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Economic Costs of Converting Crude Sunflower Oil to Methyl Esters

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FOREWORD

This report is based on research conducted under an Interdisciplinary State Project, ND1439 - Sunflower Oil as an Engine Fuel, with the Departments of Agricultural Economics and Agricultural Engineering cooperating. Previous economic and engineering research directed at small-scale extraction systems, costs, and performance evaluations of sunflower oil-diesel blends led to further investigations covering methyl ester processing, performance, and costs. This report is a continuation of that research effort in evaluating the economic costs in producing methyl ester as an alternative or substitute fuel derived from vegetable oils.

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The authors are deeply indebted to all these individuals and entities metioned, but absolve them from any responsibility for any remaining errors or omissions.

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Highlights

This research was conducted to evaluate the economic costs of transforming crude sunflower oil into a methyl ester product over a range of commercial plant sizes. Previous research has shown unmodified vegetable oils can create drawbacks when used as a diesel fuel substitute in agricultural production activities. Vegetable oils have viscosity ratings 11 to 17 times greater than diesel fuels. These high viscosities result in less efficient diesel engine performance because of poorer fuel atomization causing poor ignition and incomplete combustion. For these, and other reasons, a fuel (methyl ester) having similar viscosity characteristics to diesel fuel was analyzed on a commercial processing basis to determine if such a product could economically compete given a range of crude sunflower oil cost assumptions.

Capital investment and operating costs were synthesized for five methyl ester plant sizes with daily crude sunflower oil volume capacities ranging from 9,500 to 95,000 gallons/day. Total investment costs, based on 100 percent plant capacity, ranged from a high of 89 cents/gallon for the smallest plant to a low of 22 cents/gallon for the largest plant.

Average total alcoholysis cost for five methyl ester plant sizes (excluding sunflower seed costs and any by-product credits) ranged from 64 cents/gallon for the smallest plant to 25 cents/gallon for the largest plant at 100 percent of operating capacity. Final conversion costs (excludes crude sunflower oil cost) for the two smallest plants (9,500 and 23,500 gallons of crude sunflower oil/day) resulted in alcoholysis costs of 32 and 9 cents/gallon after crediting the market value of crude glycerol (a by-product produced in the alcoholysis process). Plant size three (47,500 gallons/day) had alcoholysis costs equal to the market value of the crude glycerol produced. The two largest plants (71,250 and 95,000 gallons/day) generated revenues of 4 and 6 cents/gallon over the cost of processing crude sunflower oil into a methyl ester fuel.

The final methyl ester cost/gallon is tied very closely to the price/gallon of crude sunflower or other vegetable oil used to derive a methyl ester fuel. The price of crude vegetable oil plus the conversion cost (or credit) must be competitively priced with diesel fuel if methyl esters are to serve as a substitute fuel. An analysis of a final methyl ester cost/gallon was evaluated varying sunflower seed values from $6/cwt. by one dollar/cwt. increments to $15/cwt. At $6/cwt. the smallest plant had a methyl ester cost of $1.55/gallon and a high of $2.93/gallon when sunflower seeds were priced at $15/cwt. The largest and most cost efficient plant had a methyl ester cost/gallon of $1.17 when sunflower seeds were priced at $6/cwt. and a cost of $2.55/gallon when sunflower seeds were priced at $15/cwt.

ECONOMIC COSTS OF CONVERTING CRUDE SUNFLOWER OIL TO METHYL ESTERS

Delmer L. Helgeson and Dwight S. Johnson*

Alternative fuel supplies have been investigated as possible replacements for fossil fuels. Interest and the commitment of resources for research tend to reflect the reliability of existing fossil fuel supplies.

Two fuel alternatives that are of interest and hold future promise for this area are alcohol and vegetable oils. These potential alternatives are attractive because they are domestically produced, renewable fuels (not fossil fuels). An additional benefit would be the diversion of surplus commodities from food to fuel consumption.

Although alcohol can be used for fuel, it would not ease potential diesel fuel shortages, because the fuels are sufficiently different to preclude their use in the same engines. Corn is the main crop used for alcohol production, but alcohol can be produced from almost any organic material. Even though alcohol is more expensive than gasoline, it does raise the octane rating when added to gasoline and can be used as a fuel extender without engine modifications.

The _1981 Annual Report to Congress_ (U.S. Dept. of Energy 1982) projects gasoline use to decline by 31 percent in the transportation sector between 1980 and 1995 and diesel fuel to increase by 96 percent. Thus, developing a potential substitute or extender for diesel fuel from vegetable oils is an attractive area for exploration in the United States and abroad.

Fuel Consumption

The transportation sector in the United States consumes large volumes of fuel, which is nearly all fossil fuels. Except for oil imports, the United States, according to the _1982 Annual Energy Outlook_ (U.S. Dept. of Energy 1983), is essentially self-sufficient in fossil fuels; it is a major coal exporter but domestically produces only 68 percent of the oil consumed. Coal production is projected to rise throughout the 1980s, while domestic oil production is projected to remain relatively constant. Imports of oil are expected to rise from 1982 levels to provide the necessary supplies for an expanding economy.

The number of diesel-powered cars and light trucks is expected to increase. The shift from gasoline to diesel fuel-powered vehicles and the projected increase in the number of miles traveled by primarily diesel-powered heavy trucks result in a projected 96 percent increase in diesel fuel use between 1980 and 1995 by the transportation sector alone.

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Vegetable Oils as Fuel

Vegetable oils are viable substitutes for diesel fuel in diesel engines, but their high visocity (the resistance of a fluid to flow), chemical reactivity, and lack of volatility may cause combustion problems. Coking (carbon deposits around the orifices on the injectors) and lubricating oil contamination from unburned oil are other problems.

Several methods or techniques are being considered to reduce viscosity of vegetable oils, such as sunflower oil (sun oil) and soybean oil. Preheating vegetable oils before combustion or changing the viscosity by chemical means both help alleviate the problem. Alcoholysis of sun and soybean oil solves the viscosity problem by chemically breaking down an oil molecule into two components, glycerol and methyl esters. Methyl esters can be used as a substitute for diesel fuel. Alcoholysis will be discussed in greater detail later in the section on processing procedures. Research by Clarke, Rashti, and Zobeck (1981) included a preliminary design of a plant that would process sunflower seed to methyl esters.

Research to expose and resolve use problems of methyl esters is beneficial even though vegetable oils have historically been priced higher than diesel fuel (Figure 1). Vegetable oil prices would have to be comparable to diesel fuel prices in order for methyl esters to compete effectively, especially if there were no tax credits given to vegetable oils. If the trend before 1981 continues, convergence of vegetable oil and fossil fuel prices appears to be within the realm of possibility.

General Procedures

The cost of producing methyl esters by alcoholysis on a large, commercial scale is not known, although this process has been performed in laboratories for many years. Economic engineering together with chemical engineering methodology will be used to design and calculate the cost of plants capable of producing methyl esters on a commercial basis. Economic engineering provides a technique in which a processing plant is designed unit by unit and costs are assigned to each unit; the result is a synthesized cost estimate for plants of various capacities. Chemical engineering supports the economic engineering technique by combining technical knowledge of chemistry with plant design to estimate economic costs associated with operating a plant.

Results of previous economic engineering studies have been used by architects, contractors, economists, and engineers to design plants and to estimate physical plant investment and operating costs. Engineering studies indicate differences in average costs which are attributable solely to differences in size and not to differences in management, technology, and accounting practices.

Specific Objectives and Procedures

This analysis estimates methyl ester costs for different size processing plants to determine if economies of size exist for the alcoholysis

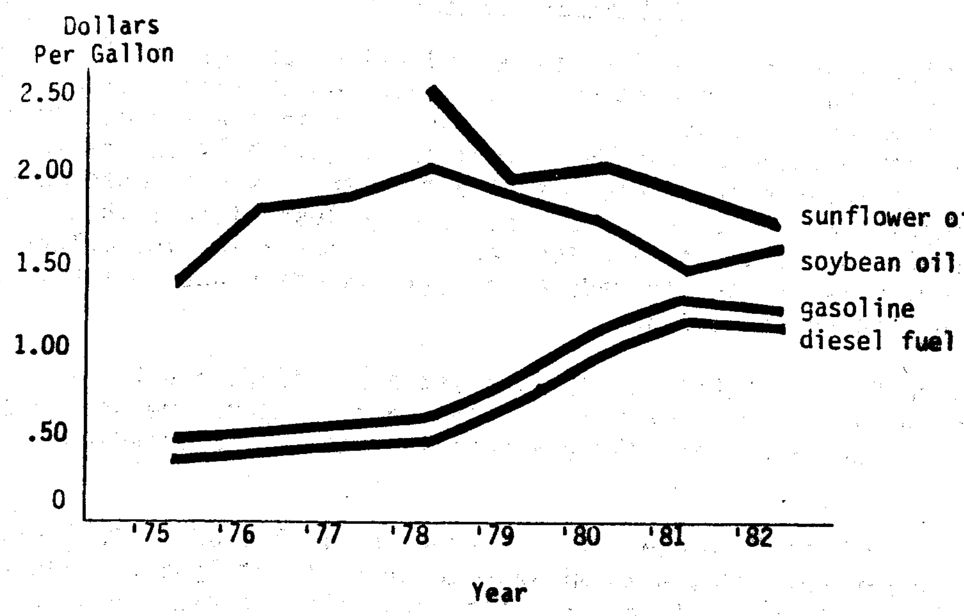

Figure 1. Average Prices of Fossil Fuels and Vegetable Oils for Several Years

SOURCE: USDA 1983 (Oil Crops); USDA 1980, 1982 (Agricultural Prices); USDA 1981, 1983 (Fats).

process. Five plant sizes were synthesized which processed 10,000; 25,000; 50,000; 75,000; and 100,000 gallons of crude sunflower oil during a 24-hour operating day. The largest methyl ester plant was sized to accommodate the crude oil processed by the smallest oilseed crushing plant in North Dakota (1,000 tons/day). A methyl ester plant of this size or larger produces amounts of glycerol that may affect the market price of that by-product. This factor established the upper size level; intervening plant sizes were scaled downward.

Unless specified, plant utilization was held at 100 percent capacity, i.e., 6,700 hours or 279 operating days per year. Building and equipment costs, other variable and fixed inputs, and raw material costs were all based on 1983 price quotations. Methyl ester plants were given an eastern North Dakota location for purposes of estimating freight and shipping costs.

Fuel grade methyl esters and glycerol are the two products produced. Fuel grade methyl esters are not refined to a 100 percent pure product, but rather to a product of about 97 percent methyl esters (the balance is unreacted sun oil). It is assumed the performance of engines using a blend of 97 percent methyl ester and 3 percent sun oil would not differ greatly from a pure methyl ester fuel. Glycerol, the other product, has an established market value that can be used as a credit in recovering alcoholysis costs.

Processing Procedure

Alcoholysis of triglycerides to methyl esters and glycerol is a simpler chemical process than the production of alcohol from organic matter. The process has been known and used for many years both in the laboratory and in making soaps from vegetable oils and animal fats. Alcoholysis breaks any vegetable oil (triglycerides) into methyl esters and glycerol when methanol is used as an input. Methyl esters are considerably less viscous than triglycerides because the methyl esters are about one-third the molecular weight. Alcoholysis is used to reduce the oil viscosity and possibly increase volatility to enhance combustion.

Triglycerides, alcohol, and a catalyst are stirred and heated for one hour to form methyl esters. From this point on the esters are separated from the glycerol and purified, and the glycerol is made into a marketable by-product.

Hasset and Hasan's process (1982) produces fuel grade methyl ester, which is 90-95 percent pure, with minimum amounts of catalyst and alcohol combined with refined oil with a free fatty acid (FFA) content near zero. This analysis uses crude sun oil with a FFA content of about 1 percent and an increased amount of alkaline catalyst to compensate for the higher FFA content. Bradshaw and Meuly (1944), in their patent on the preparation of detergents, state that crude oils can be used instead of refined oils if extra alkali (catalyst) is added to compensate for FFA neutralization. All of the catalyst is lost into the crude glycerol.

As mentioned earlier, methyl ester fuel is not a pure product because it contains some unreacted sun oil. A 90-97 percent ester fuel performs satisfactorily in an engine, according to Hawkins and Fuls (1982). They emphasized that an esterification yield in the order of 90 percent must be obtained. Tests conducted with a 70 percent ester revealed unacceptable coking within 50 hours under partial load conditions.

Hassett and Hasan combined 5.75 parts refined sun oil and 1.0 part methanol with .0057 parts sodium as a catalyst. This proportion of inputs plus extra catalyst (as explained above) is used in this analysis. This combination of inputs fills reactor R-1 (Figure 2) and is heated and stirred continuously for one hour at 144°F. Glycerol begins to form almost immediately and would settle to the bottom of the reactor if the stirring was stopped. The whole mixture then passes into the gravity separator (GS-1) where the glycerol can settle and form a lower layer. The lower portion contains most of the glycerol in the system, although it also contains most of the unreacted methanol together with soaps that form. The upper layer consists of methyl esters, glycerides (partially and unreacted sun oil), methanol, and small amounts of glycerol.

Bradshaw and Meuly (1944) analyzed the components of the methyl ester and glycerol layers. They reported three-fourths of the free methanol in the whole system was in the glycerol layer, with the balance in the methyl ester layer. Most of the glycerol (98 percent) was concentrated in the lower layer and only 2 percent was in the upper (methyl ester) layer. They used a centrifuge to make the separations and added the methanol-sodium mixture at

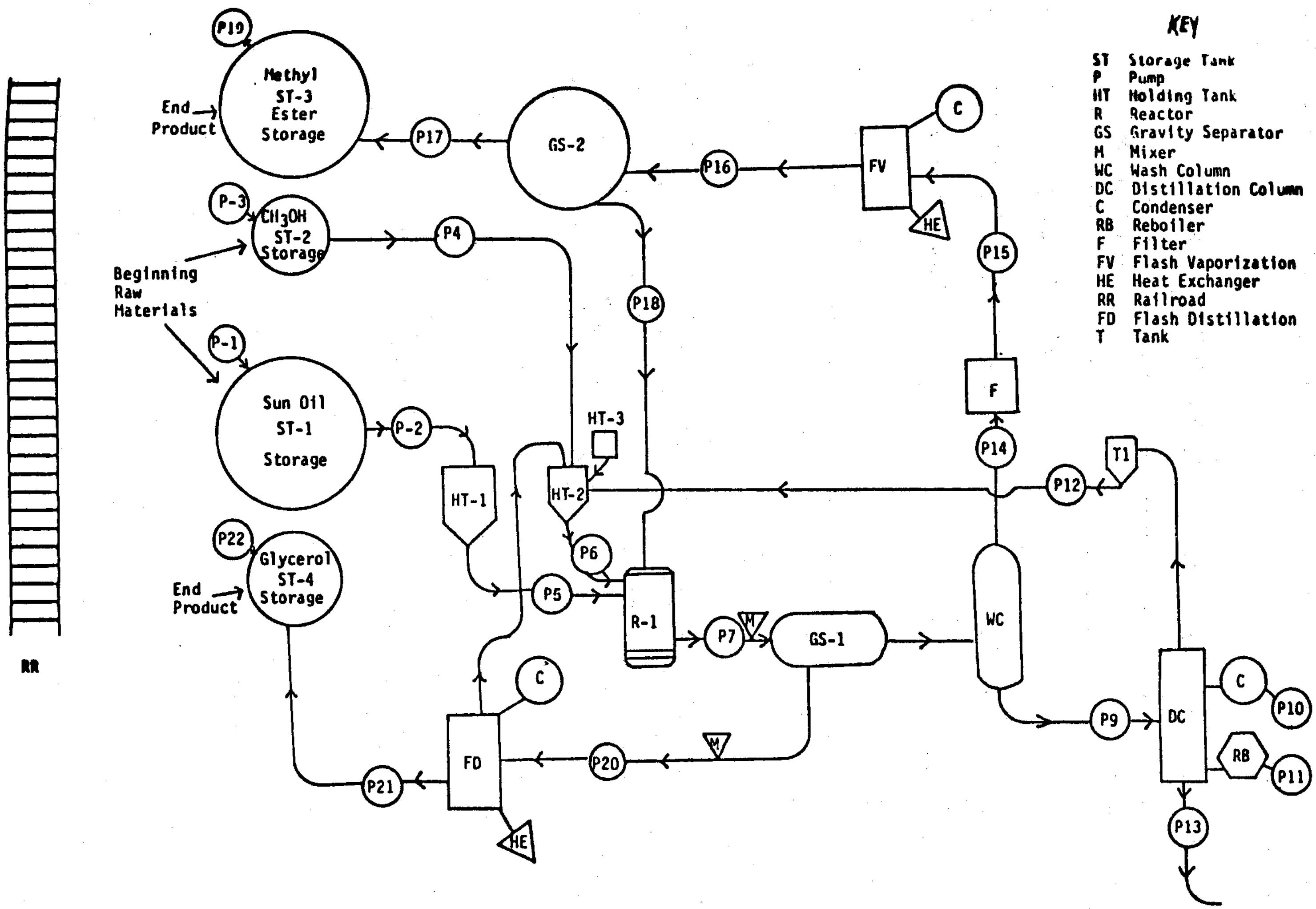

Figure 2. Flow Chart for a Methyl Ester Processing Plant.

two separate times to obtain separations. Their chemical analysis is used in this analysis in terms of the percentage composition of each layer.

