Lowering Cost of Bio-Ethanol Production Using Electrolytic Process

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ABSTRACT

Ethanol is an attractive alternative fuel for automobiles and other uses. Current ethanol costs from corn and sugarcane using conventional methods usually requires subsidies from governments to compete. An electrolytic process designed for lignin extraction from lignocellulosic biomass and caustic recovery from black liquor showed costs can be reduced to almost half by adding co-products like pulp for paper production. This paper compares technical parameters and cost projections for ethanol production from corn and sugarcane using pilot results.

INTRODUCTION

The increasing price of crude oil and other fossil fuels has increased interest in alternative fuel sources around the world. Ethanol fuel production from sugarcane and corn may need improvement in economic payback and lower energy consumption in order to be considered a viable alternative to fossil fuel. In some countries in the 1980's the production cost for ethanol was estimated over US $1.02 per gallon, or $0.27 per liter (1), which would mean that the sales price of ethanol fuel would have to be over US $2.00 per gallon, or $0.40 per liter for a country that imports the fuel product. Those costs would not allow the ethanol industry to compete in the alternate fuel market. At present, production costs for ethanol have come down to levels over US $0.88 per gallon, or $0.235 per liter (2). The ethanol industry seeks technological alternatives that would lower cost and provide higher margins in order to compete with gasoline and other fossil fuels.

This paper compares conventional methods of producing ethanol fuel with an alternative process that would reduce costs and increase revenues by incorporating the use of an electrolytic membrane technology capable of recovering caustic and extracting lignin from black liquor (alkali) streams resulting from pulping processes used in paper manufacturing.

The paper reviews the possibility of increasing revenues and lowering energy cost by using the electrolytic technology in biorefineries that produce ethanol from sugarcane and corn. The projections show that the electrolytic technology could provide an improvement in economic feasibility for ethanol production in both cases by generating additional revenues from cellulose (pulp) sales, and by reducing energy costs with the fuel credit derived from lignin (biofuel) that is extracted from the bagasse, or the corn cob materials.

Lignin is an organic compound that is present in bagasse, corn cob, wheat straw, softwood, eucalyptus, and other cellulosic (biomass) materials. The extracted lignin material contains high calorific value and can be burned as fuel to generate energy for the plant. The cellulose fiber that is produced after lignin extraction from bagasse, or other raw materials, can be used to manufacture paper.

The fresh bagasse obtained after extraction of the sugarcane juice normally contains approximately 50% moisture. This high content of water causes losses of heat in the boiler when the bagasse is used as fuel to produce steam. The lignin produced when the electrolytic process is used contains lower moisture content and can be burned more efficiently in the boiler. This paper reviews the projected economic benefits and briefly evaluates potential energy advantages that could be derived from using the electrolytic process in ethanol production from sugarcane and possibly from corn.

BACKGROUND

The alcohol industry could lower costs by generating value added co-products to increase revenues and obtain higher economic benefits. In this paper the authors evaluate the possibility of using an electrolytic membrane technology to lower energy cost and make possible the production of cellulose fiber at lower costs.

The advantage of using the electrolytic method is that the bagasse material that is normally burned to produce steam would become raw material for cellulose pulp production as an additional product. The lignin is separated from the bagasse and fed to the boiler as fuel to produce steam at higher efficiency. The lignin fuel produced can lower energy costs and the cellulose product would provide additional revenue and increase profits for the ethanol fuel producer.

This paper focuses on ethanol production from sugarcane and lignin biofuel extraction from bagasse material. The economics evaluation of ethanol production from corn is not within the scope of this paper. It could be said that there might be a similarity between economic viabilities of ethanol production from each of those raw materials. The sugarcane option includes ethanol production from fermentation of sugarcane juice and ethanol from corn involves using the corn grain by means of an enzymatic process. Both cases produce a residual biomass material containing lignin that can be a source of cellulose fiber. The economic feasibility of using electrolytic technology for ethanol production from corn grain would be the subject in another study.

