	4-2
4.3	Midwestern States Examined: Corn Density	4-4
4.4	Sugarcane Area in the Center-South	4-5
4.5	Major Parts of the Sugarcane Plant	4-8
4.6	Biomass Production.....	4-9
4.7	Projected Sugarcane Needed in Brazil	4-9
4.8	Brazil: The Value of Cane for Various Uses.....	4-11
4.9	Cumulative US Biomass Quantities by Price	4-16
5.1	Glucose and Fructose Condense to Form Sucrose and Water	5-2
5.2	Simplified Process Flow Diagram for Cane Sugar Production.....	5-4
5.3	Yeast Fermentation	5-6
5.4	Commercial Yeast Chronology.....	5-6
5.5	Flowsheet of Continuous Process Using Centrifuges	5-8
5.6	Conventional Distillation in Brazil	5-10
5.7	Multiple Pressure Distillation + PSA Molecular Sieve Process	5-11
5.8	Multiple Pressure Distillation + BNRI VP Membrane Process	5-12
5.9	Steam and Power Generation: Present Status	5-13
5.10	Sugarcane Mill Process Flow Diagram	D-3
5.11	Simplified Wastewater Flow Diagram for a Raw Sugar Factory	5-26
5.12	World Sugar Market Prices	5-28
5.13	Sugar Production Cost	5-36

ILLUSTRATIONS (Concluded)

6.1	Major Components of Bagasse	6-2
6.2	Biomass Conversion Schemes	6-5
6.3	Organosolv Hydrolysis Process	6-6
6.4	Oxiteno Hydrolysis Reactor	6-8
6.6	Ethanol from Bagasse Process Flow Diagram	D-11
6.5	Enzyme Hydrolysis of Bagasse and Cellulosic Fractions	6-10
7.1	α Amylose and Amylopectin	7-1
7.2	Corn Wet-Milling Process Overview	7-4
7.3	Comparison of Conventional and Enzymatic Corn Wet Milling.....	7-5
7.4	Starch Yield as Function of enzyme Addition.....	7-6
7.5	Corn Dry Milling	7-8
7.6	Ethanol Production and Residual Starch	7-9
7.7	Corn Dry Grind Process with Fiber Conversion to Ethanol.....	7-11
7.8	Multiple Pressure Distillation + PSA Molecular Sieve Process	7-12
7.9	Multiple Pressure Distillation + BNRI VP Membrane Process	7-13
7.10	Corn Dry Mill Process Flow Diagram	D-17
8.1	Brazil--Short-Term Interest Rates, 1995-2006	8-5
8.2	Brazil--Long-Term Interest Rates, 1995-2006.....	8-6
8.3	Government Financing fro Sugar and Ethanol Investments Period: 1999-2003 ..	8-7
8.4	Current Export Infrastructure--Center-South.....	8-8
8.5	Brazil--Nominal Exchange Rates, 1995-2006	8-9
8.6	Brazil--Real Exchange Rates, 1995-2006.....	8-10
8.7	Price Composition--Gasoline, Diesel, and Hydrous Ethanol.....	8-12

TABLES

2.1	Expected Improvements in Cane Production	2-2
2.2	Fiber Cane Productivity	2-4
2.3	Ethanol Process Economics.....	2-7
3.1	Biofuel Targets Around the World	3-2
3.2	Comparisons of 2004 Gasoline and Ethanol Equivalents.....	3-4
3.3	Major Brazilian Ethanol Producers as of 2005.....	3-7
3.4	U.S. Fuel Ethanol Production	3-8
3.5	Wet Milling vs Dry Milling.....	3-8
3.6	Major U.S. Ethanol Producers as of 2005.....	3-10
3.7	Proposed Cellulose to Ethanol Plants in the United States	3-11
3.8	Ethanol Import Tariffs	3-12
4.1	2005/06 Yields for Major U.S. Field Crops	4-2
4.2	U.S. Corn Cost and Price Projections	4-3
4.3	U.S. Domestic Corn Use Projections	4-4
4.4	Sugarcane and Juice Comparisons	4-7
4.5	Brazil Sugarcane Production.....	4-10
4.6	Expected Improvements in Cane Production.....	4-10
4.7	Fiber Cane Productivity	4-12
4.8	High Fiber Sugarcane Varieties	4-12
4.9	U.S. Sugarcane Projections	4-13
4.10	Available Biomass in the United States.....	4-15
4.11	Potential Bioethanol Production	4-16
5.1	Sugarcane Milling Coproducts	5-4
5.2	Results of Technology Improvements in Brazil	5-5
5.3	Natrontec Continuous Process Users	5-9
5.4	Sugarcane Mill Design Bases	5-15

TABLES (Continued)

5.5	Sugarcane Mill Stream Flows.....	5-19
5.6	Sugarcane Mill Major Equipment	5-21
5.7	Sugarcane Mill Utilities Summary.....	5-24
5.8	Sugarcane Mill Total Capital Investment.....	5-29
5.9	Sugarcane Mill Capital Investment by Section	5-30
5.10	Sugarcane Mill Production Costs	5-32
5.11	Sugarcane Mill Direct Costs by Section	5-34
5.12	Technology Evolution 1975-2000.....	5-35
5.13	Sugarcane Mill in Brazil Production Costs	5-38
6.1	Theoretical Ethanol Yields.....	6-3
6.2	Pretreatment Processes Patent Summary.....	A-3
6.3	Dedini Rapid Hydrolysis Yields Laboratory and Pilot.....	6-7
6.4	Comparative Composition of Bagasse.....	6-9
6.5	Ethanol from Bagasse Design Bases	6-12
6.6	Ethanol from Bagasse Stream Flows.....	6-13
6.7	Ethanol from Bagasse Major Equipment	6-16
6.8	Ethanol from Bagasse Utilities Summary.....	6-19
6.9	Pretreatment Hydrolyzer Reactions and Conversions	6-20
6.10	Saccharification Reactions and Conversions.....	6-21

TABLES (Continued)

6.11	Ethanol from Bagasse Total Capital Investment.....	6-28
6.12	Ethanol from Bagasse Capital Investment by Section.....	6-29
6.13	Ethanol from Bagasse Production Costs	6-31
6.14	Ethanol from Bagasse Direct Costs by Section	6-33
7.1	Corn Wet Milling Coproducts.....	7-2
7.2	Yield Comparison Between Enzymatic and Conventional Corn Wet Milling	7-6
7.3	Continuous Fermentation Productivities	7-10
7.4	Co-Immobilized Enzyme-Microbe Fluidized Bed Yields	7-10
7.5	Corn Dry Mill Design Bases	7-15
7.6	Corn Dry Mill Stream Flows.....	7-18
7.7	Corn Dry Mill Major Equipment	7-20
7.8	Corn Dry Mill Utilities Summary.....	7-22
7.9	DDGS Value Depending on Species.....	7-24
7.10	Corn Dry Mill Total Capital Investment.....	7-27
7.11	Corn Dry Mill Capital Investment by Section.....	7-28
7.12	Corn Dry Mill Production Costs	7-30
7.13	Corn Dry Mill Direct Costs by Section	7-32
8.1	Average Earnings for All Jobs, R\$ in 2003	8-1
8.2	Regional Monthly Earnings, R\$ in 2003.....	8-2
8.3	Brazilian Equipment Manufacturers	8-3

TABLES (Concluded)

8.4	Brazilian Location Factors	8-4
8.5	Proinfa--Electricity Purchase Prices	8-13