The two layers are distinct so they will be considered separately (Table 1). Final procedures performed on the layers hereafter are to separate the components of each layer.

TABLE 1. COMPONENT SEPARATIONS IN THE GRAVITY SEPARATOR (GS-1)

Upper Layer	Lower Layer
Methyl esters	Glycerol (98% of glycerol in GS-1)
Methanol (25% of methanol in GS-1)	Methanol (75% of methanol in GS-1)
Glycerol (2% of glycerol in GS-1)	Soaps (sodium with FFA)
Mono-di-triglycerides	

SOURCE: Bradshaw and Meuly 1944.

The glycerol (lower) layer will be considered first. Hold-up time for this mixture in the gravity separator (GS-1) is one hour. The layers should separate sufficiently so the glycerol layer can be withdrawn and pumped to the flash distillation column (FD) to remove methanol. The latter is recycled to the methanol holding tank (HT-2), and glycerol and soaps are pumped to glycerol storage (ST-4). Hydrochloric acid, which may be needed to neutralize the remaining catalyst, may be mixed in the glycerol layer before its entrance into the flash distillation column (FD). It is not known at this time whether the acid is necessary; laboratory or pilot plant tests are needed for confirmation.

The methyl ester layer needs more processing than the glycerol layer. Acid may be needed at this stage also, but this would have to be determined by laboratory or pilot plant tests. The methyl ester layer is pumped to a wash column (WC) to introduce water to the product stream. Residual glycerol and methanol which have an affinity for water form a layer which separates from the methyl ester layer. Glycerol, methanol, and water are pumped to a distillation column (DC) to remove methanol, which is then recycled back to the methanol holding tank (HT-2). Wash water with 2 to 3 percent glycerol and 1 to 2 percent unrecoverable methanol is discarded because it is not economical to recover such a small concentration of glycerol. Waste water volume for the largest plant size is 270 gallons of water per hour, causing no problems in city waste water treatment plants. Estimates of sewage volumes and disposal costs can be found in Appendix C and Appendix Table H-5, respectively.

The methyl ester layer off the top of the wash column is passed through filters (F) to remove particles larger than four microns. Bruwer et al. (1980) found fuel filter problems were reduced to a minimum with this degree of filtering.

The methyl ester stream passes through a flash vaporization unit (FV) to remove most of the remaining water. Pryde (1982), who reported physical and compositional standards for vegetable oil and ester fuels, suggested two-tenths percent as the maximum moisture content. This percentage is offered as a suggestion and is not intended to be definitive.

When methanol is not present in large amounts, the product of alcoholysis contains some mono- and digylcerides which are mixed in with the methyl esters along with some unreacted triglycerides (sun oil). Mono- and diglycerides can be settled out at the processing plant, according to Kusy (1982), who set up a flow chart for the continuous transesterification of vegetable oils. He used centrifuges to separate various components, and used a settling tank gravity separator, GS-2 in Figure 2, to separate mono- and diglycerides. Mono- and diglycerides are recycled into the reactor to repeat the alcoholysis process. They are assumed to equal about 5 percent of the volume. Since they are recycled back to the reactor, they will reduce the capacity of sun oil flowing through the plant by about 5 percent because they are processed twice. Processing plants are designed and sized for 10,000; 25,000; 50,000; 75,000; and 100,000 gallons of sun oil per day, but the recycling reduces the capacity of the plants to 95 percent of these volumes.

Input Selection

Other raw materials may be substituted for sun oil, methanol, and sodium hydroxide, but for reasons of supply, price, chemical composition, or performance the above inputs are used. Many other vegetable oils may be used for alcohoylysis besides sun oil, but their varied chemical properties may be sufficient reason to plan a processing plant differently if the qualities vary greatly. For instance, soybean oil may be used instead of sun oil, but the amount of phospholipids is so high that the plant would have to incorporate a refining step ahead of the reactor to remove phospholipids. Other chemical properties to be considered are the free fatty acid content and wax content.

Because soybean oil is cheaper than sun oil and supplies are much larger, there may be reason to use soybean oil despite the need to add a refining step to remove phospholipids. It is possible that the costs of the refining step could be recovered by the sale of the phospholipid material as a by-product. (Sun oil phospholipid content is so low that it would not be economical to recover the phospholipids.)

Sun oil would be the most appropriate oil to use if a crop were grown specifically for fuel. First, average oil production per acre is very high, and sunflower can be grown under a wide variety of climates and conditions (Table 2). Secondly, soybean oil produced per acre results in a ratio of meal to oil of 4.4:1 compared to about 1.4:1 for sunflower. This indicates an overabundance of soybean meal if the crop is being grown predominantly for fuel.

TABLE 2. AVERAGE YIELD OF MAJOR UNITED STATES OILSEED CROPS PER ACRE

	Crop			
	Cottonseed	Peanut	Soybean	Sunflower
Pounds of product	798	2,388	1,770	1,227
Oil yield (%)	16.0	31.7	17.9	40.0
Pounds of oil	128	757	317	491
Cake or meal yield (%)	45.4	41.9	78.8	55.0
Pounds of cake and meal	362	1,001	1,395	675
Ratio of cake and meal to oil	2.8:1	1.3:1	4.4:1	1.4:1

Note: Yields are based on four-year averages (1978-1981).

SOURCE: USDA 1983 (Fats) and USDA (U.S. Fats) 1963-78.

It has been suggested that ethanol be used instead of methanol in the alcoholysis process because ethanol is produced from organic matter and therefore ethyl esters would be a completely renewable fuel with no fossil fuel in the product. There are two reasons why ethanol is not used. First, ethanol recycling is more expensive per gallon than methanol. Second, in alcohol recycling in ester production, anhydrous ethanol is more costly to recover than methanol due to the extra capital investment required to dry the ethanol.

Freedman and Pryde (1982) reported that both acidic and basic catalysts can be used in the alcoholysis process. They tested four variables in the production of esters. One variable was the catalyst type and amount used in ester production. They reported acid catalysts are very slow reacting and are not recommended for large-scale use. Alkaline catalysts such as NaOH and $NaOCH_3$ are preferred over acid catalysts because the reaction is completed in a fraction of the time required for acid catalysts. $NaOCH_3$ is a better catalyst than NaOH but is several times more expensive, so NaOH is suggested as a suitable catalyst for large-scale methyl ester production.

Alternative Procedures Not Employed

Varying oil quality of different vegetable oils may necessitate the processing plant to be designed with refinement equipment or with other alterations. Degumming, neutralization, and wax removal are three refinement procedures that may be required if certain chemical properties are exceeded. Other changes may be required depending on the geographical location of the plant and upon analysis of pilot plant work.

Degumming is a refinement step considered unnecessary when using sun oil. Gum (phospholipid) content of sun oil analyzed by Pryde (1982) was 0.5 percent while soybean oil contains relatively large amounts of up to 2.0 percent. Gums, if present in large amounts, may cause problems in fuel tanks, lines, and filters by combining with moisture from the atmosphere to form insoluble gums. Therefore, gums should be removed from soybean oil. These gums, when combined with water, are oil insoluble and are a valuable by-product called lecithin, an emulsifying agent. The larger quantities of gums are worth recovering from soybean oil but not from sun oil. Some, if not most, of the gums are removed from the fuel in the processing to methyl esters.

Neutralization refers to the addition of an alkali such as NaOH to neutralize free fatty acids (FFA) which are present in varying quantities in vegetable oils. Fatty acid salts are the result of a combination of sodium from the catalyst and the FFA chains. Fatty acid salts are referred to as soapstock and eventually accumulate in the glycerol by-product. Pryde (1982) found crude vegetable oils ordinarily have less than 1 percent FFA. If vegetable oils have more than 1 percent FFA, the alkaline catalyst may be destroyed, necessitating larger amounts of catalyst and therefore more salts in the glycerol. Sun oil generally has less than 1 percent FFA so it will not be necessary to neutralize the FFA before alcoholysis.

It is possible to remove both gums and free fatty acids in one step. The addition of aqueous alkali followed by centrifugation would both degum and neutralize the oil and ready it for the reaction step.

Wax content, according to Pryde, refers to the amount of long chain fatty acids and alcohols that interfere with fuel filtration. Waxes in crude sun oil amount to 0.1 percent, more than in most of the other commercial vegetable oils. No action is taken in this analysis to remove waxes. Waxes can be removed by winterization, by cold refining, or by cold washing with detergent.

The geographical location of the plant may influence the disposition of waste wash water. Wash water with small concentrations of glycerol and methanol can be disposed of in the city sewage system. Volumes are small in comparison to the volume of water handled by most municipal sewage treatment plants. Wash water is assumed to be disposed of in a city sewage treatment plant in this analysis.

Settling tanks and gravity separators are used to separate the various liquids as they flow through the plant. Centrifuges were used by Kusy (1982) in his continuous transesterification flow diagram, but they are expensive to purchase and maintain. Farris (1979) diagrammed a plant scheme for the production of esters using settling tanks to separate the components. Considering the expense of centrifuges and the simplicity of gravity separators, the latter are used in this study. One possible placement of a centrifuge would be after the reactor and in place of the first gravity separator because soapstock and sun oil tend to form an emulsion during agitation. The gravity separator may separate the components, but a centrifuge may be more efficient by giving faster and cleaner separations.

Alterations mentioned above depend on the general oil quality and how well the alcoholysis process works. Pilot plant tests would have to be made to determine the economics of any alterations.

Impact on Prices

Prices of sunflower seed and glycerol may be affected by the production of methyl esters from the larger plants. The largest plant alone would in an average processing year (279 days) use the oil from nearly 265,000 tons of sunflower seed. This would be equal to 11 percent of the average annual United States crop from 1978 to 1981 (USDA 1983, Fats). This amount of oil diverted from the sun oil market may affect the edible oil market. Levins and Meyers (1981) studied the economic implications of converting 10 percent of the agricultural diesel used in the United States to a fuel mixture of 25 percent vegetable oil and 75 percent diesel. They reported the price of soybeans increased the first year while meal prices fell. For the long run, seven to eight years, prices moderated while acreage increased, but oil prices remained higher than they would have been without the fuel market. Sunflower prices may fluctuate even more because sunflower acreage is about 6 percent of the soybean acreage and much of the sunflower crop is exported annually.

The glycerol market may be affected by the increased amounts of glycerol produced by alcoholysis. The largest plant would annually produce over 10,100 tons of glycerol. This would amount to 6.3 percent of the average United States market for one year (Kern 1978). There is no doubt that several of the largest-sized methyl ester plants would produce volumes of glycerol large enough to affect the market price of glycerol.

Capital Investments

A methodical process used by Peters and Timmerhaus (1980) is used as a basis for most of the calculations of plant costs. Physical plant equipment, construction, engineering and supervision, construction costs, contractor's fees, and a contingency factor constitute fixed capital investment. An estimated working capital requirement is added to fixed capital investment to arrive at total estimated capital investment.

Plant Cost Estimates

Unit cost estimates will result in accurate estimates for fixed capital investments if accurate records have been kept from previous cost experience. This method also requires detailed estimates of purchased prices obtained from either index-corrected cost records and published data or quotations. Pipe, steel, concrete, insulation, instrumentation, and other such costs are obtained by take-offs from the drawings and applying unit costs to the material and labor needs. Equipment installation labor costs are specified as a fraction of the delivered equipment cost. A factor for the contractor's fee, construction expenses, and contingency is estimated from previously completed projects.

Percentage of delivered purchased equipment cost (PEC) requires careful determination of equipment cost. Other items that can be estimated as percentages or purchased equipment cost are as follows:

1. equipment installation
2. instrumentation and controls
3. insulation
4. piping, installed
5. electrical, installed
6. buildings
7. yard improvements
8. service facilities (installed)

Costs for engineering and supervision, construction, contractor's fees, and contingency can be based on average percentages of the physical plant cost (PPC) or PPC plus erection costs (PPC & EC). This method is commonly used for preliminary estimates.

Percentage of purchased equipment cost method is straight forward when the purchased equipment cost is known. This procedure works well since technical knowledge of the process is not completely known or available. Percentages used should be determined on the basis of the type of process involved, required materials of construction, design complexity, past experience, location of the plant, and other items dependent on the particular type of plant to be built.

Purchased Equipment Cost

Equipment components were sized and costs estimated for five separate methyl ester processing plants (Table 3). The number of equipment units required per plant is constant for all plant sizes. No more units are required for larger processing plants because the size of each equipment item can be varied sufficiently to accommodate all five processing plants. Appendix A describes in detail how these costs were obtained.

All pumps were sized using chemical engineering formulas which take into account the flow rate in gallons, head (pumping height as used here), the specific gravity of the liquid being pumped, and pumping efficiency. Motor efficiency was assumed to determine motor power required. Motor power was converted into kilowatts to determine kilowatts used per hour to estimate electrical power requirements of the plants. Appendix A gives the motor sizes required for each pump. Each plant requires 21 pumps and 23 motors. Motors for the pumps range from 1/3 to 10 horsepower for all plants. Two motors are used for powering propellers in the reactor and methanol holding tank. Individual motor sizes and costs are listed in Appendix A.

Tanks and holding tanks are sized by determining flow rates and hold-up time. Flow rates between major processes are given in Appendix C. Tanks are priced by volume and type of construction material. Carbon steel and stainless steel are the two types of material used. Auxiliaries, such as ladders,

TABLE 3. DELIVERED PURCHASED EQUIPMENT COSTS FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Equipment	Number Required Per Plant	Plant Size 1 (9,500 gal/da)	2 (23,750 gal/da)	3 (47,500 gal/da)	4 (71,250 gal/da)	5 (95,000 gal/da)
		dollars				
Railroad scale	1	47,000	47,000	47,000	47,000	47,000
Truck scale	1	21,000	21,000	21,000	21,000	21,000
Pumps	21	15,500	15,500	16,900	18,100	19,200
Motors	21	6,000	6,100	6,200	6,300	6,700
Propeller motors	2	630	660	840	1,200	1,200
Propellers	2	5,700	5,900	9,800	11,300	13,000
Tanks[a]	7	191,000	305,000	446,000	555,000	651,000
Holding tanks	3	400	560	1,300	1,900	2,100
Wash column	1	3,500	5,600	8,300	11,100	12,500
Distillation column	1	9,700	12,000	16,500	27,300	33,000
Condensers	3	2,700	3,100	3,500	3,800	4,100
Reboilers	1	800	900	1,000	1,100	1,100
Filters	2	10,800	13,900	14,600	14,800	15,300
Heat exchangers	2	1,600	1,700	2,000	2,100	2,200
Wash distillation	1	700	770	830	870	900
In-line mixers	2	400	400	400	400	400
Reactor	1	40,000	69,000	97,000	125,000	146,000
Flash vaporization	1	1,700	1,900	1,900	2,000	2,100
Total equipment cost (TEC)		359,130	510,990	695,070	850,270	978,800
Freight (3% of TEC)		10,800	15,300	20,900	25,500	29,400
Purchased equipment cost Delivered (PEC)		$369,900	$526,300	$716,000	$875,800	$1,008,200

[a]Includes Gravity Separators 1 and 2.

SOURCE: Appendix A.

platforms, manholes, and other features, account for 10 percent of the price of the tank and are added to some tanks, as indicated in Appendix A. Tanks are sized with excess capacity and are to be filled to only 90 percent capacity.

Specialized pieces of equipment were sized and priced by Narum (1983) since technical knowledge was necessary for design purposes. Specialized pieces include the wash and distillation columns, reboilers, filters, heat exchangers, flash vaporizaiton, and distillation units. Technical information about these units is given in Appendix A.

A reactor was sized by Clarke, Akbar, and Zobeck (1981) in their preliminary study of methyl ester production from sun oil. This design was adapted to size the five rectors for this study.

Freight costs were added to complete the delivered purchased equipment costs. Percentages applied to delivered purchased equipment costs were used to determine each component of total capital investment.