The objective of this paper is to evaluate the possibility of producing refined ethanol (96°GL) or anhydrous (99.8° GL) as a product that can compete in price with fossil fuels in the market. The data analyzed from pilot tests performed with electrolytic plants shows that production costs for ethanol could be as low as US $0.45 per gallon, or $0.12 per liter of ethanol.

MATERIALS AND METHODS

The data for extraction of caustic soda, hydrogen and lignin from liquors generated during the pulping process for bagasse, and other cellulosic biomass materials, was obtained from several pilot trials performed at pulp mills in United States, India, the Dominican Republic, Turkey and other countries. The tests were performed with electrolytic pilot plants designed by Electrosep, Inc, a company based in Oregon, USA. The pilots included a patented electrolytic membrane technology that was designed for chemical recovery from alkali streams containing high solids concentrations and capable of performing chemical extraction with minimum fouling of membranes and electrodes inside the cells.

The tests were performed at mills that produce cellulose fiber from different types of raw materials. The tests included production of cellulose from sugarcane bagasse, wheat straw, eucalyptus wood, and softwood (pine), as raw materials for pulp and paper manufacturing. The black liquor samples generated at each mill were tested in the electrolytic pilot plants to recover caustic soda, produce hydrogen, and extract lignin. The tests provided operating data on voltage, amperage, temperature, caustic concentration (conductivity), liquor pH, and caustic and lignin extraction yields for each of the above mentioned raw materials.

RESULTS AND DISCUSSION

Data and results from pilot trials

The results from the pilot tests performed for each type of raw material used in cellulose pulp production are summarized in Table 1.

Table 1. Results of caustic and lignin extraction with electrolytic pilot work using different raw materials

Description	Sugarcane bagasse	Softwood
1. 10% Caustic, 100% basis, kg /day	1.63	49.2
2. Lignin yield, g /L of liquor	35	45
3. Voltage	5.0	4.2
4. Current Density, A /m^2	4,400	5,000
5. Energy, kWh /tonne caustic	3,400	3,100

The caustic production rate for each raw material varied depending on the size of the electrolytic membrane cell. The trials for softwood raw material were performed with a pilot plant approximately 30 times larger than the unit used for testing sugarcane bagasse. The current efficiency for caustic production averaged approximately 87%. The lignin yields varied between 32 and 45 grams per liter of liquor depending on which raw material was used. The yield for bagasse raw material was approximately 35 g/L. The energy required was approximately 3,100 kWh per tonne of caustic soda (100% basis), at about 4,400 A/m^2 current density. The energy required for softwood bagasse was approximately 3,400 kWh per tonne at 5,000 A/m^2.

Process description of a biorefinery using an electrolytic system

Figure 1 includes a flow diagram of an ethanol fuel biorefinery that uses soda cooking to produce cellulose fiber and electrolysis to recover caustic soda, extract lignin, and produce hydrogen and methane gas as additional products. The example included in the diagram produces 12,000 gallon of ethanol and approximately 35 tons per day of cellulose pulp. The estimated capacity for paper production can be increased from 35 to approximately 45 tons per day by using bagasse fiber plus softwood kraft for quality and fillers in the process. The products and fuels derived from sugarcane in addition to ethanol by the application of the electrolytic technology would provide energy cost reduction as well as additional revenues for the biorefinery.

Products description

The main products for the biorefinery described in figure 1 are ethanol fuel, cellulose fiber, lignin, hydrogen and caustic soda.

Ethanol fuel

The biorefinery module described therein includes a production capacity of 12,000 gallon per day of ethanol fuel with 96 percent concentration. The price of ethanol fuel can be estimated between US $1.10 and $1.50 per gallon. The ethanol product can be sold in the international market or it can be used as fuel for alcohol-fueled stoves in third world countries as a substitute to liquid propane gas that is normally used in their kitchens.

Cellulose fiber

The cellulose fiber produced from bagasse is normally used for paper manufacturing. The bleached fiber from bagasse can also be sold in the international market at an estimated US $395 per tonne or more.

