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# Preliminary Energy Balance and Economics of a Farm-Scale Ethanol Plant

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A Division of Midwest Research Institute

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# PRELIMINARY ENERGY BALANCE AND ECONOMICS OF A FARM-SCALE ETHANOL PLANT

DAN JANTZEN
TOM MCKINNON

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PREPARED UNDER TASK NO. 3339.01

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# FOREWORD

The energy balance and economics of grain to ethanol plants are matters of current national interest, as we strive to deal with our liquid fuel supply problems. This report, prepared at the request of the Department of Energy, examines the energy balance and economic questions for a particular farm-scale plant in Campo, Colo. It shows that such plants may have a place in our national liquid fuel supply system.

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Clayton S. Smith, Manager
Chemical & Biological Division

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# SECTION 1.0

# INTRODUCTION

Motivated by the desire to have an alternative market for its grain, the Schroder family of Campo, Colo., has designed, built, tested, and modified a small-scale ethanol plant over the past 18 months. The plant currently operating is the second design. A third, and probably final, design will be installed and operating within a few months. The current plant produces approximately 30 gal/hr of 190-proof alcohol on a continuous basis. The new plant will produce 50 gal/hr of 200-proof alcohol.

A key feature of the Schroder plant is the relatively low process heat requirement, which is achieved by extensive use of waste-heat recovery heat exchangers. This is manifested in the low temperatures of the process output streams.

# SECTION 2.0

# PURPOSE

Acting on the request of the Office of Alcohol Fuels, U.S. Department of Energy, and at the invitation of the Schroder family, representatives from the Solar Energy Research Institute, Dan Jantzen and Tom McKinnon, evaluated the energy balance on the Schroder plant. The objective was to help clear up the controversy surrounding the net energy benefit of ethanol production. Although the study was site-specific to the Schroder plant and limited in scope, it is indicative of the potential performance of grain-to-ethanol plants in general.

# SECTION 3.0

# PLANT DESCRIPTION AS OF 27 MARCH 1980

The plant has two 3500-gal cookers fitted with agitators; three 7000-gal fermenter tanks, also with agitators and soon to have cooling coils; three 16 ft sieve-tray distillation columns; and two steam generators with waste heat recovery coils (see Fig. 3-1). All the heat exchangers are field-fabricated double-pipe type. The plant is designed to operate 24 hours per day, with one operator on duty. Cookers and fermenters operate batchwise on 36 hour cycles. Two cook batches are required per fermentation batch. Distillation is continuous.

To start the process, the cooker is half filled with 68°C water that is preheated in a counter-flow heat exchanger against the hot mash from the previous batch; 124 bushels of grain and an enzyme are added to the hot water. Steam is injected to raise the temperature to 88°C. The batch is held for 1-1/2 hours and is continuously agitated. The enzyme breaks the starch into dextrins (short hexose chains), liquefying the starch. The cellulose and protein from the starch remain as suspended solids.

The batch is then pumped through counter-flow heat exchangers to preheat the water for the next batch. Currently, the mashing makeup water is from a well at 16°C (see Sec. 4.0).