Total Capital Investment

Total capital investments for the five methyl ester plants ranged from $1,623,100 for the smallest plant to $4,067,100 for the largest plant (Tables 4 and 5). The percentage and abbreviation following the component refer to the cost of that component as a percentage of

1. total equipment cost (TEC)
2. purchased equipment cost, delivered (PEC)
3. physical plant cost (PPC)
4. physical plant and erection costs (PPC & EC)
5. total capital investment (TCI)

All the following components of total capital investment, except land, were estimated using percentages recommended by Peters and Timmerhaus (1980).

Equipment Installation

Purchased equipment installation involves costs for foundations, labor, construction expenses, supports, platforms, and other factors directly related to erection of purchased equipment. This usually averages 35 percent of the PEC for fluid processing plants, such as methyl ester plants.

Insulation

Insulation costs are a consideration when very high or low temperatures are involved. Methyl ester plants use several items of equipment that need to be insulated. Total cost of labor and materials necessary for insulating equipment and piping in ordinary chemical plants is 8 to 9 percent of the purchased equipment cost. Eight percent of PEC is used for estimating the insulation cost for this analysis.

TABLE 4. PHYSICAL PLANT COST FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Component		Plant Number 1 (9,500 gal/da)	2 (23,750 gal/da)	3 (47,500 gal/da)	4 (71,250 gal/da)	5 (95,000 gal/da)
		---------------	---------------	dollars	---------------	---------------
Purchased equipment, delivered		369,900	526,300	716,000	875,800	1,008,200
Spare parts	(5% TEC)[a]	18,000	25,500	34,800	42,500	48,900
Sales tax	(4% TEC)	14,400	20,400	27,800	34,000	39,200
Purchased equipment and installation	(35% PEC)[b]	129,500	184,200	250,600	306,500	352,900
Insulation	(8% PEC)	29,600	42,100	57,300	70,100	80,700
Instrumentation and controls, installed	(10% PEC)	37,000	52,600	71,600	87,600	100,800
Piping, installed	(66% PEC)	244,100	347,400	472,600	578,000	655,500
Electrical, installed	(11% PEC)	40,700	57,900	78,800	96,300	110,900
Buildings with services	(45% PEC)	166,500	236,800	322,200	394,100	453,800
Yard improvements	(10% PEC)	37,000	52,600	71,600	87,600	100,800
Service facilities, installed	(70% PEC)	258,900	368,400	501,200	613,100	705,900
Land partially developed[c]		277,500	277,500	409,500	409,500	409,500
Physical plant cost	(PPC)	$1,623,100	$2,191,700	$3,014,000	$3,595,100	$4,067,100

[a]TEC refers to Total Equipment Cost.
[b]PEC refers to Purchased Equipment Cost, Delivered.
[c]Costs from Fargo-Cass County Industrial Development Corporation.

TABLE 5. TOTAL CAPITAL INVESTMENT COST FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Component	Plant Number 1 (9,500 gal/da)	2 (23,750 gal/da)	3 (47,500 gal/da)	4 (71,250 gal/da)	5 (95,000 gal/da)
	dollars				
Purchased plant costs (PPC) and erection costs (EC)	1,623,100	2,191,700	3,014,000	3,595,100	4,067,100
Engineering and Supervision (8% PPC)	129,800	175,300	241,100	287,600	325,400
Construction expenses (10% PPC)	162,300	219,200	301,400	359,500	406,700
Total physical plant and erection costs	1,915,200	2,586,200	3,556,500	4,242,200	4,799,200
Contractor's fees (5% PPC & EC)	95,800	129,300	177,800	212,100	240,000
Contingency (10% PPC & EC)	191,500	258,600	355,600	424,200	479,900
Fixed capital investment (FCI)	2,202,500	2,974,100	4,089,900	4,878,500	5,519,100
Working capital (10% TCI)	244,700	330,500	454,400	542,100	613,200
Total capital investment (TCI)	$2,447,200	$3,304,600	$4,544,300	$5,420,600	$6,132,300

Instrumentation

Instrumentation costs include installation labor costs, instrument costs, and auxiliary equipment and materials. The amount of control required will determine total instrumentation costs and may vary from 6 to 30 percent of the purchased equipment cost. Methyl ester plants do not require sophisticated instrumentation since flows are constant and all tanks have level indicators. Instrumentation and controls were estimated at 10 percent of the delivered purchased equipment cost.

Piping

Piping costs include pipe, fittings, valves, labor, supports, and other items involved in the complete erection of all piping used directly in the process. This includes all piping in the whole system, such as air, steam, water, sewer, and other process piping, as well as raw-material, intermediate-product, and finished-product piping. Accuracy of the entire estimate can be seriously affected by the improper estimation of piping costs alone because piping can run as high as 80 percent PEC. Since detailed drawings are not available, piping costs will also be calculated by percentage of PEC. Factor percentages are based entirely on experience gained from piping costs for similar previously installed chemical process plants. Although there are no other methyl ester plants of these proportions on which to base calculations, the factoring method is still used because methyl ester plants are quite similar to other chemical plants. They require distillation and wash columns, component separations, and basic chemical operations similar to other chemical plants. Piping costs for methyl ester plants were estimated at 36 percent of PEC for material and 30 percent of PEC for labor costs for a total of 66 percent of purchased equipment cost.

Electrical

Electrical costs consist primarily of materials and labor for power and lighting. Four major components comprise the electrical installation, namely power wiring, lighting, transformation and service, and instrument and control wiring. Electrical installations cost 10 to 15 percent of the delivered purchased equipment costs in typical chemical plants. Power equipment requirements are relatively low for these plants; a factor of 11 percent was used to estimate this electrical cost component.

Building

Cost of buildings includes services and covers materials, labor, and supplies involved in the erection of all buildings. Services included in this cost are plumbing, heating, lighting, ventilation, and similar building services. Buildings and services cost about 45 percent of the purchased equipment cost for a new fluid processing plant at a new site.

Yard Improvement

Yard improvements primarily include sidewalks, railroad sidings, landscaping, roads, fencing, grading, and similar items. These usually amount to 10 to 20 percent of the purchased equipment cost. This analysis used 10 percent of PEC since no extensive landscaping will be done. The railroad siding is considered part of the land cost, and the industrial park site is partially developed. The cost of developing the industrial park site is included in the land and special assessment costs.

Service Facilities

Service facilities in an industrial plant supply utilities, such as power, steam, compressed air, water, and fuel, as well as fire protection, waste disposal, shop, first aid, and cafeteria equipment and facilities. Total cost for service facilities (installed) generally averages 70 percent of purchased equipment cost for fluid processing plants. Cost of installed service facilities may also be figured as a percentage of fixed capital investment. For consistency, percentage of delivered purchased equipment costs at 70 percent was used for the whole physical plant.

Land

Land costs were available from an industrial park and will reflect local conditions. This serves to localize land costs since they vary considerably between a rural district and a highly industrialized area. Methyl ester plants designed in this analysis were assumed to be located in an industrial park with railroad access, streets, street lights, electrical service, telephone lines, natural gas lines, and storm and sanitary sewer systems. The Fargo-Cass County Industrial Development Corporation (Sticka 1983) was contacted for estimates of land costs. A railroad spur of 250 feet having an estimated installed cost of $12,500 was included for each plant, and partially developed land was estimated at $16,500 per acre for an industrial park. Special assessments to pay for the partial developments were $10,000 per acre. Plants 1 and 2 require 10 acres of land while plants 3, 4, and 5 need 15 acres of land. Appendix B contains calculations for land charges.

Erection Costs

The above costs comprise the physical plant itself (Table 4) while the following four expenses for engineering and supervision, construction expenses, contractor's fees, and a contingency factor were added to arrive at total plant investment outlays (Table 5).

Engineering and supervision include costs for travel and living expenses, engineering, drafting, purchasing, accounting, reproductions, communications, and office expenses plus overhead. This cost is 8 percent of the physical plant costs (PPC).

Construction or field expenses include construction tools, home office personnel at the construction site, rentals, construction payroll, temporary construction and operation, taxes, insurance, travel and living, plus other construction overhead. These expenses amount to 10 percent of the total PPC.

Contractor's fees are usually 2 to 8 percent of the PPC. This analysis uses the recommended 5 percent of physical plant and erection costs (PPC & EC) for determining the contractor's fee.

Contingencies or unforeseen occurrences, such as errors in estimation, price changes, small design changes, storms, floods, and strikes, are planned for by the inclusion of a contingency factor. These expenses are included because they are statistically likely to occur. Ten percent of PPC & EC is allocated for this expense. This is higher than the average 8 percent because of the uniqueness of this plant.

Working Capital

All fixed capital investment items have been described in the previous section. The last component to be added to the fixed capital investment to calculate total capital investment is working capital, which is the total amount of capital invested in (1) raw materials and supplies carried in stock, (2) finished products in stock, (3) accounts receivable, and (4) cash kept on hand for monthly payment of operating expenses, such as salaries, wages, and raw material purchases.

The raw material inventory included in working capital usually amounts to a 30-day supply of the raw materials valued at delivery prices. Storage of sun oil is planned for seven days rather than one month because sun oil is readily available. A 30-day supply of methanol is on hand because it is not as available as sun oil. Working capital is figured at 10 percent of total capital investment, rather than at the upper range of 20 percent. Working capital as considered here is the minimum estimated level of capital which should always be available for operations.

Operating Costs

Operating costs are divided into fixed and variable costs. Fixed costs are those incurred whether the plant is in production or not and are at a constant level regardless of the output produced. Variable costs vary at a rate directly related to the production of the plant. They are incurred only when the plant is in operation, although some costs, such as interest, maintenance, and repair, have fixed cost while maintenance and repair are considered variable costs.

Fixed Costs

Fixed costs considered in the study are depreciation, local taxes, insurance, plant overhead, administration, interest, and a contingency factor. These fixed cost components are described more fully as delineated (Table 6).

TABLE 6. ESTIMATED FIXED COST OF PRODUCING METHYL ESTERS BY PLANT NUMBER, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983

Item	Methyl Ester Plant Number				
	1 (9,500 gal/da)	2 (23,750 gal/da)	3 (47,500 gal/da)	4 (71,250 gal/da)	5 (95,000 gal/da)
	dollars				
Depreciation	116,100	160,100	219,100	264,100	300,500
Local taxes	8,000	10,600	14,800	17,400	19,700
Insurance	3,400	4,800	6,500	7,900	9,100
Plant overhead	274,300	336,800	411,800	440,200	498,000
Administration	68,600	84,200	102,900	110,000	124,500
Interest	165,200	223,100	306,700	365,900	413,900
Contingency	87,800	138,100	214,500	280,400	349,700
Total fixed costs	723,400	957,700	1,276,300	1,485,900	1,715,400
AFC Per Gallon[a]	.263	.139	.093	.072	.062

[a]Average fixed costs (AFC) per gallon can be determined by dividing total fixed costs by the gallons of methyl ester fuel produced per year which are as follows: 2,755,700; 6,889,300; 13,778,500; 20,667,800; 27,557,100.

SOURCE: Appendix D and E.

Depreciation

Depreciation costs for all plant facilities were calculated using the straight-line method with zero salvage value. Different depreciation rates were applied to various assets because the estimated useful life of service facilities, buildings, and equipment varies. Buildings were depreciated over a 40-year period while other property was depreciated over a 15-year period. Fixed capital investment less the land itself, buildings and the contingency factor yields the total property that was depreciated over 15 years. Appendix D summarizes the depreciation calculations.

Taxes

Assessed value was calculated as one-half of the true and full value of the real property, which includes the buildings, land, railroad spur, and some of the erected storage tanks that are considered structures. A 300-mill levy--a rate that could be expected in an urban area--was applied to 10 percent of the assessed property value. More detailed information on property taxes and their calculation is provided in Appendix E.

Insurance

Insurance costs were based on the cost of the property at the time of construction. A rate of $.20 per $100 of insurable property with specific requirements, such as explosion proof walls and sprinkler systems, was used. Insurance was based on fixed capital investment less land and special assessments, yard improvements, and the continency factor.

Plant Overhead

Plant overhead costs are those costs other than production costs that are necessary for the plant to operate as an efficient unit. These costs are somewhat hidden costs which are not as directly involved in the processing function as are depreciation, taxes, insurance, and interest costs, but they are needed for the plant to function smoothly. Plant overhead costs may involve equipment and buildings that are necessary for the entire plant but not specifically for product manufacturing. These costs are

1. general plant maintenance
2. safety services
3. cafeteria
4. medical and hospital services
5. plant protection
6. custodial services
7. shop
8. interplant communications and transportation
9. control laboratories
10. payroll overhead including employee benefits

Plant overhead costs are closely related to the costs for all labor, which is directly connected with the production operation. This expense item usually amounts to 50 to 70 percent of the total expense of operating labor, supervision, and maintenance. Sixty percent was used in this analysis.

Administration

Top management or administrative activities cannot be charged directly to manufacturing costs, but they must be included to complete the economic analysis. Cost of office supplies and equipment, administrative buildings, outside communications, and other overhead items related to administrative activities must be included with salaries and wages for administrators, secretaries, accountants, stenographers, typists, and similar workers to figure administrative costs. No company records were available for estimating administrative costs. Fifteen percent of operating labor, supervision, and maintenance was used as recommended by Peters and Timmerhaus (1980).

Interest

Interest is the compensation paid for the use of borrowed capital, which in methyl ester plants is the total capital investment for each plant. Because the total capital investment is relatively large, interest cost was a major fixed cost. A fixed interest rate is desirable but is difficult to obtain because of the volatility of the financial markets the last four years. To obtain a reasonable rate of interest, the prime rate was averaged monthly over a 10-year period from 1973 to 1982 and came to 11.11 percent (Peters and Timmerhaus 1980). Two to three percentage points above the prime rate was recommended by financial personnel to compensate for the increased risk of methyl ester plants. The interest rate charged was 13.5 percent on the average plant investment, which is one-half the total capital investment. Thus, interest cost was the second largest fixed cost item.

Contingency

A contingency is an error factor included to cover unforeseen events, such as storms, strikes, floods, price variations, and hidden costs. A high factor of 5 percent was chosen because methyl ester plants are unique and there are no operational plants on which to base costs.

Variable Costs

Variable costs to be discussed are raw materials, operating labor, direct supervisory labor, utilities, maintenance and repair, operating supplies, laboratory costs, indirect labor costs, distribution and marketing, research and development. Several variable cost descriptions and cost percentages are from Peters and Timmerhaus (1980)(Table 7).

TABLE 7. ESTIMATED VARIABLE COST OF PRODUCING METHYL ESTERS, EXCLUDING SUN OIL COST, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983

Item	Methyl Ester Plant Number				
	1 (9,500 gal/da)	2 (23,750 gal/da)	3 (47,500 gal/da)	4 (71,250 gal/da)	5 (95,000 gal/da)
	dollars				
Raw materials[a]	368,600	918,900	1,837,700	2,759,700	3,678,700
Operating labor	282,600	333,000	383,400	383,400	433,800
Direct supervisory labor	42,400	50,000	57,500	57,500	65,100
Utilities	72,500	141,100	240,700	331,700	415,400
Maintenance and repairs	132,200	178,400	245,400	292,700	331,100
Operating supplies	19,800	26,800	36,800	43,900	49,700
Laboratory costs	28,300	33,300	38,300	38,300	43,400
W.C., G.L., & FICA[b]	33,600	39,700	45,800	45,800	52,000
Distribution and marketing	35,100	55,200	85,800	112,100	139,900
Research and development	17,600	27,600	42,900	56,100	69,900
Total variable costs	1,032,700	1,804,000	3,014,300	4,121,100	5,279,000
AVC per gallon[c,d]	.375	.262	.219	.199	.192
ATC per gallon[c,e]	.638	.401	.312	.271	.254

[a]Cost of sun oil is excluded.
[b]Workmen's compensation, general liability, and social security taxes.
[c]Methyl ester fuel produced per year are 2,755,700; 6,889,300; 13,778,500; 20,667,800; and 27,557,100 gallons.
[d]AVC is average variable cost.
[e]ATC is average total cost.

Raw Materials

The cost of crude sun oil is not included under raw materials because it is not needed to determine the conversion cost of producing methyl esters from sun oil. Sun oil price volatility has been sufficiently great over time that it can be deleted as a cost in determining a conversion cost only. In this method the current price of the major raw material, sun oil, can be added to the conversion cost to obtain the final cost of methyl esters. Other chemical costs such as methanol (CH_3OH), sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) are considered raw materials for they are as necessary for conversion as is the equipment required for the process. Annual costs for each raw material component are determined in Appendix F and summarized in Table 8.