Lignin (biofuel)

The lignin product obtained from electrolytic treatment of bagasse liquor contains a heat value of approximately 11,000 Btu per pound. The lignin from the biorefinery can be used as fuel to produce energy at high efficiency and provide electricity for the electrolytic unit and other sections of the refinery. The lignin material can also be sold as a value-added organic product to be used in manufacturing vanilla additives for food flavoring, organic fertilizers, low volatility plastics, adhesive agents, and other chemical agents of high commercial value.

Caustic soda

The electrolytic plant recovers caustic soda from the liquor generated in the digester where bagasse is treated during pulping process. The caustic extracted in the process is recycled back to the digester to continue cellulose pulp production from the bagasse or corn feed stock.

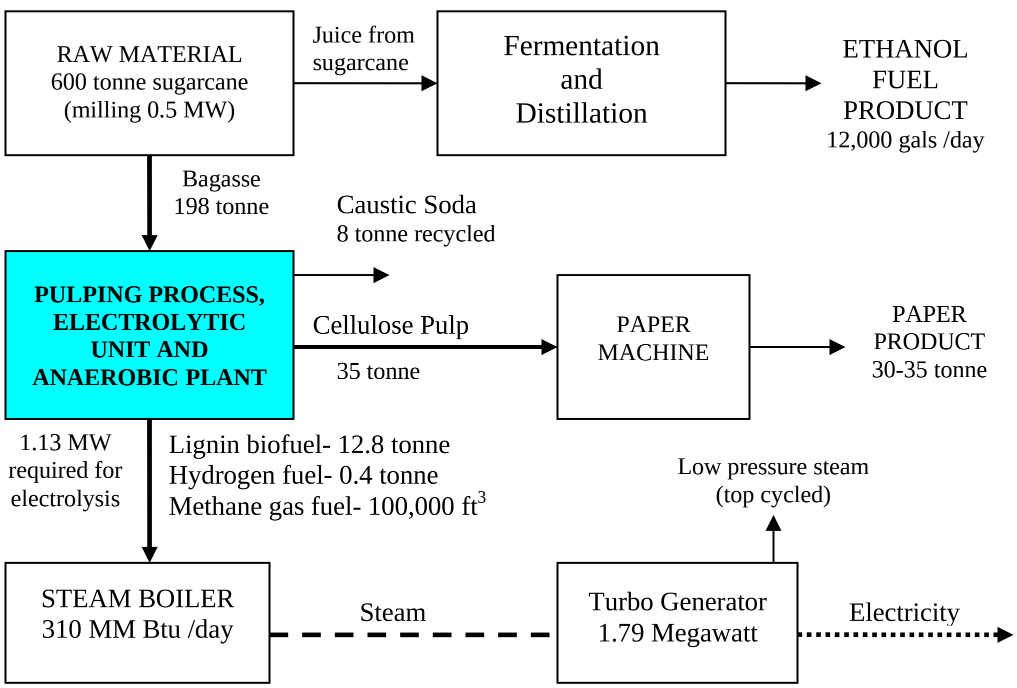
Hydrogen (fuel)

The electrolytic unit produces hydrogen gas simultaneously with the caustic extraction process. The hydrogen produced in the electrolytic cells can be burned at the plant to generate energy, or could be sold as fuel for hydrogen-fueled heat engines, or for use in upcoming fuel cell technologies in the market.

Methane gas (fuel)

The electrolytically treated stream contains hemicelluloses and other organic compounds that can be treated in the anaerobic plant to generate methane gas. The methane produced at the plant can be used as fuel for steam production.

Figure 1. Flow Diagram of a 12,000 gallon per day Ethanol Biorefinery with Electrolytic Unit



Energy balance discussion

The energy produced from burning the lignin biofuel, the hydrogen and methane gas in the boiler is estimated at 310 million Btu per day. The turbo generator would provide approximately 1.73 megawatt of power (7,500 Btu per kWh). This would be enough energy to feed the plant assuming optimum efficiency in equipment performance. If this is the case, the electrolytic unit would consume approximately 1.13 megawatt at 3,400 kWh per tonne of caustic. The mill would consume approximately 0.5 megawatt for sugarcane juice extraction. The balance of 0.1 megawatt would be available for operation of other machinery at the plant.

