SERI/STR-231-3142
UC Category: 61
DE87001186

Economic Feasibility Study of an Acid Hydrolysis-Based Ethanol Plant

A Subcontract Report

Badger Engineers, Inc.
Cambridge, MA

April 1987

SERI Technical Monitor:
J. D. Wright

Prepared under Subcontract No. ZX-3-03096-2

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401-3393

Prepared for the
U.S. Department of Energy
Contract No. DE-AC02-83CH10093

Table of Contents

Appendixes

List of Figures

List of Tables

EXECUTIVE SUMMARY AND CONCLUSIONS

This report presents the conceptual design and economic analysis of a process to convert lignocellulosic material, specifically mixed hardwood chips into fuel-grade ethanol. A key element of the technology is a novel plug flow reactor developed at Dartmouth College by Professors Grethlein and Converse in which dilute sulfuric acid is used in a continuous, short residence time, high temperature reactor to hydrolyse susceptible fractions in the feed. The products of the hydrolysis are fermentable sugars (hexose), pentose sugars, furfural, lignin residue, and a variety of minor organic constituents including hydroxymethyl-furfural (HMF); levulinic, acetic and formic acid; and terpenes and other extractives. The relative proportions of the products can be varied to some degree by adjusting reactor conditions. In the present study, reactor conditions have been specified which maximize the yield of fermentable sugars with furfural as the major process byproduct. The process also produces electric power in excess of its own requirements from the combustion of waste byproducts lignin and waste organics.

Two design capacities have been investigated, namely 25 million and 5 million gallons of ethanol per year. In addition, a second case representing an important design variation has been examined at each design capacity (Design Case II and Design Case IV). The resulting four cases are summarized in Table 1.1.

Table 1.1 Summary of Design Cases Studied

	Design Case	Design* Capacity MM Gallon Ethanol/Yr	Number Hydrolysis Stages	Wood Feed Rate Dry Metric Tons/Hour	Byproducts: Furfural MM Lb/Yr	Byproducts: Exported Electricity MW	Outside Utilities Required	Effluents
I	Base Case	25	1	73.8	130.2	22	No	Landfill, Boiler Flue, Cooling Tower**
II	Alternative Case	25	2	66	93.14	--***	No	Landfill, Boiler Flue, Cooling Tower
III	Small Scale Plant	5	1	14.8	26	4.4	No	Landfill, Boiler Flue, Cooling Tower
IV	Small Scale Plant	5	1	14.8	26	--	Electric Power 4.1 MW	Landfill, Boiler Flue, Cooling Tower

*Nominal design capacity: actual design capacity for 25 million gallon is 26.2 and for 5 million gallon is 5.24.

**Cooling tower refers to evaporation, drift, and blowdown.

***Electrical needs generated onsite.

25 million gallons ethanol per year has been adopted as the base case since this is foreseen as the nominal capacity of typical large scale plants that would be built once the uncertainties due to feedstock availability, technology, and byproduct utilization have been satisfactorily answered and the advantages of economy of scale can be taken. The 5 million gallon scale was investigated because this is the probable size of the first commercial plant.

Hydrolysis reactor scale-up considerations in progressing from the existing ½" diameter used at Dartmouth to the eventual 10" diameter for the large commercial scale plant have been addressed from the point of view of operating stability, heat transfer capacity, feed slurry handling, and yield of product.

Flexibility of location was an important consideration in the study since it is expected that this technology will be employed in more than one location. Thus, the base case plant has been designed to minimize environmental impact and to be essentially self-contained, generating all utilities onsite. Also, the capital cost estimate has been generated for a typical location in the Midwest.

An economic analysis has been carried out to determine, for each of the four design cases, the required ethanol selling price to yield a 15% discounted cash flow internal rate of return (IRR) after tax. Two parallel sets of calculations have been performed: one using economic assessment parameters requested by SERI and a second using parameters developed by Badger for this type of study. In addition, a calculation has been made on the SERI basis with a 25% IRR for the 5 million gallon plant (Design Case III) since a higher IRR than 15% may be required for the first commercial installation. The effect of the main economic parameters is shown in Figure 1.1.*

The economic analysis is extended, for Design Cases I and III, to calculation of the ethanol price sensitivity to feedstock price and capital cost. The sensitivity of ethanol price to furfural selling price is also calculated for base case (Design Case I).