Operating Labor

Operating labor for preliminary cost analysis can be calculated by any of three methods, depending on the type of plant being built. Operating labor costs can be based on (1) company experience or published information on similar processes, (2) analysis of the work to be done, or (3) principal processing steps on a flow sheet.

The first method was not possible because there were no methyl ester plants from which records could be obtained. The second method uses flow sheets and drawings of the process to determine the types of processing equipment in the plant. Typical labor requirements for each type of equipment are provided by chemical engineering references. Total labor requirements can then be estimated. This method cannot be easily adjusted for nonprocess labor requirements, which will change with various size processing plants.

TABLE 8. TOTAL RAW MATERIAL COST PER YEAR FOR METHYL ESTER PLANTS, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983[a]

	Methyl Ester Plant Number				
Raw Material	1	2	3	4	5
	dollars				
Methanol	317,000	791,000	1,582,000	2,376,000	3,167,000
Sodium hydroxide	50,000	124,000	248,000	372,000	496,000
Sulfuric acid	1,600	3,900	7,700	11,600	15,700
TOTAL	368,600	918,900	1,837,700	2,759,600	3,678,700

In this method labor requirements are a function of plant capacity, using the second method, and are based on a summation of the various principal processing steps on the flow sheets. <u>Process steps</u> are defined as any unit operation and/or unit process which takes place in one or more units of integrated equipment on a continuous or repetitive cycle. Major process steps in methyl ester plants are reaction, distillation, flash vaporization, and flash distillation. Employee hours per day for each processing step are taken from a graph (Peters and Timmerhaus 1980) which relates tons of product produced per day to labor. Total employee hours needed per day can be determined by multiplying the number of process steps by the number of employee hours per day per processing step. Calculations for labor requirements and wages are given in Appendix G. Skilled labor refers to a professional with a degree in his field, which in this case is chemical engineering. Skilled labor rates are $11.25 per hour while unskilled labor rates are $7.00 per hour. Wage rates are comparable to those paid to employees in sunflower seed crushing plants (Swenson et al. 1983). Total labor costs by plant size ranged from $282,600 for Plant 1 to $433,800 for Plant 5 (Table 9).

TABLE 9. ANNUAL OPERATING LABOR COSTS FOR METHYL ESTER PLANTS, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983

Plant Number	Skilled Labor	Unskilled Labor	Total Labor
	-----------	dollars	-----------
1	81,000	201,600	282,600
2	81,000	252,000	333,000
3	81,000	302,400	383,400
4	81,000	302,400	383,400
5	81,000	352,800	433,800

NOTE: The season includes 21 days of cleanup and repair for 300 operating days at 24 hours/day.

Direct Supervisory Labor

Direct supervisory and clerical labor is always required, in some degree, for a manufacturing operation. This type of labor is closely related to the total amount of operating labor, product quality standards, and complexity of the operation. This labor averages 15 percent of the cost of operating labor. Supervision usually remains at the 100 percent capacity rate even when operating at reduced capacities.

Utilities

Utilities include water and sewer, fuel oil, and electricity. Total annual utility costs are individually listed (Table 10). Water is used for cooling, steam production, fire protection, sanitation, and for processing methyl esters to remove contaminants that are water soluble.

Water used for cooling is circulated through cooling towers which are part of the service facilities. Cooling water requirements in gallons per

TABLE 10. ANNUAL UTILITY COSTS FOR METHYL ESTER PLANTS, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983

Utility	Methyl Ester Plant Number 1	2	3	4	5
	--------	--------	dollars	--------	--------
Water	3,100	7,100	13,500	20,100	26,600
Sewage	600	1,600	3,200	4,800	6,300
Fuel oil	63,400	125,800	215,800	297,300	371,200
Electricity	5,500	6,600	8,200	9,500	11,300
TOTAL	72,600	141,100	240,800	331,800	415,500

hour are given in Appendix H (Table H-1). Eighty-five percent of the water is recirculated while 15 percent of the water is lost through evaporation in the cooling towers or is used for "blow down." Blow down is the replacement of water in the cooling towers to prevent solids from reaching saturation levels.

Water requirements and costs for processing methyl esters are summarized in Appendix Table H-2. Process water is necessary in the wash column to wash methyl esters to separate water soluble materials from those that are insoluble. Water is also required for steam production. Although 85 percent is reused, 15 percent must be added each hour because of steamleaks and for blow down. Water necessary for steam production is listed in Appendix Table H-3.

Waste water disposal does not pose a problem if methyl ester plants have access to sewage treatment plants. Contaminants such as methanol and glycerol are not a problem when diluted in large volumes of water. If these same contaminant flows are treated at small water treatment plants the contaminants may cause problems because they are not being sufficiently diluted. Since methyl ester plants are assumed to be located in industrial parks in urban areas, water disposal is not a problem and regular sewage charges are applied to the waste water sewage. Sewage costs for each plant are summarized in Table 10 and Appendix Table H-5.

Fuel oil is necessary for steam production for heating the reactor, reboiler, heat exchangers, and office. It is the major utility cost (see Table 10) because large amounts of heat are needed for maintaining the reactor temperature at 144°F. Steam requirements and calculations for determining fuel oil used are provided in Appendix Table H-6.

Electrical power is needed to run pump motors and for lighting. Appendix A lists the kilowatt requirements for motors in each plant. Costs for electricity include a charge of 2.7 cents per kilowatt and a demand charge of $5.59 per month per kilowatt of power. Complete calculations for electrical requirements are listed in Appendix Table H-7.

Maintenance and Repairs

Maintenance and repairs are necessary if the plant is to be kept in efficient operating condition. Costs for labor, materials, and supervision are included as a variable cost. Annual costs for equipment and repairs range from 2 to 20 percent of the equipment cost if service demands are light to severe. This analysis used 6 percent of the fixed capital investment as an average cost per year for maintenance and repairs. When operating at a reduced capacity, maintenance and repair costs are generally estimated at 75 percent of full capacity for a 50 percent operating rate and at 85 percent of full capacity for a 75 percent operating rate. Full capacity for methyl ester plants is 6,700 hours of operation per year.

Operating Supplies

Operating supplies (e.g., test chemicals, lubricants, charts, and custodial supplies) are items that cannot be considered as raw materials or maintenance and repairs but are needed to keep the plant functioning efficiently. These items cost an estimated 15 percent of the total cost of maintenance and repairs.

Laboratory Charges

Laboratory charges are necessary for quality control of the intermediate products, the finished methyl esters, and the glycerol. This expense is calculated by estimating the employee hours involved and multiplying the hours by the wage rate. The number of hours necessary for laboratory work is unknown so an estimate of 10 percent of the operating labor cost was used.

Workmen's Compensation, General Liability, and FICA Taxes

These costs are figured as a percentage of the wages paid. Workmen's compensation for each employee costs 6.87 percent on the first $3,600 of wages. General liability is about 3.0 percent, and the employer share of FICA taxes (social security) is 6.7 percent of gross earnings in 1983. Individual component costs and totals are provided in Appendix Table I-1.

Distribution and Marketing

Costs incurred for distribution and marketing are supply expenses, salaries, wages, sales office expenses, advertising costs, commissions, and traveling expenses for salesmen. This component varies greatly from one plant to another depending on the type of product being produced. These costs range from 2 to 20 percent of the total product cost (TPC) (Peters and Timmerhaus 1980). The higher number usually applies to a new product or to one sold in small quantities to a large number of customers. This study uses 2 percent of TPC because the lower percentage rate applies to large volume products, such as bulk chemicals. This cost may decrease over time as the market becomes better established.

Research and Development

Research and development (R & D) are needed to study and improve the techniques and processes used for producing methyl esters. These costs are included in most chemical plants. Research and development costs include fixed and operating expenses for equipment and machinery involved, salaries and wages, material and supply costs, direct overhead expenses, and miscellaneous costs. Peters and Timmerhaus (1980) recommend 5 percent of the total product cost should be allotted for R & D costs. One percent of total product cost was considered appropriate because there is only one main product and the production process would generally be quite well established by the time plants are built.

Cost Relationships

Several cost relationships can be drawn from the information developed. Together with information on vegetable oil prices, these relationships can help determine the feasibility of establishing methyl ester plants under varying economic conditions. This section is a discussion of the final conversion costs (including the glycerol credit), the effect of vegetable oil prices on the final price of methyl esters, economies of size among the five plants, and the effect of utilization levels on conversion costs.

Conversion Cost Including Glycerol Credit

Average total costs for converting sun oil to methyl esters were estimated (Table 7). Final conversion cost was developed after estimating the revenue from selling the by-product glycerol.

Pure glycerol is not produced in this process because impurities, such as soaps and sodium salts, comprise approximately 17 percent of the material in the glycerol storage tank. Impurities cannot be separated from the crude glycerol at this plant without further refining equipment. Crude glycerol must be sold to a glycerol refiner on a percent-composition basis. Proctor and Gamble of Cincinnati provided an estimated value for 83 percent glycerol of 67.7 percent of the refined glycerol selling price, which was quoted at 71.5 cents per pound for 99.5 percent pure glycerol. Thus, the crude glycerol price would be 48.41 cents per pound (67.7% X 71.5) at the refinery in Chicago (1983 price quotations). This assumes no special problems in the removal of impurities.

Freight rates for glycerol in bulk tanks from Fargo to Chicago were estimated by Burlington Northern Railroad at $5.68 per hundredweight. Thus, the value of crude glycerol at the methyl ester plant was 42.7 cents per pound (48.41 - 5.68 cents). It is very possible a lower freight rate could be obtained because glycerol is not hazardous to transport, will not ignite, nor does it need to be refirgerated or pressurized.

Total glycerol value is the product of the following factors:

1. pounds of crude glycerol produced per hour (365 pounds for Plant 1 as indicated in Appendix C)
2. percent purity (82.7%)
3. hours of operation per year (6,700 hours)
4. price of crude glycerine ($.427) in eastern North Dakota.

The total glycerol value and total fixed variable costs were developed for each of the five methyl ester plants at 100 percent capacity (Table 11). Average fixed and variable costs and the average glycerol credit of 31.3 cents per gallon of methyl esters were estimated providing the final average cost of converting sunflower oil to methyl esters.

For Plants 1 and 2, alcoholysis costs are 32 and 9 cents per gallon, respectively. Plant 3 would break even with methyl esters being sold at the same price per gallon that the sun oil was purchased at. Plants 4 and 5 would break even with methyl esters selling 4 and 6 cents less per gallon than the price of sun oil itself because the glycerol value exceeds the conversion cost, resulting in a glycerol credit.

Vegetable Oil Prices

The final conversion cost is determined on the basis of the information presented, but the final methyl ester cost per gallon depends largely on the price of each gallon of sunflower or vegetable oil itself. The price of oil plus the conversion cost (or credit) must be competitively priced with diesel fuel if methyl esters are to be a substitute fuel. Ethyl alcohol is more expensive than gasoline but it receives tax breaks to compete effectively. Whether or not fuel tax breaks would be available for methyl esters is unknown. Sun oil prices per pound and gallon for various sunflower seed prices provide a range for evaluating the cost of methyl esters (Table 12).

Final methyl ester prices for Plants 1-5 for a range of sun oil prices are provided (Table 13). Methyl esters from Plants 1 and 2, respectively, cost 32 and 9 cents per gallon more than sun oil itself because of the positive alcoholysis cost. The product from Plant 3 costs the same as the sun oil price since alcoholysis costs the same as the glycerol credit. Esters from Plants 4 and 5 actually are 4 and 6 cents per gallon cheaper than the purchased oil because the glycerol credit is larger than the alcoholysis cost.

Soybean oil could easily be substituted for sun oil provided phospholipids are removed from the oil prior to alcoholysis. (Since phospholipids combined with water are a valuable by-product called lecithin, the cost of this step could be recovered by selling the lecithin). This oil usually is priced lower than sun oil. Differences in average oil prices of sun and soybean oils for 1978-85 range from 12 to 45 cents per gallon (Table 14); soybean oil has averaged 29 cents less than sun oil.

TABLE 11. TOTAL AND AVERAGE COSTS OF CONVERTING SUN OIL TO METHYL ESTERS, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983

Cost	Methyl Ester Plant Number				
	1 (9,500 gal/da)	2 (23,750 gal/da)	3 (47,500 gal/da)	4 (71,250 gal/da)	5 (95,000 gal/da)
	dollars				
Total fixed cost	723,400	957,700	1,276,300	1,485,900	1,715,400
AFC[a]	.263	.139	.093	.072	.062
Total variable cost	1,032,700	1,804,000	3,014,300	4,121,100	5,279,000
AVC[a]	.375	.262	.219	.199	.192
Total cost	1,756,100	2,761,700	4,290,600	5,607,000	6,994,400
ATC[a]	.638	.401	.312	.271	.254
Total glycerol credit	863,600	2,158,900	4,317,900	6,476,800	8,635,800
Average glycerol credit	.313	.313	.313	.313	.313
Total cost less credit	892,500	602,800	(27,300)[b]	(869,800)[b]	(1,641,400)[b]
Final conversion cost	.32	.09	0	(.04)[b]	(.06)[b]

[a]Gallons of methyl ester fuel produced at 100 percent capacity during the 279-day processing season for Plants 1-5 are as follows: 2,755,000; 6,889,300; 13,778,500; 20,667,800; 27,557,100, respectively.
[b]The glycerol credit exceeds the alcoholysis cost.

SOURCES: Tables 5 and 6.

TABLE 12. PRICE RELATIONSHIPS BETWEEN SUNFLOWER SEED, MEAL, AND OIL

Sunflower Seed Value to Farmer	Sunflower Seed Value To Processor[a]	Meal Value	Sun Oil Value	Sun Oil Value
$/cwt.	$/cwt.	$/ton	$/lb.	$/gal.
6	8	66	.16	1.23
7	9	75	.18	1.38
8	10	83	.20	1.53
9	11	91	.22	1.69
10	12	99	.24	1.84
11	13	108	.26	1.99
12	14	116	.28	2.15
13	15	124	.30	2.30
14	16	133	.32	2.45
15	17	141	.34	2.61

NOTE: Relationships assume that the oil value is 76.8 percent of the seed value to the processor, the meal value is the balance, seed contains 38.5 percent oil, and 56 percent meal and hulls.

[a]Assumes processing transportation, storage, and other costs from country elevators to the processor are $40 per ton.

SOURCES: USDA 1982, 1983, Fats; USDA 1983 Oil; Cobia 1980.

Economies of Size

Economies of size are evident from Figure 3 by the decrease in per unit costs as plant size increases. This assumes 100 percent plant utilization at 6,700 hours of operation. Average total cost begins to level off after Plant 3 because both average variable and fixed costs begin to decrease at a lesser rate. Total variable costs do not increase proportionally to the increase in production because most component costs listed in Table 7 have a minimum or base requirement of inputs and because any increases in production only add marginal amounts of inputs to increase costs.

A minimum requirement can be illustrated by this example. Assume there are four major processing steps with one person employed at each processing step. If a plant were built with half the capacity of the first plant, labor would not be cut in half to two people because the minimum requirement is one person per processing step. Thus, labor requirements do not decrease in proportion to capacity.

An example of marginal amounts of input and minimum resource requirements for increased production can be found in the labor requirements between Plants 1 and 5. Plant 1 requires 108 employee hours per day while

TABLE 13. FINAL METHYL ESTER COSTS AT VARIOUS SUN OIL PRICES, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983[a]

	Methyl Ester Plant Number				
	1	2	3	4	5
Sun Oil	(9,500 gal/da)	(23,750 gal/da)	(47,500 gal/da)	(71,250 gal/da)	(95,000 gal/da)
	dollars per gallon				
1.23	1.55	1.32	1.23	1.19	1.17
1.38	1.70	1.47	1.38	1.34	1.32
1.53	1.85	1.62	1.53	1.49	1.47
1.69	2.01	1.78	1.69	1.65	1.63
1.84	2.16	1.93	1.84	1.80	1.78
1.99	2.31	2.08	1.99	1.95	1.93
2.15	2.47	2.24	2.15	2.11	2.09
2.30	2.62	2.39	2.30	2.26	2.24
2.45	2.77	2.54	2.45	2.41	2.39
2.61	2.93	2.70	2.61	2.57	2.55

[a]Includes glycerol credit for each plant used.