The thermal energy required at the plant would be provided with the low-pressure steam exhaust from the turbo generator (top cycled arrangement) as shown on figure 1.

Capital cost estimation

The estimated capital cost for the design and installation of a biorefinery rated for 12,000 gallons per day of ethanol fuel and using an electrolytic unit is described on table 2.

Energy benefits in comparison with other sources and types of fuels

The cost of energy for an electric power generating plant using ethanol and other fuels produced at a biorefinery using electrolytic technology can be estimated at US $53 per megawatt-hr, according to the following calculations:

US $179,000 net production cost per month
336,000 gals per month x 76,000 Btu per gallon = 25,540 million Btu per month
25,540,000 Btu /7,500 = 3,400 megawatt-hrs per month (7,500 Btu per kWh)
$179,000 /3,400 megawatt-hrs = US $53 per megawatt-hr

Table 2. Estimated capital cost

Equipment description	Est. installed cost in US dlrs
1. Sugarcane milling machinery	586,000
2. Fermentation and distillation plant	1,850,000
3. Pulping equipment (paper machine not included)	4,204,000
4. Electrolytic plant	4,700,000
5. Anaerobic system	790,000
6. Steam boiler and turbo generator	1,550,000
7. Building and construction	1,800,000
8. Engineering	995,000
9. Land and miscellaneous	750,000
Total estimated capital cost	17,225,000

Projected revenues and cost projections

The revenues and cost projections for a 12,000-gallon per day ethanol biorefinery that uses electrolysis are included in table 3.

Table 3. Projected Revenues /Costs of typical month at Biorefinery using Electrolysis

Description		Value (US $)
1. Projected monthly revenues		
Ethanol fuel sales, US $1.50 /gal		506,000
Cellulose fiber sales, US $ 395 /tonne		416,000
Total revenues		922,000
2. Projected monthly costs		
Raw material, sugarcane at US $18 /tonne		310,000
Operation		75,000
Total cost		385,000
3. Gross benefit		537,000
4. Estimated loan payments, 10 yrs at 8% interest		210,000
5. Volume of ethanol product, gallons per month	336,000	
6. Projected unit cost of ethanol, US $ cost per gallon factor (179,000 /336,000):		0.45

385,000 raw material and operations
210,000 loan payments
595,000 total cash outflow
416,000 credit cellulose fiber sales
179,000 net production cost monthly (336,000 gals of ethanol)

The cost of energy for power generation with biofuels would be equivalent to US $53 per megawatt-hr. Figure 2 compares projected costs for electric power generators using eolic energy, carbon, propane gas, fuel oil, and the fuels produced from sugarcane by using the electrolytic process and generating ethanol, lignin biofuel, hydrogen, and methane gas.

Figure 2. Energy Cost Comparison for Different Sources and Fuels

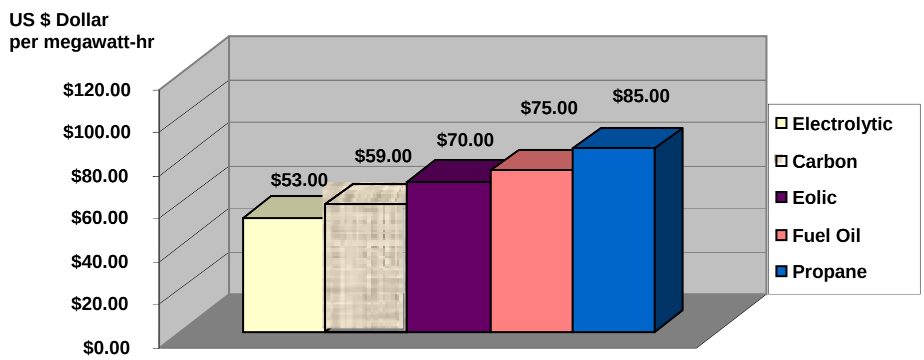


Table 4 summarizes the annual financial benefits projected for a biorefinery module rated for 12,000 gallon of ethanol fuel and which uses the electrolytic technology to produce approximately 35 tons per day of cellulose fiber from the bagasse material generated from the sugarcane mill.

