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A process model to estimate biodiesel production costs

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Abstract

'Biodiesel' is the name given to a renewable diesel fuel that is produced from fats and oils. It consists of the simple alkyl esters of fatty acids, most typically the methyl esters. We have developed a computer model to estimate the capital and operating costs of a moderately-sized industrial biodiesel production facility. The major process operations in the plant were continuous-process vegetable oil transesterification, and ester and glycerol recovery. The model was designed using contemporary process simulation software, and current reagent, equipment and supply costs, following current production practices. Crude, degummed soybean oil was specified as the feedstock. Annual production capacity of the plant was set at 37,854,118 l (10×10^6 gal). Facility construction costs were calculated to be US$11.3 million. The largest contributors to the equipment cost, accounting for nearly one third of expenditures, were storage tanks to contain a 25 day capacity of feedstock and product. At a value of US$0.52/kg ($0.236/lb) for feedstock soybean oil, a biodiesel production cost of US$0.53/l ($2.00/gal) was predicted. The single greatest contributor to this value was the cost of the oil feedstock, which accounted for 88% of total estimated production costs. An analysis of the dependence of production costs on the cost of the feedstock indicated a direct linear relationship between the two, with a change of US$0.020/l ($0.075/gal) in product cost per US$0.022/kg ($0.01/lb) change in oil cost. Process economics included the recovery of coproduct glycerol generated during biodiesel production, and its sale into the commercial glycerol market as an 80% w/w aqueous solution, which reduced production costs by ≈6%. The production cost of biodiesel was found to vary inversely and linearly with variations in the market value of glycerol, increasing by US$0.0022/l ($0.0085/gal) for every US$0.022/kg ($0.01/lb) reduction in glycerol value. The model is flexible in that it can be modified to calculate the effects on capital and production costs of changes in feedstock cost, changes in the type of feedstock employed, changes in the value of the glycerol coproduct, and changes in process chemistry and technology.
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1. Introduction

Over the past three decades the desires to establish national energy self-reliance and to develop alternatives to finite fossil fuel resources have resulted in the development of fuel technologies that are based on the use of renewable agriculture-based materials as feedstocks. In the case of renewable fuels for compression ignition (diesel) engines, the majority of efforts to date have focused on 'biodiesel', which consists of the simple alkyl esters of the fatty acids found in agricultural acylglycerol-based fats and oils. Biodiesel has been shown to give engine performance generally comparable to that of conventional diesel fuel while reducing engine emissions of particulates, hydrocarbons and carbon monoxide (Graboski and McCormick, 1998). Information on the production, quality specifications, performance and

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emissions properties of biodiesel has accumulated steadily over the past three decades. In addition to extensive laboratory testing, millions of miles have been traveled by test and demonstration vehicles running on biodiesel. Announcements of its adoption by municipalities, school districts, businesses, governmental agencies, entrepreneurs, and show business entertainers appear on a regular basis. Thus, biodiesel technology is making the transition from a research endeavor to a worldwide commercial enterprise.

In support of this increasing consumption there have been substantial increases in biodiesel production in recent years, a trend that is expected to continue. Europe and the US are the leading biodiesel producers at this time, with European production in 2003 estimated at 1.7×10^9 l (450 million gal) (European Biodiesel Board, 2004), and US production in 2004 estimated at 114 million l (30 million gal) (McCoy, 2005). This growth is the result of the construction of new production plants and the expansion of existing ones.

Biodiesel can be produced from any material that contains fatty acids, be they linked to other molecules or present as free fatty acids. Thus various vegetable fats and oils, animal fats, waste greases, and edible oil processing wastes can be used as feedstocks for biodiesel production. The choice of feedstock is based on such variables as local availability, cost, government support and performance as a fuel.