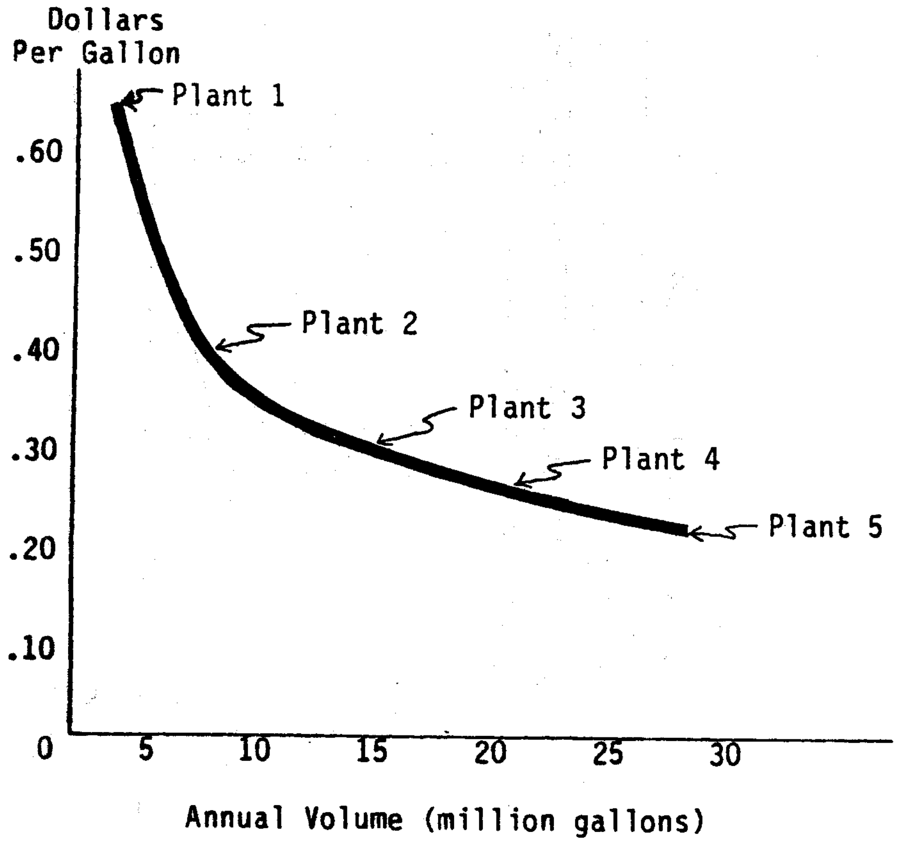

Figure 3. Average Total Conversion Cost, Methyl Ester Plants, 279-Day Processing Season, North Dakota, 1983

TABLE 14. YEARLY COMPARISON AND PRICE DIFFERENTIAL BETWEEN SUN AND SOYBEAN OILS, 1978-1983

Year	Sun Oil	Soybean Oil	Price Differential
	----------dollars per gallon----------		
1978	2.53	2.09	.44
1979	1.99	1.87	.12
1980	2.06	1.75	.31
1981	1.91	1.46	.45
1982[a]	1.75	1.59	.16
1983[a]	2.65	2.39	.26

[a]Forecasts.

SOURCES: USDA 1983, Fats; USDA 1983, Oil.

Plant 5 needs 184 hours. A tenfold increase in production (Plant 5 compared to Plant 1) requires an increase in labor requirements of only 70 percent rather than 1000 percent if labor were directly proportional to volume. Similar requirements occur with utilities; for example, as plants increase in size, more water is needed for cooling but only marginal amounts in comparison to the initial water requirements of the cooling system. Marginal increases in water cost are much less than proportional to the plant's production so the average variable cost per gallon decreases with increases in plant size.

Most other variable component costs in Table 7 are based on operating labor and total product costs (TPC). When operating labor costs do not increase proportionally, neither do direct supervisory labor, laboratory costs, FICA taxes, Workmen's Compensation, or general liability. Likewise, when the TPC does not increase in direct proportion with plant volume, neither do distribution and marketing nor research and development costs.

Because average total cost (ATC) continues to decrease with increasing plant sizes, there is reason to question why much larger plants are not considered so that ATC could continue to decline below $.25 per gallon. There are several reasons why even larger plants were not considered.

First, the supply of sun oil is limited in the short run, and the number of crushers are limited because of seed supplies. Because methyl ester plants are limited by the oil available to them from the crushing plants, it is not feasible to build a methyl ester plant capable of handling the oil from two large crushing plants if there is only one crushing plant delivering sun oil.

Second, most economies of size are captured by plants the size of Plants 4 and 5. Costs decrease only 4.1 cents between Plants 3 and 4 and only 1.7 cents between Plants 4 and 5. Significant decreases in ATC cannot be expected with plants larger than 95,000 gallons of sun oil per day.

Third, if the glycerol credit was dependent on making methyl esters competitive with diesel fuel, larger plants may produce enough glycerol to glut the market and cause the glycerol value to decline.

Fourth, minor decreases in ATC below 25 cents per gallon are not worth the potential problems that may result from processing such large volumes. Management may be a problem in larger plants, and it becomes more expensive to idle the huge capital investment of a larger plant if it needs to be shut down.

Utilization Changes

A 100 percent utilization level as depicted in Figure 3 may be unrealistic. There are circumstances which can reduce utilization down to near 50 or 75 percent. Alternatively, utilization may increase if circumstances permit. As previously stated, 100 percent utilization, as arbitrarily chosen by Clarke, Akbar, and Zobeck (1981), is 6,700 hours of operation per year or 279 24-hour days per year. Operating hours could easily increase when the plant is set up and operating efficiently. One hundred twenty percent of 6,700 hours (335 days) is used as an extended operating season.

Reasons for various utilization levels are labor strikes, major equipment breakdowns, reduced availability of sun oil and methanol, or low prices for diesel fuel. Sunflower seed crushing plants in North Dakota have closed due to seed shortages, so shortages of oil are a possibility. Utilization will be reduced if the price of sun oil or methanol become so high as to cause the price of methyl esters to exceed the diesel fuel price.

Total fixed costs per plant do not change with a change in utilization (Table 15). Average fixed costs double from 100 to 50 percent utilization. Total variable costs are not reduced to half when utilization is 50 percent because of base requirements for water, labor, and similar items. Certain variable costs, such as operating labor, direct supervisory labor, utilities, and laboratory costs, do not vary in direct proportion to production, so average costs are cheaper with higher utilization levels for the same reasons as described above for economies of size. Average total costs are higher for reduced utilization primarily because AFC per unit have increased dramatically. Average total costs over a range of utilization levels from 50 to 120 percent are graphically presented (Figure 4).

Summary and Conclusions

Summary

Alternatives for fossil fuels have been sought because of volatile changes in fuel prices, especially during the last decade. The problem is further complicated by an expected relative change in usage from gasoline to diesel fuel. Alcohol is used as an extender or substitute for gasoline, and vegetable oils are considered substitutes or extenders for diesel fuel.

A major problem with using vegetable oils as fuel is their high viscosity. Viscosity can be reduced by a chemical process called alcoholysis. The cost of large-scale alcoholysis of vegetable oils (sunflower oil) to methyl esters has not been determined in previous studies.

The primary objective of this analysis was to estimate the cost of producing methyl esters from crude sun oil over a range of plant sizes: 9,500; 23,750; 47,500; 71,250; and 95,000 gallons of sun oil per day.

The secondary objective was to determine the total capital investment required to process sun oil into methyl esters for each plant. Very limited public and proprietary information was available on the cost of building methyl ester plants. Therefore, processing plants had to be synthesized by economic and chemical engineering methods whereby all equipment costs in the processing plant were itemized. Chemical engineering factors were applied to the itemized purchased equipment costs to obtain components that comprise total capital investment (TCI). Total capital investment for Plants 1 through 5 are $2,447,200; $3,304,600; $4,544,300; $5,420,600; and $6,132,300, respectively.

TABLE 15. ESTIMATED ANNUAL OPERATING COSTS OF METHYL ESTER PLANTS AT VARIOUS UTILIZATION LEVELS, NORTH DAKOTA, 1983

Plant Number and Percent Utilization	Methyl Ester Output	Total Fixed Cost	Average Fixed Cost	Total Variable Cost	Average Variable Cost	Total Cost	Average Total Cost
	(gallons)	($)	($/gallon)	($)	($/gallon)	($)	($/gallon)
Plant 1							
50% (140 days)	1,377,800	723,400	.525	570,900	.414	1,294,300	.939
75% (209 days)	2,066,800	723,400	.350	766,000	.371	1,489,400	.721
100% (279 days)	2,755,700	723,400	.263	1,032,700	.375	1,756,100	.637
120% (335 days)[a]	3,306,800	723,400	.219	1,195,100	.361	1,918,500	.580
Plant 2							
50% (140 days)	3,444,600	957,700	.278	981,300	.285	1,939,000	.563
75% (209 days)	5,167,000	957,700	.185	1,354,700	.262	2,312,400	.448
100% (279 days)	6,889,300	957,700	.139	1,804,000	.262	2,761,700	.401
120% (335 days)[a]	8,267,200	957,700	.116	2,107,200	.255	3,064,900	.371
Plant 3							
50% (140 days)	6,889,200	1,276,300	.185	1,618,900	.235	2,895,200	.420
75% (209 days)	10,333,900	1,276,300	.124	2,276,100	.220	3,552,400	.344
100% (279 days)	13,778,500	1,276,300	.093	3,014,300	.219	4,290,600	.311
120% (335 days)[a]	16,534,200	1,276,300	.077	3,540,600	.214	4,816,900	.291
Plant 4							
50% (140 days)	10,333,900	1,485,900	.144	2,276,300	.220	3,762,200	.364
75% (209 days)	15,500,800	1,485,900	.096	3,163,000	.204	4,648,900	.300
100% (279 days)	20,667,800	1,485,900	.072	4,121,200	.199	5,607,100	.271
120% (335 days)[a]	24,801,400	1,485,900	.060	4,940,200	.199	6,426,100	.259
Plant 5							
50% (140 days)	13,778,600	1,715,400	.124	2,790,100	.202	4,505,500	.327
75% (209 days)	20,667,800	1,715,400	.083	3,991,700	.193	5,707,100	.276
100% (279 days)	27,557,100	1,715,400	.062	5,279,000	.192	6,994,400	.254
120% (335 days)[a]	33,068,500	1,715,400	.052	6,232,800	.188	7,948,200	.240

[a]An extended operating season of 335 days represents an optimum situation using new equipment and with the alcoholysis process working near perfect, which may be possible when the equipment is new but not over the long run.

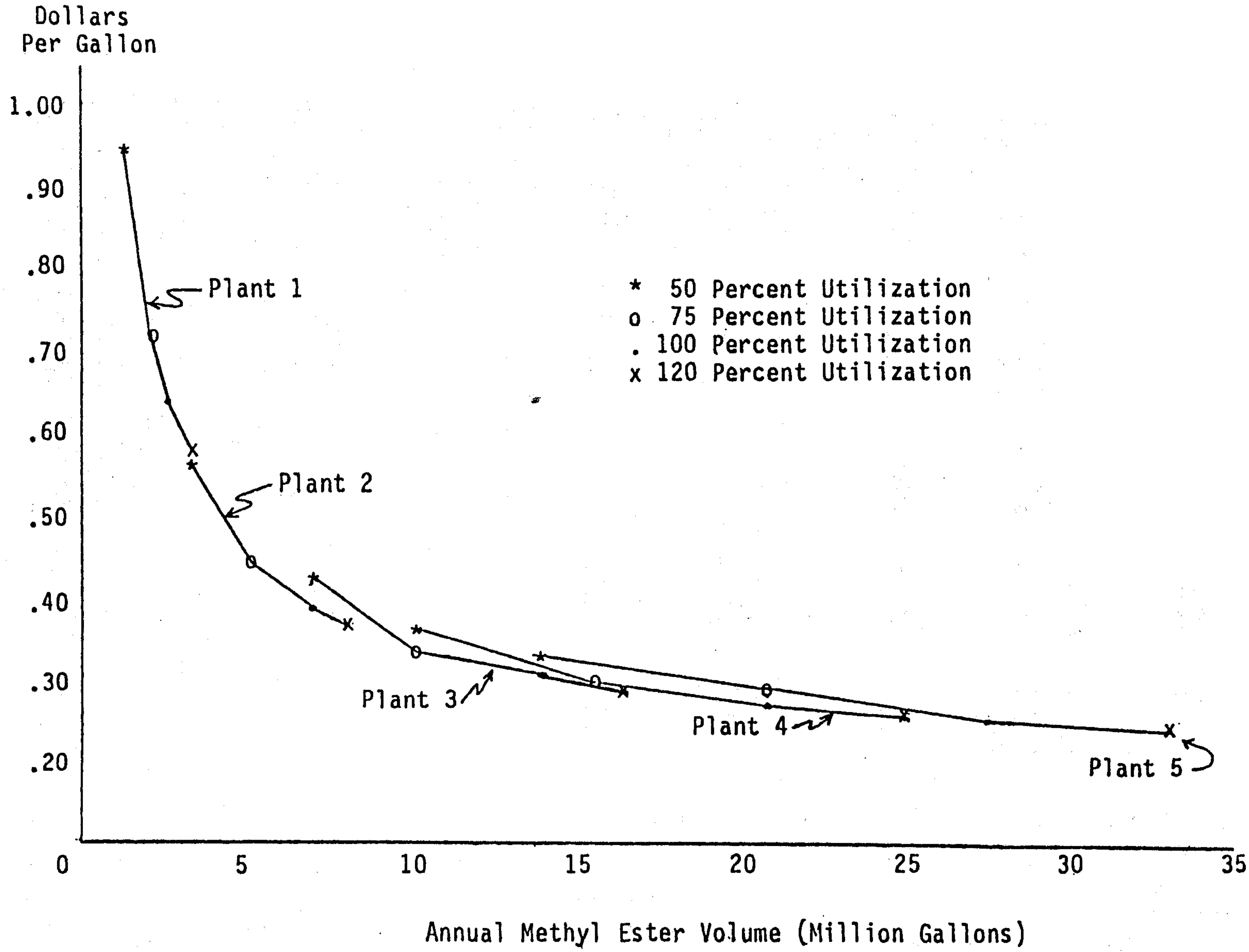

Figure 4. Short-Run Average Total Costs, Methyl Ester Plants, North Dakota, 1983

Operating costs include both fixed and variable costs. Fixed costs use information from the total capital investment section to determine fixed costs on an annual basis. Average fixed cost (AFC) per gallon of methyl esters was determined to be 26, 14, 9, 7, and 6 cents at full utilization (6,700 hours) for Plants 1 through 5. Variable costs do not include the crude sunflower oil cost because only conversion costs were estimated. Average variable costs (AVC) for Plants 1 through 5 are 38, 26, 22, 20, and 19 cents per gallon at full utilization levels. Average variable costs for Plants 2 through 5 are about two to three times as high per gallon of product as average fixed costs.

The by-product, 83 percent crude glycerol, is worth 42.7 cents per pound at the methyl ester plant. This credit averages 31 cents per gallon of methyl esters. The final conversion cost per gallon of methyl esters with the glycerol credit included is 32 and 9 cents for Plants 1 and 2. The glycerol credit equals the alcoholysis cost in Plant 3, while in Plants 4 and 5 the glycerol credit exceeds the conversion cost by 4 and 6 cents per gallon.

Economies of size were illustrated by comparing the average total (conversion) cost (ATC) of the five plant sizes at full utilization. Definite economies of size exist among Plants 1 through 3. The ATC for Plant 4 starts to decrease at a diminishing rate, and for Plant 5 most of the economies of size have been captured.

One major problem with using vegetable oils is their extreme price volatility, which would cause problems with plant utilization if vegetable oil prices became too high relative to diesel fuel. It appears the larger plants have advantages at full utilization, and even at reduced capacities. Average total cost per gallon for Plant 5 at 50 percent utilization is 32.7 cents, while the ATC for Plant 3 (one-half the size of Plant 5) at 100 percent capacity is still 31.3 cents per gallon.

The larger plants would lose more money in absolute total dollar amounts than the smaller plants if they were idled for an extended period simply because their total fixed costs are larger.

Recommendations and Conclusion

Information contained in this analysis has some limitations because amounts of materials used and produced have not been confirmed in a laboratory nor in a pilot plant. Numbers were calculated from chemical mass balance formulas based on what is expected to take place following the procedures employed. No experimental information was available that exactly duplicated the alcoholysis process used in this analysis. Available information was utilized to synthesize a method of alcoholysis to convert crude sun oil into methyl esters.

The glycerol credit is a very significant factor in reducing the final conversion cost to near zero or below. If several large plants similar to Plant 5 were to be put into operation, the glycerol market price would likely decrease because a single plant of that size would produce the equivalent of about 6 percent of the United States's glycerol usage. The glycerol credit could not be maintained at calculated levels if supply were sufficient to reduce glycerol value.