*NOTE: An energy tax credit has been included in the Badger analysis of 10% of installed cost. This has the effect of reducing the ethanol selling price by 15¢ per gallon ($1.95 to $1.80) for the base case.

The technical risk involved in commercialization of the process based on the present level of development is analyzed and quantified, and possible process development strategies are assessed by a methodology developed by the Rand Corporation. Recommendations for future development are based on the results of the Rand Method. (Reference 30)

Conclusions

The major conclusions reached in the study are listed below:

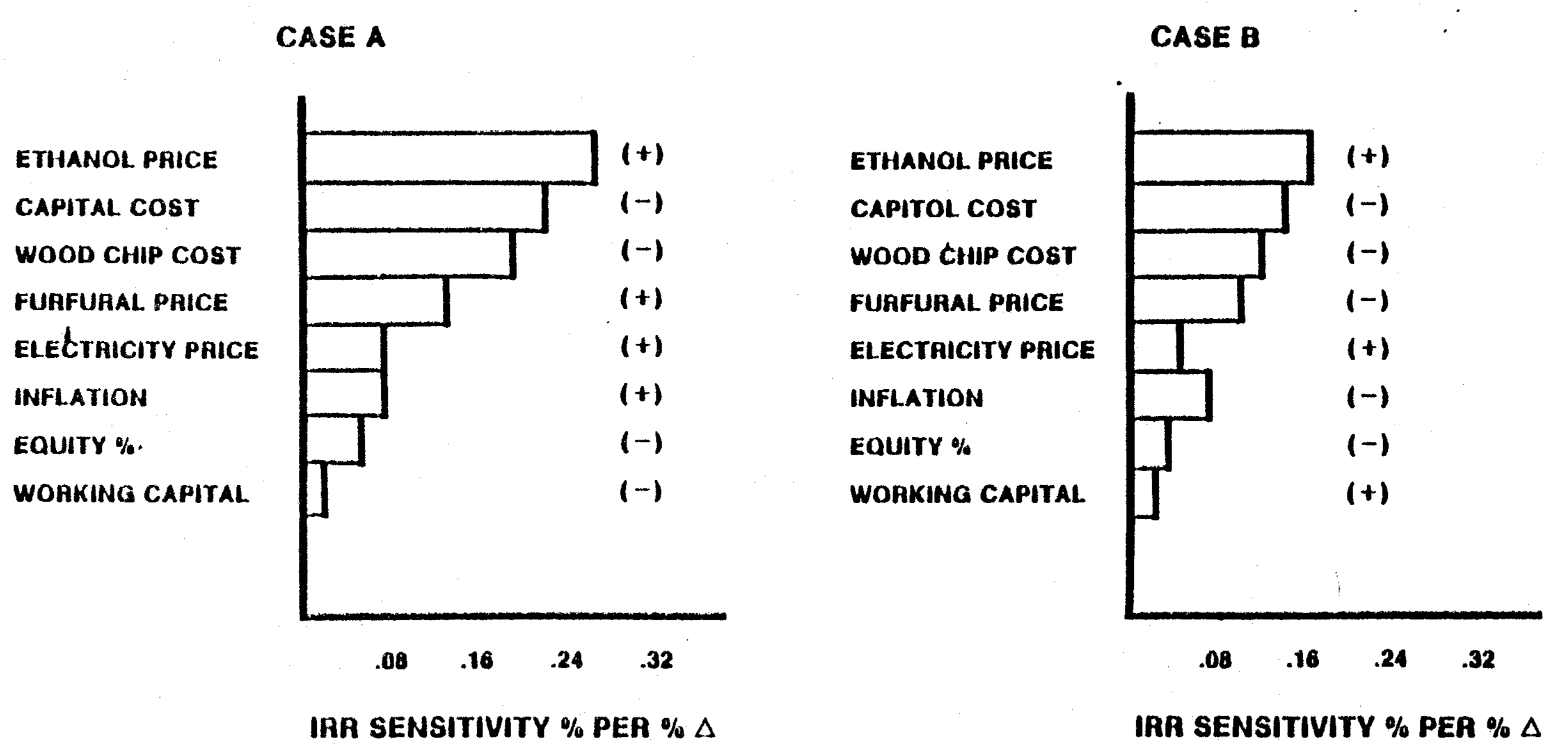
(1) The process design presented is operationally feasible from an engineering viewpoint. However, a high level of risk of capital cost growth and of performance shortfall would be expected without a process demonstration phase and a site-specific cost analysis. These two exercises should result in a sufficient level of confidence to justify commitment of funds by an industrial producer.