A variety of different types of reaction configurations can be employed in biodiesel synthesis, and may involve inorganic acid, inorganic base or enzymatic catalysis, biphasic or monophasic reaction systems, and ambient or elevated pressures and temperatures. The choice of which chemical technology to employ in a production plant depends on the feedstock and its quality. This choice of conversion technology will in turn influence costs. The scale of the operation will also bear upon both construction and operation costs. In any case, individuals considering the construction or modification of a biodiesel production facility need a means of estimating the cost of biodiesel production based on the components of the operation and its construction costs (‘capital’ cost).

Some reports to date have estimated these values. Bender (1999) reviewed 12 studies, involving several feedstocks and operational scales, of the economic feasibility of biodiesel production. Calculated production costs (which included the cost of the feedstock and of its conversion to biodiesel) ranged from US$0.30/l ($1.14/gal) for fuel produced from soybeans to US$0.69/l ($2.62/gal) when rapeseed was the feedstock. These estimates were for operations where the biodiesel production facility was integrated into an oilseed crushing and processing plant, and thus employed the intact oilseeds as the starting material in their calculations and factored the market value of the meal coproduct into the cost of the biodiesel.

When situations do not allow integration with an oilseed processing facility, it may be necessary for a biodiesel operation to obtain its oil feedstock in the marketplace. Using an estimated process cost, exclusive of feedstock cost, of US$0.158/l ($0.60/gal) for biodiesel production, and estimating a feedstock cost of US$0.539/l ($2.04/gal) for refined soy oil, an overall cost of US$0.70/l ($2.64/gal) for the production of soy-based biodiesel was estimated (American Biofuels Association, 1994). Details regarding the chemical processes or the production facility used to draft this estimate were not provided. Canakci and Van Gerpen (2001) reported a production cost, exclusive of feedstock expense, of US$0.42/l ($1.58/gal) for biodiesel produced from refined, bleached and deodorized soy oil in a small pilot scale plant (190/l, batch process). These authors did not include profits from the sale of coproduct glycerol, and did not estimate or include capital costs for their operation. Graboski and McCormick (1998) summarized a model for the production of 37.8 million liters (10 million gal) of biodiesel annually, concluding that the joint cost of feedstock and of its conversion to biodiesel would be US$0.57/l ($2.15/gal). A high pressure transesterification process for the production of fatty acid esters from vegetable oils has been described in general terms, although without an economic analysis (Kreutzer, 1984). Zhang et al. (2003) recently presented a process design and technological assessment of biodiesel production from both virgin vegetable oil and waste cooking oil at near ambient pressures, but the report did not include an economic analysis of process costs.

Note that in all the cases cited above, feedstock cost comprises a very substantial portion of overall biodiesel cost. This highlights the need for the development of technologies allowing the use of lower value feedstocks.

These reports estimated the cost of biodiesel production based on assumptions, made by their authors, regarding production volume, feedstock, and chemical technology. There could be great value, however, in having a flexible model that allows the user to make changes in these variables and examine the impact of such changes on product cost. Since all studies to date have shown relatively high costs for biodiesel production, a flexible model could aid in the comparison of alternate production routes for their abilities to achieve a very desirable reduction in production costs. It could also highlight the costliest operations in a proposed production scheme, allowing the focus of cost reduction efforts where they might have the greatest impact. Such a model could thus assist in determining the overall economic feasibility of a proposed operation, and guide choices regarding feedstock, chemical process, plant capacity and design. We have designed such a model, describe here its features, and demonstrate its usefulness in estimating capital and production costs for the synthesis of biodiesel from soy oil.

2. Components of the model biodiesel production facility

2.1. General features of the design

The approach involved the design of a model industrial operation for biodiesel production, the assembly of data for the purchase and assembly of its components, and the estimation of its operating expenses, resulting in an estimate of biodiesel production costs. Information on biodiesel production was collected from various technical sources, including engineering firms that provide biodiesel processing expertise, equipment suppliers, and researchers and practitioners experienced with this topic. In the choice of construction materials, the most economical of available options was chosen. Thus, for example, storage tanks were specified to be constructed of carbon steel, while stainless steels were specified in other applications as appropriate.