Table 4. Projected annual economic benefits for biorefinery using the electrolytic technology to generate additional revenue

Description	Projected Value
Projected Revenues from products and coproducts sales:	US $ 9,635,000
Ethanol (US $1.50 per gallon) $5,365,000 /yr	
Cellulose (US $ 395 per tonne) $4,270,000 /yr	
Lignin (Fuel)	
Caustic Soda (Recycled)	
Hydrogen (Fuel)	
Methane gas (Fuel)	
Estimated Operating Costs:	$ 4,129,000
Projected Gross Benefits:	$ 5,506,000
Estimated Investment:	$17,300,000
Internal Rate of Return (IRR) at US $1.50 per gallon ethanol fuel:	29%
Internal Rate of Return (IRR) at US $1.10 per gallon of ethanol fuel:	21%

The profit margin for the operation of the biorefinery is increased by the addition of sales revenues from the cellulose fiber product equivalent to $4,270,000 per year. These revenues increase the income from $5,365,000 to $9,635,000 per year. The internal rate of return is estimated at 29% for an ethanol price of $1.50 per gallon. The IRR for ethanol fuel at $1.10 is estimated at 21%. These high margins would allow ethanol fuel producers to maintain affordable prices for the consumer and still obtain moderate profits.

CONCLUSIONS

The additional revenues and energy savings derived from the electrolytic technology for ethanol production bring significant advantages for the industry and provide increase in economic feasibility for the installation of ethanol refineries that wish to compete in a fuels product market that is very competitive in nature. The data gathered in this study shows that ethanol production from sugarcane can offer prices that are competitive with conventional fossil fuels in the market and maintain attractive economic benefits for investors that wish to participate in the biofuels production industry.

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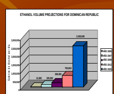

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High Ethanol Production Costs and Energy Requirement

Ethanol production costs should be competitive with current prices for fossil fuels. The following table compares sources:

Description	Fossil fuel	Ethanol (Import)	Ethanol (EL)
Production Cost	---	---	US $ 0.45
Available Price	US $1.20 Import LPG	US $ 1.55 per gallon	$1.10 – 1.50 per gallon

Note: Prices based on market data for 2005 in the Dominican Republic, one of the countries that grows sugarcane.

Products Derived from Sugarcane

SUGARCANE as Raw Material - List of Products derived by using 'Electrolytic Membrane Process'

- **ETHANOL from Sugarcane Juice**
- **CELLULOSE Fiber for Paper or Ethanol production**
- **CAUSTIC Soda using Electrolytic Process**
- **LIGNIN bio-fuel**
- **Hydrogen**
- **Methane gas** (anaerobic process)
- **Electricity**

Other products include:

Lignin as valued product and organic fertilizers

CORN as Raw Material - List of Products derived by using 'Electrolytic Membrane Process'

- **CORN grain or ETHANOL from grain**
- **CELLULOSE Fiber for Paper or Ethanol production**
- **CAUSTIC Soda using Electrolytic Process**
- **LIGNIN bio-fuel**
- **Hydrogen**
- **Methane gas** (anaerobic process)
- **Electricity**

Other products include:

Lignin as valued product and organic fertilizers

The Electrolytic Technology

The Electrolytic Membrane Process

1. The Electrolytic membrane technology developed and patented by Electrosep Inc. is designed for recovery of CAUSTIC soda from black liquor streams which are generated in digesters during cellulose fiber production for papermaking