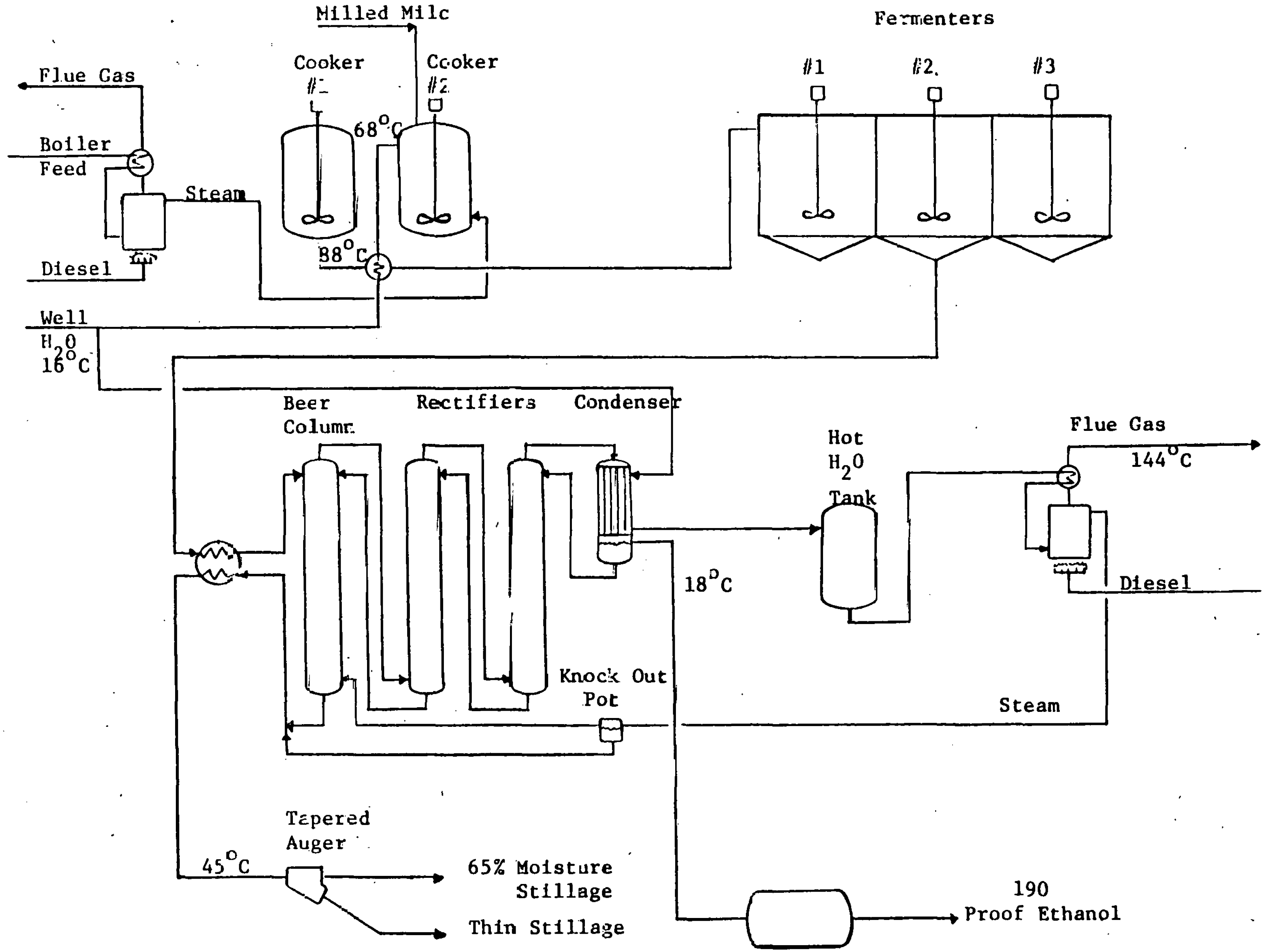


**Figure 3-1. Schroder Ethanol Plant as of 27 March 1980.**

Two cooker batches are put in the fermenter tank along with the saccharifying enzyme and a concentrated yeast solution where the dextrin is converted to glucose, then ethanol. The fermentation takes approximately 36 hours at 45°C. The fermenters are also continuously agitated.

Upon completion of fermentation, the beer solution should be 12% ethanol. This beer solution with stillage suspended is pumped through a counter-flow heat exchanger where the beer is heated against the hot stillage from the bottom of the beer column; the heated beer is then pumped to the top of the beer column. Two rectifying columns in series are then used to distill the ethanol to 192 proof. The alcohol is then condensed, with the condenser water entering at 16°C and leaving at 70°C. It is saved in a large insulated tank and used as boiler feedwater.

The cooled stillage is pumped to a tapered auger which produces a solid product with a 65% moisture content and a thin stillage that contains approximately one-third of the solids. The solids, which are 28-32% protein on a dry basis, are a valuable protein supplement product sold to livestock growers. The thin stillage is not currently being used.

## SECTION 4.0

## PLANT IMPROVEMENT

The Schroders are building a new plant (see Fig. 4-1) which will incorporate a number of improvements to increase production, reduce operating labor, and further reduce process heat demands.

The new plant will have molecular sieve drying columns to take the alcohol from 188 proof to 200 proof (anhydrous) so it may be used as a gasoline octane booster. The molecular sieve columns are expected to have much lower energy demands relative to benzene distillation schemes. By reducing the proof from the distillation columns from 192 to 188 proof, considerable distillation energy will be saved by reducing the reflux rate on the rectifier.

The new plant will use hot water from the hot water storage tank for makeup water to the cookers rather than well water. Thus, the condenser will be the only process water input to the system.

An improved recovery scheme will be developed for the stillage to reduce the loss of the solids in the thin stillage.

This plant design has significantly reduced process heat demands, but the electricity consumption remains high. The tank agitators are run more than necessary, and the heat exchangers may be causing large pumping losses.