Two changes in the process are worth considering. One change concerns the removal of free fatty acid (FFA), and a second alteration is to refine glycerol at the process plant site.

Methyl ester plants considered here use crude sunflower oil which contains about 1 percent free fatty acids. Extra sodium hydroxide was used to compensate for the FFA which must be neutralized. If the FFA were removed by alkali refining prior to alcoholysis, the cost of extra sodium hydroxide could be saved and the resulting glycerol would contain less impurities because FFA becomes soaps. There are three benefits from FFA removal. Free fatty acid material could be sold as soapstock, freight costs could be saved by shipping less impurities in the crude glycerol, and less sodium hydroxide could be used in the alcoholysis process.

A second alternative would be to refine crude glycerol at the methyl ester plant. Freight would not have to be paid on the impurities that are shipped to the refiner. Although glycerine refining equipment may be a major investment, the large volumes involved in some of the larger plants would make the investment worthwhile. Plant 5 would probably then be the largest refiner in the country since it would produce about 6 percent of the total glycerol produced domestically.

One of the greatest difficulties in deciding to build a methyl ester plant is the uncertainty of the relationship between diesel fuel and vegetable oil prices. Drought, frost, insects, disease, and various farm programs can affect vegetable oil crop supplies and eventually influence vegetable oil prices. If vegetable oil prices were to fall below diesel fuel prices for several years and a crop failure occur, much higher vegetable oil prices may result in the shutdown of methyl ester plants built during the period of relatively cheaper vegetable oils. This situation would be serious because multimillion dollar plants cannot be left idle very long for there are no economic returns to capital during the shutdown. However, this situation would not be unique to methyl ester plants because many processors of agricultural products face the same price uncertainties.

Price uncertainty of substitutes is one of the major problems plaguing alternative fuel development. Coal gasification is being undertaken at Beulah, North Dakota, for the production of methane gas. This plant has had pricing difficulties because synthetic gas is more expensive than natural methane. Part of the problem of producing gasohol (ethanol added to gasoline) was consumer acceptance and the higher price of gasohol. Originally, the reason for using ethanol was to extend short gasoline supplies while raising the octane level and reducing engine knock. This reasoning may need to be applied to methyl esters in the years ahead when either diesel fuel shortages or price increases occur.

Americans should not be lulled into a mood of complacency by temporary price decreases and ample fuel supplies. The oil glut of the early 1980s is only a correction and not a change in the fundamental conditions of supply. Research needs to be carried out to provide alternatives before potential crisis situations are reached. Many alternatives will be needed because vegetable oils at best could only replace the diesel fuel needs of the agricultural sector alone, leaving little if any surplus to service the needs of the much larger industrial and transportation sectors. Vegetable oils have the potential to help solve energy problems, but many other energy sources may be required to help relieve the world's dependence on fossil fuels.

APPENDIX A

APPENDIX A

Calculations and Costs for Equipment Listed in Table 3.

1. Scales

Railroad and truck scale prices are from a local vendor. Scales are the same price and size no matter what the size of plant. The railroad scale was priced at $46,000 to $47,000 while the truck scale cost $20,000 to $21,000 each.

2. Pumps

Pumps were calculated using the following formula which was used by Clarke, Akbar, and Zobeck (1981) to calculate pump sizes and motor power.

$$LHP = \frac{(GMP\ (head)\ (SG)}{3960}$$

where: LHP = liquid horsepower
GPM = capacity in gallons per minute
head = pumping height in feet
SG = specific gravity
3960 = constant

Pumps and their costs can be determined from Figure 13-40 in Peters and Timmerhaus (1980), when GPM and head are known. Pump prices were inflated by a Marshall and Swift cost index from January 1979 to January 1983. The factor was $\frac{778}{561}$ or 1.387.

3. Motors

Pump sizes were calculated using the format Clarke, Akbar, and Zobeck (1981) used to figure brake horsepower (BHP). Pump efficiency is found from Figure 13-37 in Peter and Timmerhaus (1980) when GPM is known. BHP can be calculated as shown:

$$BHP = \frac{LHP}{\text{Pump Efficiency}}$$

Motor efficiency can be found from Figure 13-38 in Peters and Timmerhaus when BHP is known. Motor power (MP) required to operate the motor is calculated as shown:

$$MP = \frac{BHP}{\text{Motor Efficiency}}$$

MP is converted to electrical power by a conversion factor as shown:

$$MP \times \frac{.7457 \text{ kw}}{1 \text{ hp}} = \text{number of kilowatts}$$

An example is given using pump number 6 in Plant 1 (P-6-1):

$$LHP = \frac{(8.3)\ (4)\ (.909)}{3960}$$

$LHP = .008$

Pump Efficiency = 20%

$$BHP = \frac{.008}{.20} = .038 \text{ hp}$$

Motor Efficiency = 80%

$$\text{Motor Power} = \frac{.038}{.80} = .048 \text{ hp}$$

$$\text{Kilowatts} = .048 \text{ hp} \ \frac{.7457 \text{ kw}}{1 \text{ hp.}} = .036 \text{ kw}$$

Motor size is based on brake horsepower. BHP has been increased by 25 percent for a contingency factor. Motor size chosen must be equal to or larger than the BHP. BHP varies considerably so the motor sizes are grouped in 1/3, 1, 2, 5, and 10 horsepower sizes so the number of spare motors can be reduced. Pump size and cost as well as motor size and cost can be determined for all pumps in each plant by using the information given in Appendix Table A-1. Again, the first number after P is the pump number and the second is the plant number.

4. Propellers and Motors

Motor power for the propellers in the methanol holding tank (HT-2) and the reactor (R) was calculated by a method used by Clarke Akbar, Zobeck (1981), even though all are not dual marine propellers.

$$P = \frac{Np\ (N)^3 DL^5}{550\ (32.2)}$$

where:
- P = power of agitator (propeller)
- Np = .9 for dual marine propellers
- N = revolutions per second
- D = density of material
- L = length of propeller

APPENDIX TABLE A-1. INFORMATION REQUIRED TO CALCULATE MOTOR AND PUMP SIZES FOR METHYL ESTER PLANTS, 1983

Pump Number	Liquid Volume (gal/min)	Head[a] (feet)	Specific Gravity[b]	Motor Size (hp)	Electricity Consumption (kw)	Pump Cost (dollars)	Motor Cost (dollars)
P-1-1	217	26	.915	5	1.83	1285	530
P-1-2	217	34	.915	5	2.36	1285	530
P-1-3	217	43	.915	5	2.98	1285	530
P-1-4	217	48	.915	5	3.29	1680	530
P-1-5	217	53	.915	5	3.63	1680	885
P-2-1	6.9	7.0	.915	1/3	.05	640	265
P-2-2	17.4	9.2	.915	1/3	.17	640	265
P-2-3	34.7	11.6	.915	1/3	.22	790	265
P-2-4	52.1	13.3	.915	1	.33	820	315
P-2-5	69.4	14.7	.915	1	.44	915	315
P-3-1	1.4	24	.791	1/3	.03	790	265
P-3-2	3.5	33	.791	1/3	.11	790	265
P-3-3	7.1	42	.791	1	.28	1000	315
P-3-4	10.6	48	.791	1	.47	1125	315
P-3-5	14.1	52	.791	1	.68	1125	315
P-4-1	6.9	7.2	.915	1/3	.05	640	265
P-4-2	17.4	9.8	.915	1/3	.18	640	265
P-4-3	34.7	12.4	.915	1	.26	790	315
P-4-4	52.1	14.2	.915	1	.35	820	315
P-4-5	69.4	15.6	.915	1	.47	915	315
P-5-1	1.4	7.2	.791	1/3	.01	640	265
P-5-2	3.6	9.8	.791	1/3	.03	640	265
P-5-3	7.1	12.4	.791	1/3	.08	640	265
P-5-4	10.7	14.2	.791	1/3	.14	640	265
P-5-5	14.2	15.6	.791	1/3	.21	640	265
P-6-1	8.3	4.0	.909	1/3	.04	640	265
P-6-2	20.9	5.0	.909	1/3	.08	640	265
P-6-3	41.8	7.0	.909	1/3	.16	790	265
P-6-4	62.7	8.0	.909	1/3	.22	915	265
P-6-5	83.5	9.0	.909	1	.32	1000	315
P-7-1	7.4	3.0	.882	1/3	.02	640	265
P-7-2	18.0	4.0	.882	1/3	.08	640	265
P-7-3	36.8	4.0	.882	1/3	.08	790	265
P-7-4	55.2	4.0	.882	1/3	.09	820	265
P-7-5	73.6	5.0	.882	1/3	.15	915	265
P-8-1	.6	10	.962	1/3	.01	640	265
P-8-2	1.5	10	.962	1/3	.02	640	265
P-8-3	3.0	10	.962	1/3	.03	640	265
P-8-4	4.5	15	.962	1/3	.08	640	265
P-8-5	6.0	15	.962	1/3	.10	640	265
P-9-1	.45	18.5	.791	1/3	.01	460	265
P-9-2	1.13	18.5	.791	1/3	.02	460	265
P-9-3	2.25	18.5	.791	1/3	.04	460	265
P-9-4	3.38	28	.791	1/3	.09	570	265
P-9-5	4.50	28	.791	1/3	.12	570	265
P-10-1	5.0	1.0	.963	1/3	.01	460	265
P-10-2	12.4	1.0	.963	1/3	.01	460	265
P-10-3	24.8	1.0	.963	1/3	.02	460	265
P-10-4	37.2	1.0	.963	1/3	.02	570	265
P-10-5	49.7	1.0	.963	1/3	.02	590	265
P-11-1	3.3	6.2	.791	1/3	.02	460	265
P-11-2	8.3	8.0	.791	1/3	.06	460	265
P-11-3	16.7	10.0	.791	1/3	.16	460	265
P-11-4	25.0	11.5	.791	1/3	.18	460	265
P-11-5	33.3	12.5	.791	1/3	.22	570	265

- CONTINUED -

APPENDIX TABLE A-1. INFORMATION REQUIRED TO CALCULATE MOTOR AND PUMP SIZES FOR METHYL ESTER PLANTS, 1983 (CONTINUED)

Pump Number	Liquid Volume	Head[a]	Specific Gravity[b]	Motor Size	Electricity Consumption	Pump Cost	Motor Cost
	(gal/min)	(feet)		(hp)	(kw)	(dollars)	(dollars)
P-12-1	.5	10	1.0	1/3	.01	460	265
P-12-2	1.1	10	1.0	1/3	.01	460	265
P-12-3	2.3	10	1.0	1/3	.03	460	265
P-12-4	3.4	10	1.0	1/3	.04	460	265
P-12-5	4.6	10	1.0	1/3	.05	460	265
P-13-1	7.3	1	.89	1/3	.01	460	265
P-13-2	18.3	1	.89	1/3	.02	460	265
P-13-3	36.7	1	.89	1/3	.02	570	265
P-13-4	55.0	1	.89	1/3	.03	590	265
P-13-5	73.4	1	.89	1/3	.03	660	265
P-14-1	7.3	3	.89	1/3	.02	460	265
P-14-2	18.3	3	.89	1/3	.06	460	265
P-14-3	36.7	3	.89	1/3	.06	570	265
P-14-4	55.0	3	.89	1/3	.08	590	265
P-14-5	73.4	3	.89	1/3	.09	660	265
P-15-1	7.2	10	.88	1/3	.07	460	265
P-15-2	17.9	14	.88	1	.26	460	315
P-15-3	35.8	18	.88	1	.33	570	315
P-15-4	53.6	20.5	.88	1	.51	590	315
P-15-5	71.5	22.5	.88	1	.67	660	315
P-16-1	6.9	20	.88	1/3	.14	570	265
P-16-2	17.2	27	.88	1	.48	570	315
P-16-3	34.4	33	.88	1	.59	645	315
P-16-4	51.6	38	.88	2	.90	720	345
P-16-5	68.8	42	.88	2	1.18	775	345
P-17-1	.3	8	1.08	1/3	.01	460	265
P-17-2	.7	11	1.08	1/3	.01	460	265
P-17-3	1.4	13.5	1.08	1/3	.02	460	265
P-17-4	2.2	15	1.08	1/3	.04	460	265
P-17-5	2.9	16.6	1.08	1/3	.06	460	265
P-18-1	2.17	15	.88	2	1.04	870	345
P-18-2	2.17	15	.88	2	1.04	870	345
P-18-3	2.17	15	.88	2	1.04	870	345
P-18-4	2.17	15	.88	2	1.04	870	345
P-18-5	2.17	15	.88	2	1.04	870	345

[a]Head, in this study, refers to the height in feet the liquid is pumped.
[b]Specific gravity is the density of a substance relative to water.

To calculate the power of the propeller motor for the propeller in the reactor use:

Np = .9
N = .67 revolutions per second
D = .897 X 62.4 = 55.97 lb m/ft^3 (.897 is the specific gravity of sun oil/methanol mixture)
L = 2.9, 3.9, 5.0, 5.7, 6.25 feet for Plant 1-5 as the propeller size.

An example is shown which calculates motor power and kilowatts for the power requirement of the propeller motor in the reactor:

$$P = \frac{.9\ (.67\ \text{rev./sec.})^3\ (56\ \text{lb.m./ft.3})\ (2.9\ \text{ft.})^5}{550 \qquad (32.2\ \text{ft./sec.})}$$

$$P = .176\ \text{hp}$$

$$P = .176\ (1.1) + .5 = .693\ \text{hp.}\ \frac{.7457\ \text{kw}}{1\ \text{hp}} = .517\ \text{kw}$$

APPENDIX TABLE A-2. SPECIFICATIONS OF THE REACTOR PROPELLER MOTOR, 1983

Plant Number	Horsepower	Motor Size	Motor Cost	Electricity Consumption
	(hp)	(hp)	(dollars)	(kw)
1	.7	1	315	.5
2	1.4	2	345	1.0
3	3.4	5	530	2.6
4	6.2	10	885	4.6
5	9.5	10	885	7.1

The cost of propellers is shown in Table A-3.

APPENDIX TABLE A-3. COST OF REACTOR PROPELLER, 1983

Plant Number[a]	Horsepower	Carbon Steel Cost	Stainless Steel Propeller[b]	Current Propeller Cost[c]
	(hp)	(dollars)	(dollars)	(dollars)
1	.7	1500	1680	2330
2	1.4	1600	1790	2480
3	3.4	4100	4590	6370
4	6.2	5000	5600	7770
5	9.5	6000	6720	9320

[a]A carbon steel propeller is priced for Plants 1 and 2; in Plants 3, 4, and 5 a carbon steel dual impeller is priced.
[b]Cost of carbon steel propellers are multiplied by a factor of 1.12 to obtain stainless steel propeller costs.
[c]A cost index of 1.387 brings January 1979 prices up to January 1983.

SOURCE: Peters and Timmerhaus (1980).

Hours required to install propellers can be determined from Figure 13-59 in Peters and Timmerhause (1980). Installed propeller costs are given in Table A-4.

Propeller and motor costs and specifications for the agitator in HT-2 are given in Table A-5. The same power formula from above is used with the numbers below.

N = .25 revolutions per second
D = 50.85 (specific gravity times 62.4)
L = 1.4, 1.9, 2.4, 2.7, 3.0 feet

APPENDIX TABLE A-4. INSTALLED REACTOR PROPELLER COSTS, 1983

Plant Number	Horsepower	Installation	Installation Cost[a]	Propeller Cost	Installed Cost
	(hp)	(hours)	(dollars)	(dollars)	(dollars)
1	.7	25	500	2330	2830
2	1.4	27	540	2485	3025
3	3.4	32	640	6370	7010
4	6.2	36	720	7765	8485
5	9.5	40	800	9320	10,120

[a]Wage per hour is assumed to be $20.

APPENDIX TABLE A-5. SPECIFICATIONS OF THE METHANOL HOLDING TANK PROPELLER MOTOR, 1983

Plant Number	Horsepower	Motor Size	Motor Cost	Kilowatts
	(hp)	(hp)	(dollars)	(kw)
1	.50	1	315	.37
2	.50	1	315	.37
3	.50	1	315	.38
4	.51	1	315	.38
5	.51	1	315	.38

The propeller in HT-2 is the same price for all plant sizes. Propeller cost is based on horsepower not on length of propeller. The smallest carbon steel propeller in Figure 13-59 in Peters and Timmerhaus (1980) is one horsepower which costs $1,500. Stainless steel costs 12 percent more so the cost is $1,680. The inflation factor of 1.387 increases the price to $2,330 while labor costs $500 for a total installed propeller cost for each plant of $2,830.