(2) Recommendations for design and operation of the commercial-scale reactor have been made. These include measures to reduce the effects of tar pluggage, to ensure adequate heat transfer, and to facilitate pumping the high consistency wood slurry feed. These recommendations have been supported, where possible, by experimental work at Dartmouth College or Badger's Weymouth Laboratory.

Figure 1.1 Effect of Economic Parameters on IRR

FIG. 1.1

SENSITIVITY OF DCFIROR TO ECONOMIC PARAMETERS



(3) Feedstock availability investigation reveals that sufficient quantities of waste wood from logging, lumber mill, and forest thinning operations would be available in most forested areas to supply a 25 million gallon plant. The scale of collection required is the same as that now being carried out by Burlington Electric Company for their McNeil wood-fired power plant. A conservative figure of $42 per dry metric ton has been used in the economic assessment based on information from wood chip brokers, large scale chip users, forestry consultants, and published literature.

(4) The market for fuel-grade ethanol is expected to grow to well over 1000 million gallons per year by 1990 primarily as a result of the increasing demand for gasoline blending components. Consequently, the market would experience little downward pressure on price as a result of the additional output from several 25 million gallon plants.

The question of the furfural market is not clear cut. Although furfural is a versatile chemical intermediate, its demand in the U.S. has been dropping in recent years as lower cost alternatives have eroded its traditional outlets. The introduction of the quantities of furfural produced by a 25 million gallon, acid-based, ethanol from wood plant would be expected to depress the price severely. As the price of furfural drops, however, its attractiveness as a chemical intermediate in the production of such commodity chemicals as adipic acid, maleic anhydride, ethylbenzene, and butanol increases.

Analysis of the potential market for furfural from published data (reference 10) shows that at 15¢ per pound a potential market of over 2 billion pounds per year and at 10¢ per pound a potential market of over 3 billion pounds per year exists. The above figures suggest that the combined ethanol and furfural markets have the potential to absorb the output of 15 to 20 large commercial scale plants.

The establishment of such major furfural markets will not occur overnight and could reasonably be expected to take 10 to 15 years to develop. However, future disruption of oil supplies with resultant increases in the prices of petrochemical feedstocks could accelerate this scenario.

(5) A market for electric power is assumed to exist under the Public Utilities Regulatory Policies Act (PURPA). The 25 million gallon plant would produce a total of 44.5 megawatts which is below the present PURPA maximum limit of 80 megawatts. The price assumed in the study for this byproduct is 5¢ per kilowatt hour.

(6) The commercial potential of the other organics produced has not been investigated in this study nor has credit been taken for them as products. However, these organics are concentrated in the process which facilitates recovery if warranted and technically feasible.

(7) The selling price of fuel grade ethanol calculated by SERI and Badger economic assessment parameters is given in Table 1.2.

The figures suggest that the technology looks attractive in the long term. Economic assistance may be necessary to introduce the technology in the short term at small commercial scale. However, economic analysis of the small commercial plant suggests that this might be an attractive venture should a cheap local source of feedstock be available.

Table 1.2

Selling Price of Denatured Ethanol for the Four Design Cases

		Ethanol Selling Price $ Per Gallon		
		SERI Parameters		Badger Parameters
Design Case		15% IRR	25% IRR*	15% IRR
I	25 Million Gallon (Base)**	1.23		1.80
II	25 Million Gallon (Alternative)	1.65		2.23
III	5 Million Gallon***	1.42	2.15	2.83
IV	5 Million Gallon (Purchased Power)	1.63		2.85

*For rationale behind using 25% DCFIROR for 5 million gallon per year cases see Page 9, Section 5.

**Furfural Priced at ¢ 15/lb.

***Furfural Priced at ¢ 55/lb.