## SECTION 5.0

## ENERGY BALANCE MEASUREMENTS

The energy inputs to the system are diesel fuel and electricity. The other inputs are grain, water, and enzymes. The diesel fuel was measured by weighing the fuel into a

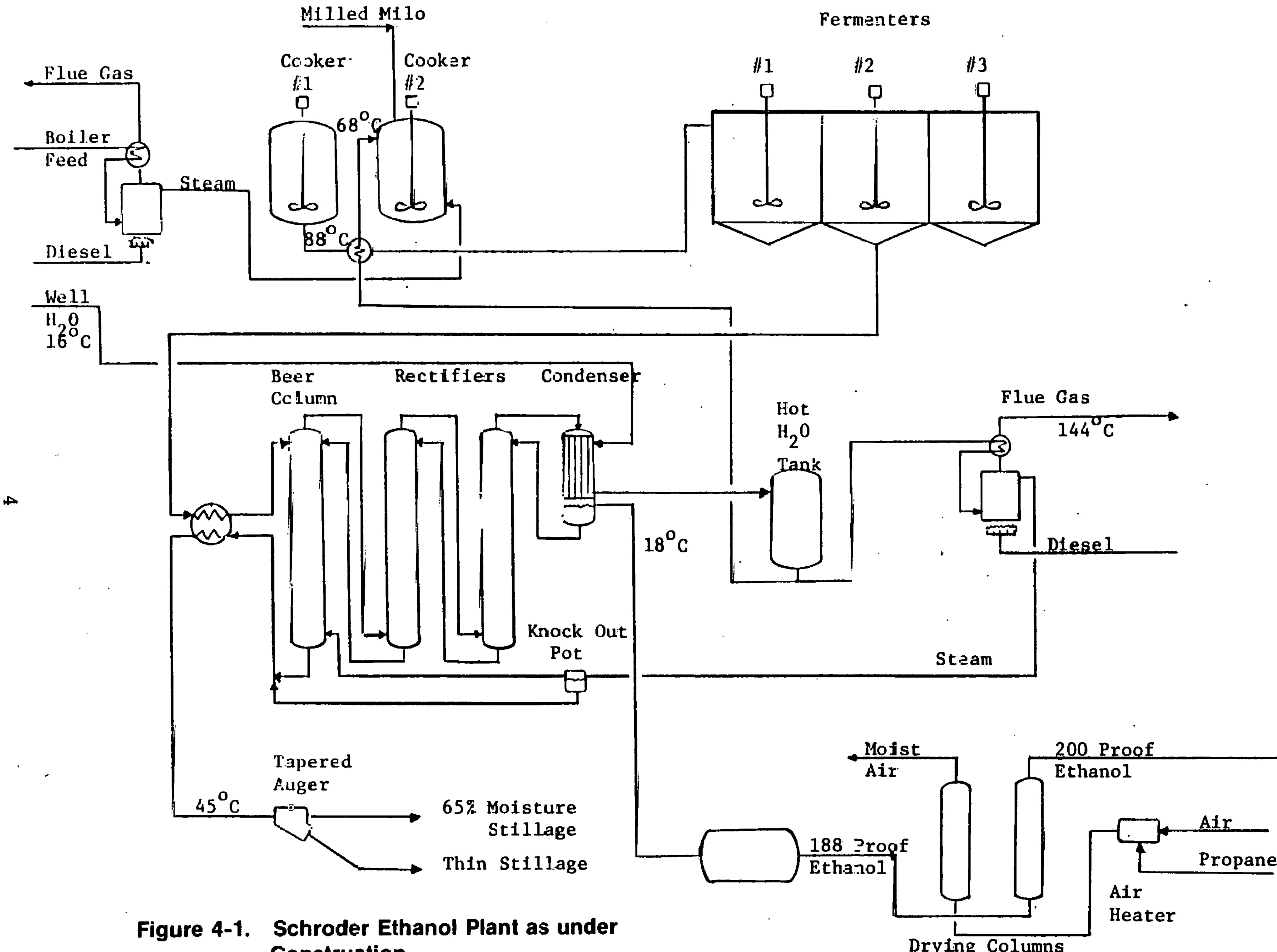


**Figure 4-1. Schroder Ethanol Plant as under Construction.**

tank specially set up for the test. The electricity was measured with a watt-hour meter on the plant. The process outputs are ethanol, stillage, and excess hot condenser outlet water. The ethanol was measured with a calibrated integrating flowmeter. The stillage was not measured. The diesel inputs occur in the cooking and distillation steps. The electricity is used for agitators, pumps, and lights. Two steam generators are used, one for the distillation and one for cooking, and thus the heat inputs to each step could be measured separately.