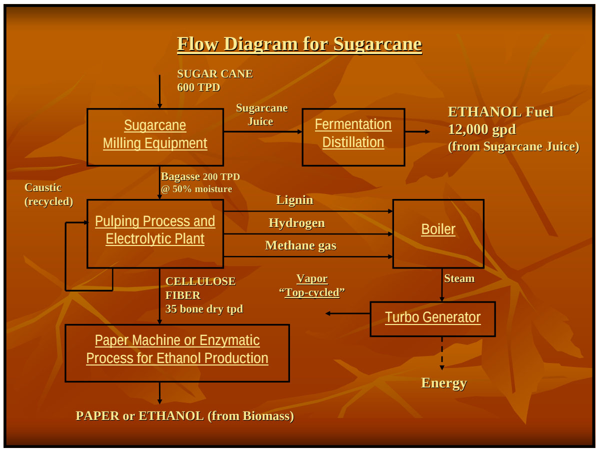
2. The electrolytic technology also provides a viable method of extracting LIGNIN from the weak black liquor as a powder that can be used as biofuel for power boilers

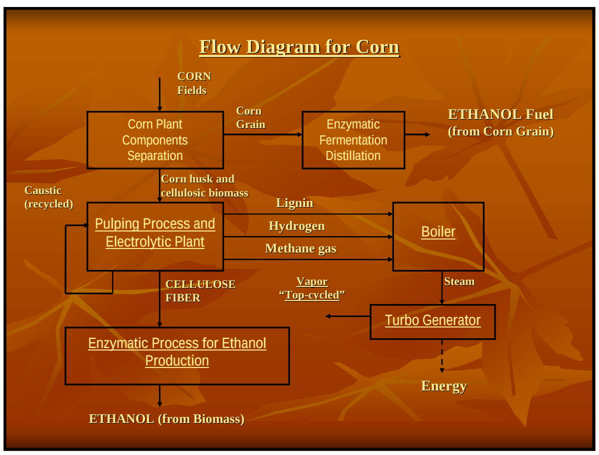
3. In ethanol fuel production from sugarcane and corn, sales of cellulose fiber and other byproducts can provide additional revenues for the biorefinery and reduce net operating costs to approximately US $ 0.45 per gallon of alcohol

The Electrolytic Membrane Process (cont'd)

4. The electrolytic process was successfully pilot tested in pulp and paper mills located in the United States, in South America, Turkey and India

5. The electrolytic pilot tests included wood and nonwood types of raw materials like:
   - softwood
   - sugarcane bagasse
   - wheat straw
   - eucalyptus


Flow Diagram for Sugarcane
SUGAR CANE
600 TPD
Sugarcane Milling Equipment
Sugarcane Juice
Fermentation Distillation
ETHANOL Fuel
12,000 gpd
(from Sugarcane Juice)
Bagasse 200 TPD
@ 50% moisture
Caustic (recycled)
Pulping Process and Electrolytic Plant
Lignin
Hydrogen
Methane gas
Boiler
CELLULOSE FIBER
35 bone dry tpd
Vapor
"Top-cycled"
Steam
Turbo Generator
Paper Machine or Enzymatic Process for Ethanol Production
Energy
PAPER or ETHANOL (from Biomass)


Flow Diagram for Corn
CORN
Fields
Corn Plant Components Separation
Corn Grain
Enzymatic Fermentation Distillation
ETHANOL Fuel
(from Corn Grain)
Corn husk and cellulosic biomass
Caustic (recycled)
Pulping Process and Electrolytic Plant
Lignin
Hydrogen
Methane gas
Boiler
CELLULOSE FIBER
Vapor
"Top-cycled"
Steam
Turbo Generator
Enzymatic Process for Ethanol Production
Energy
ETHANOL (from Biomass)


Test Results

Electrolytic Test Results

Description	Sugarcane Bagasse	Softwood
1. 10% Caustic 100% basis, kg /day	1.63	49.2
2. Lignin yield g lignin /L of liquor	35	45
3. Voltage	5.0	4.2
4. Current Density A /m²	4,400	5,000
5. Energy kWh /tonne caustic	3,400	3,100

