Biomass to Ethanol Process Evaluation

A report prepared for
National Renewable Energy Laboratory
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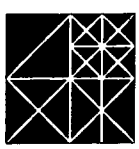

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I EXECUTIVE SUMMARY

Chem Systems has been commissioned to perform a technical and economic evaluation of the plant design described in the SERI draft report entitled "Technical and Economic Analysis of an Enzymatic Hydrolysis Based Ethanol Plant" dated 1991. In addition Chem Systems has been asked to examine the effect of selected process improvements on the cost of production of ethanol. It has been assumed that these improvements could be attained through R&D on the feedstock and the conversion process and through operational experience on scaled-up processes. The 1991 SERI analysis determined a base case product cost of $1.27 per gallon of ethanol product, and a target product cost of $0.67 per gallon.

Using the SERI report as a basis and starting point, Chem Systems developed a heat and material balance for the wood-to-ethanol process using its own process and engineering design experience and a process simulator computer software program licensed to Chem Systems. This program also generated most of the equipment size specifications. The design basis parameters included data on feedstock composition, as well as yield, operating conditions and material balance for prehydrolysis and hydrolysis reaction, fermentation, and enzyme production. Based on a 580 thousand metric tons per year (160,000 pounds per hour) of wood (dry) feed rate at a 1993 southeast US location, investment capital (both inside and outside battery limits) and production costs have been estimated.

To improve the usefulness and accuracy of the model as a tool for carrying out sensitivities, Chem Systems has developed algorithms that generate equipment cost estimates as a function of material balances flows. These have been used to generate the total investment cost for a specific sensitivity. In addition to the capital cost algorithms, production costs algorithms have also been developed. These algorithms have proved to be a useful vehicle for conducting extensive sensitivity analysis in the past for NREL (SERI).

An economic analysis has been performed on a fuel ethanol (90 percent ethanol, 5 percent water, and 5 percent gasoline) plant producing approximately 160 thousand metric tons per year (54 million gallons per year). The feedstock to the plant is assumed

to be whole-wood tree chips delivered to the site at a cost of $46 per dry metric ton ($42 per short ton).

The capital investment is provided in the appendix and summarized in Table I.1. At this level of detail the capital cost estimate is judged to have an accuracy of plus or minus 25 percent. The purchased equipment for the ISBL totals $25 MM and the corresponding installed cost is estimated to be $40 MM. The major investment in this area is the SSF facilities having an installed cost of over $17 MM. In the off-site area the major investment item is the boiler package (circulating fluid-bed boiler, BFW system and bag house) which is expected to cost about $27 MM (installed). The total installed plant cost (both ISBL and OSBL) is estimated to be $101 MM. Adding in the indirects to this total gives a total capital investment of $150 MM. The total project investment including the owner's other project costs is estimated to be $165 MM.

TABLE I.1
INVESTMENT COST SUMMARY - BIOMASS TO ETHANOL PLANT
(millions dollars, 1993 basis)

	Plant Area		Installed Equipment
ISBL	100	Wood handling	3.20
	200	Prehydrolysis	7.75
	300	Xylose fermentation	3.19
	400	Cellulase production	1.74
	500	SSF	17.68
	600	Ethanol recovery	6.49
		Total	**40.05**
OSBL	700	Off-site tankage	2.12
	800	Waste treatment	6.09
	900	Utilities	
		Boiler package (including BFW system)	26.61
		Process water	0.45
		Turbogenerator	9.19
		Cooling water package	3.08
		Chilled water package	1.23
		Plant, instrument and fermentation air	5.33
		CIP/CS	0.30
		Buildings	1.60
		Site development	3.60
		Additional piping	1.80
		Total	**61.38**
Indirects		Prorateable costs	10.14
		Field expenses	10.14
		Home office construction and fees	25.36
		Contingency	3.04
		Total capital investment	150.12
		Owner's costs	15.01
		Total project investment	**165.13**

A detailed cost of production estimate is provided in Section VI and summarized in Table I.2. The net raw materials is estimated to be $208 per metric ton (62 cents per gallon). Utilities are estimated to provide a credit of about $33 per metric ton (10 cents per gallon). The total variable cost is $175 per metric ton (52 cents per gallon).

TABLE I.2
COST OF PRODUCTION SUMMARY
(US$ per metric ton)

Raw materials	205
By-product credits	3
Net raw materials	**208**
Utilities	(34)
Variable cost	**175**
Direct fixed costs	26
Allocated fixed costs	21
Total cash cost of production	**222**
Annual capital charges	207
Cost of denatured ethanol	**430**

Adding in the direct fixed costs ($27 per metric ton) and allocated fixed costs ($21/per metric ton) gives a total cash cost of production of $222 per metric ton or 66 cents per gallon.

Adding in the annual capital charge (20 percent of total investment) almost doubles the production cost. The resulting cost of denatured ethanol is $430 per metric ton or $1.27 per gallon. This corresponds very closely with the results of the 1991 SERI report.

The report prepared in 1991 by SERI examined numerous parameters and their influence on the biomass process. In order to approach the target of 67 cents per gallon, in this

study several improvements have been combined within one sensitivity. The changes to the base case can be grouped into three categories (see Table I.3):

- Technology improvements (yields, fermentation times, equipment, ethanol concentrations, enzyme loading, etc.)
- Feedstock production improvements (cost and content)
- More optimistic cost of production factors (electricity selling price and onstream time)

TABLE I.3
PROCESS PARAMETERS AND ASSUMPTIONS

	Base Case	Sensitivity (goal)
Cellulose to ethanol yield, %	75.7	90
Xylose to ethanol yield, %	85.5	95
Xylan to xylose yield, %	80.0	90
SSF fermentation time, days	7	3
Xylose fermentation time, days	2	1
Ethanol concentration in SSF, %	4.17	6
Cellulase loading, IU/g	7	3
SSF and xylose seed fermentations	yes	eliminated
Feedstock cost, $/dry ton (short)	42	34
Feedstock carbohydrate content, %	70.2	77.2
On-stream time, %	91.3	98
Electricity selling price, cents/KWH	4.2	6
Ethanol purification	distillation	mole sieve

The flow scheme for the sensitivity case remained essentially unchanged from the base case except for the distillation section where a pressure swing adsorption unit (mole

sieve) has been used in place of the rectifying column to bring the concentration of ethanol from 4.7 to 94.5 percent in the final product.

The results of the sensitivity case shows a savings in investment of $25 million in the total capital investment or about 15 percent less than the base case. The yield or production of ethanol per unit of wood feedstock has increased by about 30 percent over the base case. The consumption of utilities improved in all areas. The estimate of the cost of production shows that the cost has been lowered to $251 per metric ton (74 cents per gallon).

As a result of this study, Chem Systems has concluded that the overall process concept appears to be feasible and is generally supported by reasonable engineering judgement. Areas that need further investigation and substantiation include:

- The affect of the solids concentration in the feed to the on the distillation system
- The affect of the high pH on the fermentation tanks and finding a suitable lining for the same
- Development/verification of the sensitivity case assumptions (e.g., yields, etc.) in order to achieve reasonable plant economics
- Verify large scale equipment feasibility

If, in addition to the improvements discussed and implemented in this report, efforts are made to reduce power consumption, to continue to optimize other aspects of the process, and to increase the carbohydrate content of the feedstock, one could expect the ethanol price to be reduced even further.