The test was conducted by measuring the diesel fuel used in one cook batch and that used to distill a different fermentation batch. The cooking energy was doubled since two cooks are used per fermentation batch.

The Schroders made a crude estimate of the quantity of diesel fuel required to load, mill, and unload the grain from the storage bins to the cooker. Thus, the system boundaries are the grain bins on the farm to the ethanol tanks and stillage pile on the farm.

Energy balance calculations for the conversion process are shown below. A global energy balance would include, in addition, energy debits for production and delivery of fuel and enzymes, construction of the plant, distribution of alcohol and stillage, and farming energy. An energy credit would be given for stillage.

## PROCESS ENERGY BALANCE CALCULATIONS

| Input | | Btu x $10^6$ |
|---|---|---|
| Grain Input | 6957 lb/cooker x 2 cookers = 13,914 lb or 238.5 bu | |
| Cooking Energy Input | 75 lb diesel x 2 cooks x 18,500 Btu/lb | = 2.78 |
| Distillation Energy | 398 lb diesel x 18,500 Btu/lb | = 7.36 |
| Electrical Input | 270 kWh x 11,600 Btu/kWh (29% conversion efficiency) | = 3.13 |
| Grinding, Augering, Site Transport Energy | 5 gal diesel x 138,700 Btu/gal | = 0.69 |
| | Total Energy Input: | = 13.96 |
| **Output** | | |
| 190-Proof Ethanol | 481 gal x 0.95 x 85,000 Btu/gal | = 38.84 |
| Stillage | 11 lb (dry)/bu x 248.5 bu = 2733 lb | |

Energy Requirements/Gallon 190-Proof Ethanol $\frac{13{,}960{,}000 \text{ Btu}}{481 \text{ gallons}}$ = 29,020 Btu/gal

Net Energy Ratio (Processing Only) $\frac{38{,}840{,}000}{13{,}960{,}000}$ = 2.78

Note: This energy balance was run on a fermentation batch using a new supply of yeast, and the alcohol yield is said by Gene Schroder to be less than yields in previous batches.

## SECTION 6.0

## PRELIMINARY ECONOMIC ANLAYSIS

Basis: Farm-scale ethanol plant processing 160,000 bu/yr of grain sorghum producing 400,000 gal of 190 proof ethanol; total capital cost of plant is $400,000 installed, per Gene Schroder.

| Cost/Bushel Grain Processed | | |
|---|---|---|
| $1.90 | Value of Sorghum on the Farm | |
| -1.25 | Credit for Stillage Sales | $\$0.04/\text{wet lb} \times \frac{11 \text{ lb dry/bu}}{0.35 \text{ dry matter}}$ |
| 0.65 | Net Feedstock Cost for Alcohol | |
| 0.05 | Electricity Costs | $\frac{\$0.05/\text{kWh} \times 270 \text{ kWh}}{248 \text{ bu}}$ |
| 0.44 | Diesel Costs | $1.10/gal x 0.40 gal/bu |
| 0.38 | Enzymes | $0.15/gal x 2.5 |
| 0.60 | Capital | $400,000; 20% interest; 10 yr<br>Capital Recovery Factor = 0.238<br>$95,200/160,000 bu |
| 0.50 | Labor | 4 men x $20,000/yr/160,000 bu |
| 0.08 | Bonding, Insurance, Taxes | $12,000/160,000 bu |
| 0.06 | Maintenance | 2.5% of capital<br>0.025 x 400,000/160,000 bu |
| 0.25 | Depreciation | 10-year straight line<br>$40,000/160,000 bu |
| $3.01 | Production Cost/Bushel<br>or, $1.20/gal at 2.5 gal/bu | |

Assume alcohol sells for $1.90/gal:

| | |
|---|---|
| Gross Profit | $0.70/gal x 400,000 gal<br>= $280,000 |
| Net Profit After 50% Taxes | $140,000 |
| ROI | $\frac{\$140,000}{400,000} = 35\%$ |

See Fig. 6-1 for sensitivity of ethanol production costs and Fig. 6-2 for sensitivity of return on investment.