Summary of Products Projected for Plant rated at 12,000 gpd Ethanol

Raw Material

600 Tons /day of Sugarcane

Caustic soda - EL
8 Ton /day (Recycled)

→ *Ethanol Fuel* — *12,000 gals /day*
→ *Cellulose Fiber* — *38 Ton /day*
→ *Lignin* — *30,000 Lbs /day*
→ *Hydrogen* — *650 Lbs /day*
→ *Methane* — *102,000 ft3 /day*
→ *Electricity* — *7 megawatts*

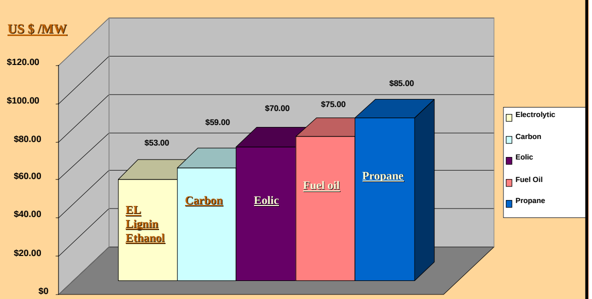
Operating Costs and Sales Revenues

Projected Revenues /Costs of Biorefinery using Electrolysis

Description of Plant rated for 12,000 gal /day ethanol	Value (US $)
1. Projected monthly Ethanol fuel sales, US $1.50 /gal	506,000
Cellulose fiber sales, US $ 395 /tonne	416,000
Total revenues	922,000
2. Projected monthly costs	
Raw material, sugarcane at US $18 /tonne	310,000
Operation	75,000
Total cost	385,000
3. Gross benefit	537,000
4. Estimated loan payments, 10 yrs at 8% interest	210,000
5. Volume of ethanol product, gallons per month	336,000
6. Projected production cost per gallon ethanol US $ /gal	0.45

Energy and Biofuels

GRAPH OF PROJECTED COSTS FOR POWER GENERATION



Capital Cost

Estimated capital cost

Equipment description	Est. cost, US dlrs
1. Sugarcane milling machinery	586,000
2. Fermentation and distillation plant	1,850,000
3. Pulping equipment	4,204,000
4. Electrolytic plant	4,700,000
5. Anaerobic system	790,000
6. Steam boiler and turbo generator	1,550,000
7. Building and construction	1,800,000
8. Engineering	995,000
9. Land and miscellaneous	750,000
Total estimated capital cost	17,225,000

Summary of Economic Benefits

Projected annual economic benefits for 12,000 gpd Ethanol and 38 TPD Cellulose Fiber

Benefits Plant using Electrolytic Process	Projected Value
Projected Revenues from products sales:	US $ 9,635,000
Ethanol (US $1.50 per gallon) $5,365,000 /yr Cellulose (US $ 395 per tonne) $4,270,000 /yr Lignin (Fuel) Caustic Soda (Recycled) Hydrogen (Fuel) Methane gas (Fuel)	
Estimated Operating Costs:	$ 4,129,000
Projected Gross Benefits:	$ 5,506,000
Estimated Investment:	$17,300,000
Int. Rate of Return (IRR), US $1.50 /gal ethanol:	29%
Int. Rate of Return (IRR), US $1.10 /gal ethanol:	21%
Estimated Payback Period at $1.10 /gal:	3.8 yrs

CONCLUSIONS

The electrolytic membrane process offers significant benefits to the industry

The addition of products and byproducts such as cellulose fiber, lignin fuel, hydrogen, and others, lower the net production costs and energy fuel requirements for ethanol production

The cost of power generation using the technology can be less than US $ 53 per megawatt

The net production cost of ethanol fuel production can be reduced to less than US $ 0.45 per gallon

The PRICE of ethanol can be set between US $ 1.10 and 1.50 per gallon while maintaining the Internal Rate of Return at more than 21%