5. Tanks

Tanks are sized by determining the volumes they would accumulate in one hour. They will only be filled to 90 percent capacity, so the actual volume they will hold is divided by 90 percent to obtain excess capacity. All tanks are carbon steel unless specified as stainless steel. Prices are from tank companies, Figure 13-58, and Table 5, page 573 in Peters and Timmerhaus. Tank specifications are given in Appendix Table A-6.

Major process equipment, except the reactor, was sized by Narum. Available specifications are listed below in Appendix Tables A-7 through A-15.

6. Wash Columns

7. Condensers

Three condensers are needed, one for the distillation column, flash vaporization unit, and flash distillation unit. The column headed "mH_2O" refers to the pounds of water per hour needed for cooling.

8. Reboilers

A reboiler is needed on the distillation column. Specifications are given below.

APPENDIX TABLE A-6. TANK SPECIFICATIONS AND COSTS, 1983

Tank Number	Diameter (feet)	Length (feet)	Volume (gallons)	Cost (dollars)
ST-1-1[a]	23.7	23.7	77,777	44,000
ST-1-2	32.1	32.1	194,443	63,800
ST-1-3	40.5	40.5	388,893	88,000
ST-1-4	46.3	46.3	583,335	115,500
ST-1-5	51.0	51.0	777,778	140,800
ST-2-1	18.8	18.8	39,006	30,000
ST-2-2	25.5	25.5	97,515	43,000
ST-2-3	32.1	32.1	195,034	58,000
ST-2-4	36.8	36.8	292,543	70,000
ST-2-5	40.5	40.5	390,060	80,000
T-1-1	1.7	3.4	55	110
T-1-2	2.3	4.6	139	150
T-1-3	2.9	5.7	278	150
T-1-4	3.3	6.6	417	230
T-1-5	3.6	7.2	556	275
GS-1-1	3.6	7.2	556	275
GS-1-2	4.9	9.8	1,394	550
GS-1-3	6.2	12.4	2,789	1,200
GS-1-4	7.1	14.2	4,184	1,700
GS-1-5	7.8	15.6	5,579	2,150
GS-2-1	9.9	19.9	11,442	3,740
GS-2-2	13.5	27.0	28,604	14,850
GS-2-3	17.0	34.0	57,207	40,700
GS-2-4	19.5	38.8	85,811	45,100
GS-2-5	21.4	42.8	114,422	49,500
ST-3-1[a,b]	18.7	18.7	38,519	62,700
ST-3-2	25.4	25.4	96,298	93,500
ST-3-3	32.0	32.0	192,595	129,800
ST-3-4	36.6	36.6	288,893	154,000
ST-3-5	40.3	40.3	385,190	180,400
ST-4-1[a,b,c]	8.3	8.3	3,382	50,300
ST-4-2	11.3	11.3	8,456	89,300
ST-4-3	14.2	14.2	16,912	128,500
ST-4-4	16.3	16.3	25,365	168,400
ST-4-5	17.9	17.9	33,821	198,000
HT-1-1	3.4	6.8	463	250
HT-1-2	4.6	9.2	1,157	400
HT-1-3	5.8	11.6	2,315	1,050
HT-1-4	6.7	13.3	3,772	1,600
HT-1-5	7.3	14.7	4,629	1,800
HT-2-1	1.8	5.2	94	140
HT-2-2	2.4	7.1	236	150
HT-2-3	3.0	9.0	471	250
HT-2-4	3.4	10.3	707	310
HT-2-5	3.8	11.3	942	330
HT-3-1	.5	.5	.8	7
HT-3-2	.6	.6	1.5	7
HT-3-3	.8	.8	3.0	7
HT-3-4	.9	.9	4.5	7
HT-3-5	1.0	1.0	6.8	7

[a]These tanks have auxiliaries included at 10 percent of the tank cost.
[b]Two tanks are required. Length, diameter, and volume are for each tank. Cost listed is the total cost for both.
[c]These tanks are stainless steel. The price is from Figure 13-58 in Peters and Timmerhaus, with 10 percent cost added for auxiliaries. Cost of auxiliaries are based on a carbon steel tank of the same volume.

APPENDIX TABLE A-7. WASH COLUMN SPECIFICATIONS, 1983

Wash Column Number	Length	Diameter	Cost
	(feet)	(feet)	(dollars)
WC-1	7	3.5	3,470
WC-2	9.5	4.75	5,550
WC-3	12	6.0	8,320
WC-4	13.5	6.75	11,100
WC-5	15	7.5	12,500

APPENDIX TABLE A-8. CONDENSER SPECIFICATIONS, 1983

Condenser Number	Area	mH_2O	Cost
	(feet^2)	(pounds)	(dollars)
C-1-1	3.4	5,110	760
C-1-2	8.5	12,900	900
C-1-3	17.1	25,800	970
C-1-4	25.6	38,800	1,080
C-1-5	34.2	51,700	1,110
C-2-1	1.5	5,630	1,250
C-2-2	3.8	14,300	1,390
C-2-3	7.7	28,600	1,660
C-2-4	11.5	42,800	1,800
C-2-5	15.3	57,100	1,940
C-3-1	2	4,810	700
C-3-2	5	12,000	830
C-3-3	10	24,100	900
C-3-4	15	36,100	970
C-3-5	20	48,200	1,040

APPENDIX TABLE A-9. REBOILER SPECIFICATIONS, 1983

Reboiler Number	Area	Ms[a]	Cost
	(feet^2)	(pounds)	(dollars)
Rb-1-1	4.2	123	800
Rb-1-2	10.5	309	900
Rb-1-3	21.1	622	1,010
Rb-1-4	32.4	954	1,110
Rb-1-5	42.3	1,246	1,140

[a]Refers to the pounds of steam required per hour as a heat source.

9. Filters

Two filters are required for each plant to filter solid material out of the methyl esters. They have four micron size screens. Filtering area and total cost for both filters are given below.

APPENDIX TABLE A-10. FILTER SPECIFICATIONS, 1983

Filter Number	Filtering Area	Total Cost
	(feet^2)	(dollars)
F-1-1	90	10,750
F-1-2	226	13,900
F-1-3	452	14,600
F-1-4	678	14,800
F-1-5	903	15,300

10. Heat Exchangers

Two heat exchangers are needed per plant. Specifications are given below.

APPENDIX TABLE A-11. HEAT EXCHANGER SPECIFICATIONS, 1983

Heat Exchanger Number	Area	Ms[a]	Cost
	(feet^2)	(pounds)	(dollars)
HE-1-1	2.6	124	750
HE-1-2	6.5	314	830
HE-1-3	13.0	628	960
HE-1-4	19.5	940	1,030
HE-1-5	26.0	1,250	1,070
HE-2-1	4	41	800
HE-2-2	10	103	900
HE-2-3	20	206	1,040
HE-2-4	30	310	1,110
HE-2-5	40	413	1,140

[a]Refers to the pounds of steam required per hour as a heat source.

11. Distillation Columns

Diameter and length of the distillation column (DC) were calculated by Narum (1981). Tower costs were determined by Hall, Motley, and McMaughton (1982). Volumes of each tower were determined and that volume of packing was priced from Figure 41 in Chemical Engineering. One-half inch saddle-type porcelain packing was used. Specifications are shown in Tables A-12 and A-13.

APPENDIX TABLE A-12. DISTILLATION COLUMN SPECIFICATIONS, 1983

Distillation Column Number	Length	Diameter	Tower Cost
	(feet)	(inches)	(dollars)
DC-1	18.5	5	9,000
DC-2	18.5	7	11,000
DC-3	18.5	10	15,000
DC-4	28	12	24,500
DC-5	28	14	29,400

APPENDIX TABLE A-13. PACKED DISTILLATION COLUMN COSTS, 1983

Distillation Column Number	Volume	Packing Cost[a]	Packed Tower Cost	Packed Tower Cost, 1983[b]
	(feet^3)	(dollars)	(dollars)	(dollars)
DC-1	2.5	155	9,155	9,670
DC-2	5	310	11,310	11,950
DC-3	10	620	15,620	16,500
DC-4	22	1,360	25,864	27,325
DC-5	30	1,860	31,260	33,025

[a]Packing costs are based on $62 per cubic foot of one-half inch packing.
[b]Inflation factor up to January 1983 is 1.056.

12. Flash Distillation

Flash distillation (FD) units were sized by Narum (1981). Specifications and costs are given in Table A-14.

APPENDIX TABLE A-14. FLASH DISTILLATION SPECIFICATIONS, 1983

Unit Number	Length	Diameter	Volume	Cost
	(feet)	(inches)	(feet^3)	(dollars)
FD-1	4.0	4	.35	700
FD-2	4.1	6	.8	770
FD-3	4.4	8	1.5	830
FD-4	4.3	10	2.3	870
FD-5	4.1	12	3.2	900

13. Flash Vaporization

These units were sized by Narum (1981). Specifications are given in Table A-15.

APPENDIX TABLE A-15. FLASH VAPORIZATION SPECIFICATIONS, 1983

Unit Number	Length	Diameter	Cost
	(feet)	(inches)	(dollars)
FV-1	5.5	6	1,730
FV-2	5.5	9	1,870
FV-3	5.5	12	1,940
FV-4	5.5	14	2,010
FV-5	5.5	17	2,080

14. Reactor

Reactors were sized by Clarke, Akbar, and Zobeck (1981) for the production of methyl esters from sun oil. Their design was adapted in this paper. Actual volumes for the reactor are from Appendix C where flow rates are shown. Reactor costs are from Figure 15-37 in Peters and Timmerhaus (1980). It is a 300-pound per square inch stainless steel, jacketed, agitated tank reactor. Specifications are given in Table A-16.

APPENDIX TABLE A-16. REACTOR SPECIFICATIONS, 1983

Reactor Number	Material Volume	Reactor Size[a]	Diameter	Length	Cost	1983 Cost[b]
	($feet^3$)	($feet^3$)	(feet)	(feet)	(dollars)	(dollars)
R-1	67	74.5	3.6	7.2	29,000	40,200
R-2	168	186.4	4.9	9.8	50,000	69,300
R-3	336	372.9	6.2	12.4	70,000	97,100
R-4	503	559.3	7.1	14.2	90,000	124,800
R-5	671	745.9	7.8	15.6	105,000	145,600

[a]Volume of material was divided by 90 percent because the reactor is usually filled to 90 percent capacity.
[b]Marshall and Swift index for inflation is 1.387.

15. Mixers

Two in-line mixers are included for $200 each, a price suggested by Dr. D.N. Baris at the University of North Dakota. These are used to neutralize the stream flows if needed.

APPENDIX B

APPENDIX B

Land Costs

Plants 1 and 2

10 acres at $16,500 per acre - land	$165,000
10 acres at $10,000 per acre - special assessments	100,000
250 foot railroad spur at $50 per foot installed	12,500
	$277,500

Plants 3, 4, and 5

15 acres at $16,500 per acre - land	$247,500
15 acres at $10,000 per acre - special assessments	150,000
250 foot railroad spur at $50 per foot installed	12,500
	$409,500

APPENDIX C

APPENDIX C

Raw Material and Product Relationships and Flow Rates Between Processes

Pounds of CH_3OH and NaOH needed for Plant 1 (9,500 gallons per day) to operate at capacity are calculated below. Products formed are also calculated. To determine material amounts for Plants 2 through 5, multiply pounds of raw materials or products by 2.5, 5.0, 7.5, or 10.0.

Abbreviations used in this appendix:

Term	Abbreviation
gallon	gal.
hour	hr.
pound	lb.
mole	mo.
methyl esters	m.e.
glycerol	gly.
sun oil	oil
free fatty acids	FFA

Plant 1: $\frac{9500 \text{ gal. oil}}{1 \text{ day}} \bigg| \frac{1 \text{ day}}{24 \text{ hr.}} \bigg|$ 395.83 gal. oil/hr.

$$\frac{395.83 \text{ gal. oil}}{1 \text{ hr.}} \bigg| \frac{7.67 \text{ lb.}}{1 \text{ gal. oil}} = 3036 \text{ lb. oil/hr.}$$

$$\frac{3036 \text{ lb. oil}}{\frac{878 \text{ lb.}}{\text{lb. mo. oil}}} = 3.458 \text{ lb. mo. oil}$$

To calculate pounds of methyl esters per hour from Plant 1:

3.458 lb. mo. oil + .173 lb. mo. oil[a] = 3.63 lb. mo. oil

$$3.63 \text{ lb. mo. oil} \bigg| \frac{3 \text{ lb. mo. m.e.}}{1 \text{ lb. mo. oil}} \bigg| \frac{294 \text{ lb. m.e.}}{1 \text{ lb. m.e.}} \bigg| \frac{.92}{1.00} \bigg| = 2946 \text{ lb. methyl esters per hour}$$

To calculate the required amount of CH_3OH needed for the reactor per hour:

$$3.63 \text{ lb. mo. oil} \bigg| \frac{3 \text{ lb. mo. } CH_3OH}{1 \text{ lb. mo. oil}} \bigg| \frac{32.04 \text{ lb. } CH_3OH}{1 \text{ lb. mo. } CH_3OH} \bigg| \frac{1.6}{1.0} \bigg| = 558.4 \text{ lb. } CH_3OH$$

---

[a]One hundred fifty-two pounds per hour of mono- and diglycerides (5% of eachhour of production weight) are recycled from GS-2 (152 lb. ÷ 878 lb/lb. mole = .173).

Sixty percent excess CH_3OH is used to help the reaction proceed to methyl esters. One hundred percent is required (3 moles CH_3OH) for every one mole of oil) while 60 percent excess helps drive the reaction to methyl esters. The reaction is only abut 92 percent complete so 8 percent plus 60 percent excess make 68 percent of the CH_3OH available for recycling.

$$3.63 \text{ lb. mo. oil} \left| \frac{3 \text{ lb. mo. } CH_3OH}{1 \text{ lb. mo. oil}} \right| \frac{32.04 \text{ lb. } CH_3OH}{1 \text{ lb. mo. } CH_3OH} \left| \frac{.68}{1.00} \right| = 237.1 \text{ lb. recoverable } CH_3OH$$

The difference between the two calculations above is 321.3 pounds.

558.4 lb. - 237.1 = 321.3 lb. (actually consumed in process)
22. lb. (lost in waste water and glycerol)
343. lb. (used per hour)

Glycerol quantities are calculated below:

$$3.631 \text{ lb. mo. oil} \left| \frac{1 \text{ lb. mo. gly}}{1 \text{ lb. mo. oil}} \right| \frac{92.09 \text{ lb. gly.}}{1 \text{ lb. mo. gly.}} \left| \frac{.92}{1.00} \right| = 308 \text{ lb. glycerol}$$

Six pounds are lost into wash water: 308 - 6 = 302 lb. glycerol

Calculations for the salts formed are shown below:

$$\frac{3036 \text{ lb. oil}}{\text{hr.}} \times 1\% \text{ FFA} = 30.36 \text{ lb. FFA}$$

$$\frac{30.36 \text{ lb. FFA}}{\frac{280 \text{ lb.}}{\text{lb. mo.}}} = .108 \text{ lb. mo. FFA}$$

The calculation below finds lbs. of NaOH needed in the reactor to neutralize 30.36 lbs. of FFA.

$$.108 \text{ lb. mo FFA} \left| \frac{\text{lb. mo. HaOH}}{\text{lb. mo. FFA}} \right| \frac{40.01 \text{ lb. NaOH}}{1 \text{ lb. mo. NaOH}} \right| = 4.34 \text{ lb. NaOH}$$

Hassett and Hasan (1982) used 1 percent of the CH_3OH weight as the weight of NaOH needed as a catalyst. Five hundred fifty-eight pounds of CH_3OH used in the reactor per hour requires 5.6 lbs. of NaOH (1 percent of 558). Total pounds of NaOH used per hour is 4.34 + 5.6 = 9.9 or 10 lbs. per hour.

The catalyst (5.6 lb. NaOH) needs to be neutralized by acid. H_2SO_4 is used for this and is calculated below.

$$\frac{5.6 \text{ lb. NaOH}}{\frac{40.01 \text{ lb.}}{\text{lb. mo.}}} = .14 \text{ lb. mo. NaOH}$$

$$.14 \text{ lb. mo. NaOH} \left| \frac{1 \text{ lb. mo. } H_2SO_4}{2 \text{ lb. mo. NaOH}} \right| \frac{98 \text{ lb. } H_2SO_4}{1 \text{ lb. mo. } H_2SO_4} = 6.9 \text{ lb. } H_2SO_4 \text{ per hour}$$

Total salts and soaps

30.36 lb. FFA	(1 percent of oil)
2.50 lb. NA^+	(4.34 lb. NaOH is used to neutralize FFA; NA^+ portion is 23/40 X 4.34 = 2.50)
6.76 lb. SO_4	(SO_4 = portion of the H_2SO_4; 96/98 X 6.9 = 6.76)
3.25 lb. Na^+	(Na^+ portion of NaOH which was 1 percent of the oil; 23/40 X 5.6 = 3.25)
43	

Glycerol contains most of the soaps and salts calculated above. Not all the methanol could be removed by flash distillation, 18 pounds per hour remained. Therefore 61 pounds of impurities are contained in 302 pounds of glycerol. Percent glycerol is calculated below:

$$\frac{302}{61 + 302} = 83\%$$

Flow rates of materials between plant equipment are given below. These are determined by Narum on a pound per hour basis. Amounts are for Plant 1. Multiply these numbers by 2.5, 7.5, and 10 to obtain flow volumes for Plants 2-5.