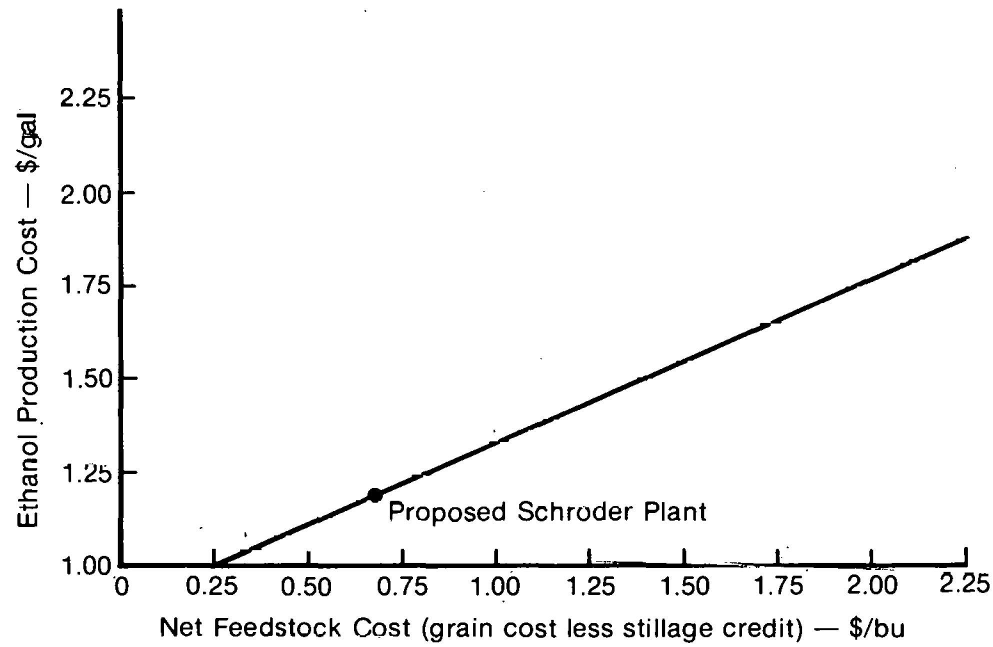


**Figure 6-1. Sensitivity of Ethanol Production Costs to Net Feedstock Costs**

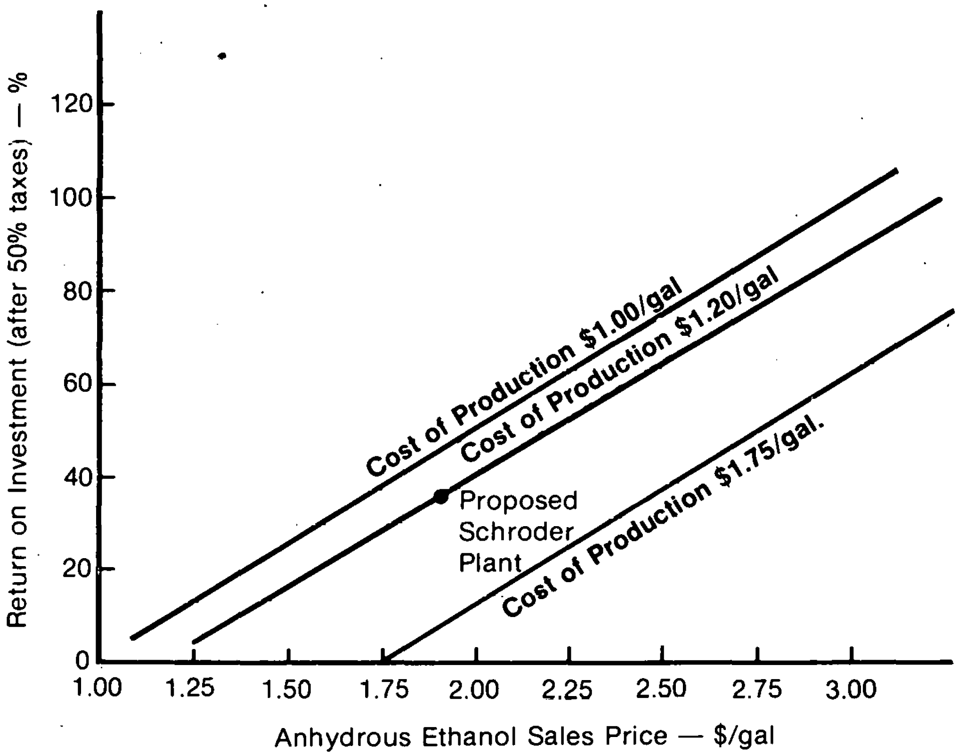


**Figure 6-2. Sensitivity of ROI to Ethanol Sales Price**

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Measurements of the energy inputs to a farm-scale grain to ethanol plant are given, showing a total processing energy requirement of approximately 29,000 Btu per gallon of 190-proof ethanol. This gives a positive process net energy balance of 2.78. A preliminary economic analysis of a 400,000-gal per year plant is made, showing an expected ROI of 35% after taxes. The plant as currently set up is described, and a flow sheet is given for an improved plant currently under construction.

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