Position	Material Pounds	Gallons
Holding tanks to reactor (HR to R)	3036 sun oil	396
	558 CH_3OH	84.5
	10 NaOH	.6
	152 mono, diglycerides	.7
		482
Gravity Separator No. 1 to Wash Column (GS-1 to WC)	2946 methyl esters	
	59 methanol	
	6 glycerol	
	224 mono, di, triglycerides	
Gravity Separator No. 1 to Flash Distillation (GS-1 to FD)	302 glycerol	
	178 methanol	
	10 Na_2SO_4	
	35 Na^+	
Flash Distillation to Glycerol Storage (FD to ST-4)	302 glycerol	
	18 methanol	
	10 Na_2SO_4	
	35 Na^+	
Flash Distillation to Methanol Holding Tank (FD to HT-2)	160 methanol	
Wash Column Through Filter to Flash Vaporization (WC to F to FV)	98 water	
	2946 methyl esters	
	224 mono, di, triglycerides	
Wash Column to Distillation Column WC to DC)	220 water	
	6 glycerol	
	59 methanol	
Distillation Columns to Methanol Holding Tank (DC to HT-2)	55 methanol	
Wash Column to Sewage	220 water	
	6 glycerol	
	4 methanol	
Flash Vaporization to Gravity Separator No. 2 (FV to GS-2)	2946 methyl esters	
	224 mono, di, triglycerides	
	5 water	
Gravity Separator No. 2 to Methyl Ester Storage Tank (GS-2 to St-3)	2946 methyl esters	401.3
	72 triglycerides[a]	9.4
	5 water	.6
		411.3
Gravity Separator No. 2 to Reactor (GS-2 to R)	152 mono and diglycerides	

[a]Triglycerides or oil make up about 30 percent of the mono, di, and triglycerides mixture or 65 to 75 pounds.

APPENDIX D

APPENDIX D

Depreciation

APPENDIX TABLE D-1. ANNUAL DEPRECIATION FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Fixed Capital Investment	Assets, 15-Year Life[a]	Annual Depreciation	Buildings 40 Year Life	Annual Depreciation	Total Annual Depreciation[b]
	-dollars-					
1	2,202,500	1,679,500	111,970	166,500	4,160	116,130
2	2,974,100	2,313,700	154,200	236,800	5,900	160,100
3	4,089,900	3,164,600	211,000	322,200	8,100	219,100
4	4,878,500	3,812,700	254,200	394,100	9,900	264,100
5	5,519,100	4,337,900	289,200	453,800	11,300	300,500

[a]Equals the fixed capital investment less the land itself (see Appendix B), building, and the contingency factor.
[b]Includes annual depreciation of 15- and 40-year assets.

SOURCE: Tables 4 and 5.

APPENDIX E

APPENDIX E

Taxes

Taxes are based on estimated real property values.

APPENDIX TABLE E-1. REAL PROPERTY IN METHYL ESTER PLANTS, 1983

Property	Methyl Ester Plant Number				
	1[a]	2	3	4	5
	dollars				
Buildings	166,500	236,800	322,200	394,100	453,800
Land	165,000	165,000	247,500	247,500	247,500
Railroad Spur	12,500	12,500	12,500	12,500	12,500
Storage Tank (ST-1)	44,000	63,800	88,000	115,500	140,800
Storage Tank (ST-2)	30,000	43,000	58,000	70,000	80,000
Storage Tank (ST-3)	62,700	93,500	129,800	154,000	180,400
Storage Tank (ST-4)	50,300	89,300	128,500	168,400	198,000
Total Real Property	531,000	703,900	986,500	1,162,000	1,313,000

[a]Property tax on Plant 1 would be about $8,000. (531,000 ÷ 2 = 265,500; 10 percent X 265,500 = 26,550; 300 mills X 26,550 = $7,965).

APPENDIX F

APPENDIX F

Raw Material Costs

Prices for methanol (CH_3OH), sodium hydroxide ($NaOH$), and sulfuric acid (H_2SO_4) are from the Chemical Marketing Reporter (1983). Methanol at the Gulf costs \$.48 per gallon while transportation costs \$.43 per gallon from Louisiana to North Dakota for a delivered cost per gallon of \$.91. Sodium hydroxide cost between \$.61 and \$.86 per pound or an average of \$.74. This may be obtained cheaper in lots larger than 100-pound drums. Sulfuric acid ranged in price from \$55.80 to \$80.25 per ton, with an average price per pound at \$.034. Annual raw material costs are calculated below. Raw material amounts are from Appendix C.

$$\frac{343\ \text{lb. } Ch_3OH}{\text{hour}} \left| \frac{6700\ \text{hour}}{1\ \text{year}} \right| \frac{1\ \text{ft}^3}{.7914 \times 62.4\ \text{lb.}} \left| \frac{7.48\ \text{gal.}}{1\ \text{ft.}^3} \right| \frac{\$.91}{\text{gal.}} \Big| =$$

Plant 1	\$ 316,761	or	\$ 317,000
2	790,516	or	791,000
3	1,581,956	or	1,582,000
4	2,376,167	or	2,376,000
5	3,166,683	or	3,167,000

$$\frac{10\ \text{lb. } NaOH}{1\ \text{hour}} \left| \frac{6700\ \text{hour}}{1\ \text{year}} \right| \frac{\$.74}{\text{lb.}} \Big| =$$

Plant 1	\$ 49,580	or	\$ 50,000
2	123,950	or	124,000
3	247,900	or	248,000
4	371,850	or	372,000
5	495,800	or	896,000

$$\frac{6.86\ \text{lb. } H_2SO_4}{1\ \text{hour}} \left| \frac{6700\ \text{hour}}{1\ \text{year}} \right| \frac{\$.037}{\text{lbs.}} \Big| =$$

Plant 1	\$ 1,563	or	\$ 1,600
2	3,873	or	3,900
3	7,745	or	7,700
4	11,618	or	11,600
5	15,718	or	15,700

APPENDIX G

APPENDIX G

Operating Labor

Methyl ester plants have four major process steps. Employee hours per day for each processing step are given in Figure 5-8 in Peters and Timmerhaus. The graph gives employee hours when the tons of product per day are known. Appendix C gives pounds of fuel grade methyl esters and glycerol per hour. Tonnage per day for Plant 1 is 40 tons. Calculations for number of employees and their wages are given below:

$$\begin{array}{rl} 27 & \text{(employee hours/day/process step)} \\ \underline{\times\ 4} & \text{(process steps)} \\ 108 & \text{(hours of labor needed per day)} \end{array}$$

There are three shifts per day so 36 hours of labor are needed per eight-hour shift. Each employee works eight hours per day so five people are needed one each shift at one time. (There are five positions to be filled each shift.) Five people are needed for each position to cover three shifts per day, weekends, vacations, holidays, and sickness. Plant 1 employs 25 people. On each shift one of the five employees is skilled and the others are unskilled labor. Operating labor costs are given on the next page.

APPENDIX TABLE G-1. OPERATING LABOR COSTS FOR METHYL ESTER PLANTS, 279-DAY PROCESSING SEASON, NORTH DAKOTA, 1983

Plant Number	Product Quantity	Employee Labor	Employee Labor	Number of Employees	Skilled Labor	Unskilled Labor	Total Labor Cost[a]
	(tons/day)	(hours/day)	(hours/shift)	(employees)	(dol/shift)	(dol/shift)	(dol/year)
1	40	108	36	5	90	224	282,600
2	100	132	44	6	90	280	333,000
3	200	160	53	7	90	336	383,400
4	300	172	57	7	90	336	383,400
5	400	184	61	8	90	392	433,800

[a]For Plant 1 four unskilled employees per shift work eight hours per day for $7.00 per hour totaling $224. One skilled employee per shift costs $90.00 ($11.25 per hour times eight hours). Total annual labor bill for Plant 1 follows: ($90 + $224) X (3 shifts per day) X (279 days processing + 21 days clean-up and repair) = $282,600.

APPENDIX H

APPENDIX H

Utilities

Listed in this appendix are calculations and costs for utilities such as water, sewage disposal, fuel oil, steam requirements, and electricity.

Water is required mainly for cooling, steam production, and processing. The following tables show water usage for each purpose. Water charges are based on the rates given below.

$6.00 per month for one inch meter (Plants 1-4)
$9.00 per month for one and one-half inch meter (Plant 5)
$1.25 per 1000 gallons in excess of 2000 gallons but not exceeding 200,000 gallons
$1.10 per 1000 gallons in excess of 200,000 gallons but not exceeding 2,000,000 gallons

Cooling water is necessary for three condensers. Gallon per hour requirements are listed below. Water temperature is assumed to be 77°F.

Water is required for a phase separation in the wash column. Initially 318 pounds of water are used although 93 pounds are recycled, so actual water use per hour is 225 pounds in Plant 1, as shown in Column 1 in Table H-2.

Steam is required to heat the reactor, reboiler, and two heat exchangers. Steam temperature is 300° F saturated. Most water is recycled in the steam system, although steam leaks and blow-down require about 15 percent replacement per hour. Steam and water requirements are given in Table A-4.

Fuel oil use is a function of the steam needed. One pound of steam contains 910 BTU. One gallon of fuel oil contains 140,000 BTU.

Electricity costs $.027 per kilowatt-hour. A demand charge of $5.09 per kilowatt for eight winter months and $6.59 per kilowatt for four summer months averages $5.59 per kilowatt over the entire year. Electrical requirements and costs are given below.

There are 279 processing days (6,700 hours) and 86 days that need lighting and miscellaneous power but no motor power.

APPENDIX TABLE H-1. WATER REQUIREMENTS FOR COOLING FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Condenser 1[a]	Condenser 2[a]	Condenser 3[a]	Total Recirculated	Hourly Requirements[b]	Annual Water Requirements[c]
	(gal/hour)					(gal/year)
1	613	675	577	1,865	280	1,876,000
2	1,547	1,715	1,439	4,701	710	4,757,000
3	3,094	3,429	2,890	9,413	1,410	9,447,000
4	4,652	5,132	4,329	14,113	2,120	14,204,000
5	6,199	6,847	5,779	18,825	2,820	18,894,000

[a]Cooling water requirements from Appendix Table A-8. Divide pounds by 8.34 for gallons.
[b]Total used is 15 percent of the previous column.
[c]Annual requirement is the previous column (gallons per hour) multiplied by 6,700 hours operation per year.

APPENDIX TABLE H-2. PROCESS WATER REQUIREMENTS AND COST FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Process Water[a]	Process Water	Annual Water Requirements[b]
	(pounds/hour)	(gallons/hour)	(gallons)
1	225	27	181,000
2	562	67	449,000
3	1,125	135	904,000
4	1,688	202	1,353,000
5	2,250	270	1,809,000

[a]Obtained from Appendix C, flow rates between process equipment.
[b]Assumes 6,700 hours operation per year.

APPENDIX TABLE H-3. STEAM AND WATER REQUIREMENTS FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Reboiler	Heat Exchanger 1	Heat Exchanger 2	Reactor	Total Steam	Replacement Water[a]	Annual Water Requirements[b]
	- - - - - - - - -pounds of steam per hour-				- - - - - - - -	(pounds/hour)	-(gal/year)-
1	123	124	41	949	1,240	186	149,400
2	309	314	103	1,757	2,480	372	298,800
3	622	628	206	2,813	4,270	640	514,100
4	954	940	310	3,689	5,890	884	710,200
5	1,246	1,250	413	4,452	7,360	1,104	886,900

[a]Replacement water is 15 percent of previous column.
[b]Replacement water in pounds per hour is divided by 8.34 (one gallon of water equals 8.34 pounds) and multiplied by 6,700, the number of hours of operation per year.

APPENDIX TABLE H-4. TOTAL ANNUAL WATER REQUIREMENTS FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Cooling	Process	Steam	Total[a]	Cost[b]
	------------1000 gallons per year------------				(dollars/year)
1	1,876	181	149	2,427	3,000
2	4,757	449	299	6,056	7,100
3	9,447	904	514	11,952	13,500
4	14,204	1,353	710	17,894	20,100
5	18,894	1,809	887	23,749	26,600

[a]Total is 110 percent of the previous three column's sum to cover contingencies.
[b]Total is divided by 12 (for monthly requirements) and the water charges listed at the beginning of Appendix H are applied.

APPENDIX TABLE H-5. SEWAGE QUANTITIES AND DISPOSAL COSTS, NORTH DAKOTA, 1983

Plant Number	Blow-down, Cooling[a]	Blow-down, Steam[a]	Process Sewage[b]	Total Sewage[c]	Annual Cost[d]
	---------------1000 gallons per year----------------				(dollars)
1	1,257	100.1	187.6	1,699	600
2	3,187	200.2	462.3	4,234	1,600
3	6,329	344.4	924.6	8,358	3,200
4	9,517	475.8	1,386.9	12,518	4,800
5	12,659	594.2	1,849.2	16,613	6,300

[a]Two-thirds of the replacement water from Appendix Tables H-1 and H-3 are assumed to be used for blow-down and must be disposed of. The other third is evaporated and lost through leaks in the system.
[b]Determined from Appendix C, from flow rates between processes. Divide pounds of waste water per hour by 8.34 pounds per gallon and multiply by 6,700 hours operation per year.
[c]Calculated as 110 percent of the summation of the previous three columns.
[d]Disposal cost is $.38 per 1000 gallons.

APPENDIX TABLE H-6. FUEL OIL COSTS FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Steam Requirements	BTU Requirements[a]	Fuel Oil Requirements[b]	Cost[c]
	(pounds/hour)	(BTU/hour)	(gal/year)	(dollars)
1	1,240	1,241,200	60,400	63,400
2	2,480	2,482,500	119,800	125,800
3	4,270	4,274,300	205,600	215,800
4	5,890	5,895,900	283,200	297,300
5	7,360	7,367,400	353,600	371,200

[a]Includes 10 percent line loss.
[b]Includes 50 gallons of fuel oil per week for 20 weeks for office heating and 6,700 hours of plant operation per year.
[c]Assumes fuel oil price is $1.05 per gallon.

APPENDIX TABLE H-7. ELECTRICAL REQUIREMENTS AND COSTS FOR METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Motor Requirements[a]	Lighting and Miscellaneous	Total Electricity[b]	Total Cost[c]
	(kwh)	(kwh)	(kwh)	(dollars)
1	6	10	20	5,500
2	8	11	24	6,600
3	11	13	30	8,200
4	14	14	35	9,500
5	19	15	42	11,300

[a]Summation of the kilowatts listed in Appendix A.
[b]Summation of columns 1 and 2 and increased by 25 percent to allow for line losses and contingencies.
[c]Costs are determined below for Plant 1.

(6,700 hours) (20 kwh) ($.027/kwh)	=	$3,618
(86 days) (24 hours/day) (10 kwh) ($.027/kwh)	=	557
($5.59/kwh/month) (20 kwh) (12 month)	=	1,342
		$5,517 or $5,500

APPENDIX I

APPENDIX I

Workmen's Compensation, Genral Liability, and FICA Taxes

APPENDIX TABLE I-1. FICA TAXES, GENERAL LIABILITY, AND WORKMEN'S COMPENSATION FOR OPERATING LABOR IN METHYL ESTER PLANTS, NORTH DAKOTA, 1983

Plant Number	Number of Employees	Operating Labor Cost	Workmen's Compensation[a]	General Liability[b]	FICA Taxes[c]	Total Costs
			----dollars----			
1	25	282,600	6,180	8,480	18,930	33,600
2	30	333,000	7,410	9,990	22,310	39,700
3	35	383,400	8,640	11,500	25,690	45,800
4	35	383,400	8,640	11,500	25,690	45,800
5	40	433,800	9,880	13,010	29,060	52,000

[a]Workmen's compensation is 6.87 percent on the first $3,600 of wages or $247 per employee.
[b]General liability is 3 percent of operating labor costs.
[c]FICA taxes are 6.7 percent of operating labor costs.

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