ASPEN PLUS (2001) process simulation software was employed in the development of a process model for the production of 37,854,118 l (10×10^6 gal) per year of soy-based biodiesel meeting the specifications of the American Society for Testing and Materials (Anonymous, 2002). This is an intermediate size for a contemporary biodiesel facility. The plant was designed to operate three shifts per day, 47 weeks per year.

The ASPEN PLUS (2001) process simulation software is a sophisticated chemical engineering computer tool that is used in designing processes such as that for biodiesel production. Specific information on the calculations and databases this program utilizes may be obtained by contacting Aspen Technologies (Cambridge, Mass, USA).

The economic model was developed by methods generally used to prepare conceptual cost estimates from flowsheets, as recommended by the Association for the Advancement of Cost Engineering (1990).

In the design of this model, material and performance parameters of each piece of equipment involved in the process were specified. Data from this program were exported to a Microsoft Excel 2000 spreadsheet (Microsoft Corporation, 1999), where year 2003 capital costs for each piece of equipment, and operational expenses, were added. Equipment costs were based on Richardson Process Plant Construction Estimating Standards (2001), Chemcost Capital Cost and Profitability Analysis Software (1990), information from equipment suppliers, and historical equipment costs from our own files. These values were then used to calculate total installed costs through the use of Installation Factors (Hand, 1992), which convert the supply costs of equipment to total installed costs. The total calculated installed cost also includes the equipment installation costs and the cost of all required piping, electrical and other materials for the functioning unit. Table 1 lists the values chosen for various expendables, utilities, labor and other expenses.

Table 1
Operating cost and revenue values employed in this study

Item	Cost (US$)
Raw materials, utilities	
Soy oil (crude, degummed)	0.52/kg (0.236/lb)
Methanol	0.286/kg (0.130/lb)
Sodium methylate, 25% (w/w)	0.98/kg (0.445/lb)
Hydrochloric acid	0.132/kg (0.06/lb)
Sodium hydroxide	0.617/kg (0.280/lb)
Electricity	0.05/kW h
Natural gas	4.80/thousand cubic feet
Wastewater treatment	50,000/year
Process water	0.353/MT (0.32/thousand lb)
Additional operating costs	
Plant operating labor	2 Persons/shift
Plant operators base rate	US$12.50/h.
Maintenance labor	US$45,000/yr
Supervision	US$126,000/year
Labor fringe benefits	40% of total labor costs
Operating supplies	20% of operating labor
Maintenance supplies	1% of capital costs, annually
General and administrative	0.50% of capital costs, annually
Taxes-property	0.1% of capital costs, annually
Insurance	0.5% of capital costs, annually

A depreciable life of 10 years was assumed. The escalation rate was set at 1% annually. Economic factors not accounted for were: Internal rate of return, economic life, corporate tax rate, salvage value, debt fraction, construction interest rate, and long term interest rate. Working capital, environmental control equipment, marketing and distribution expenses, the cost of capital, and the existence of governmental credits or subsidies were excluded from these calculations. The total capital cost for the facility will be impacted by the cost of working capital, the interest during construction, and the cost of pollution control equipment. The working capital cost may be significant, and could approach one and three quarter million dollars if the total expenses of one month of operation were to be covered. Interest costs could add 3–5% to the capital costs. The cost of pollution control equipment for the gas fired boiler should not be excessive.

The resulting model is intended to be generic, and representative of contemporary industry practices. It is not meant to represent the actual biodiesel design offered by any single technology provider.

The design was based on the use as feedstock of crude, degummed soybean oil with a phospholipid content less than 50 ppm and a negligible free fatty acid content. Oils with higher phospholipid contents are less desirable since phosphorus reduces the efficacy of the alkaline catalysts used in the transesterification process by which triacylglycerol oils are converted to biodiesel (Freedman et al., 1984).

The facility contained three processing sections (Fig. 1): (1) a transesterification unit where the vegetable oil

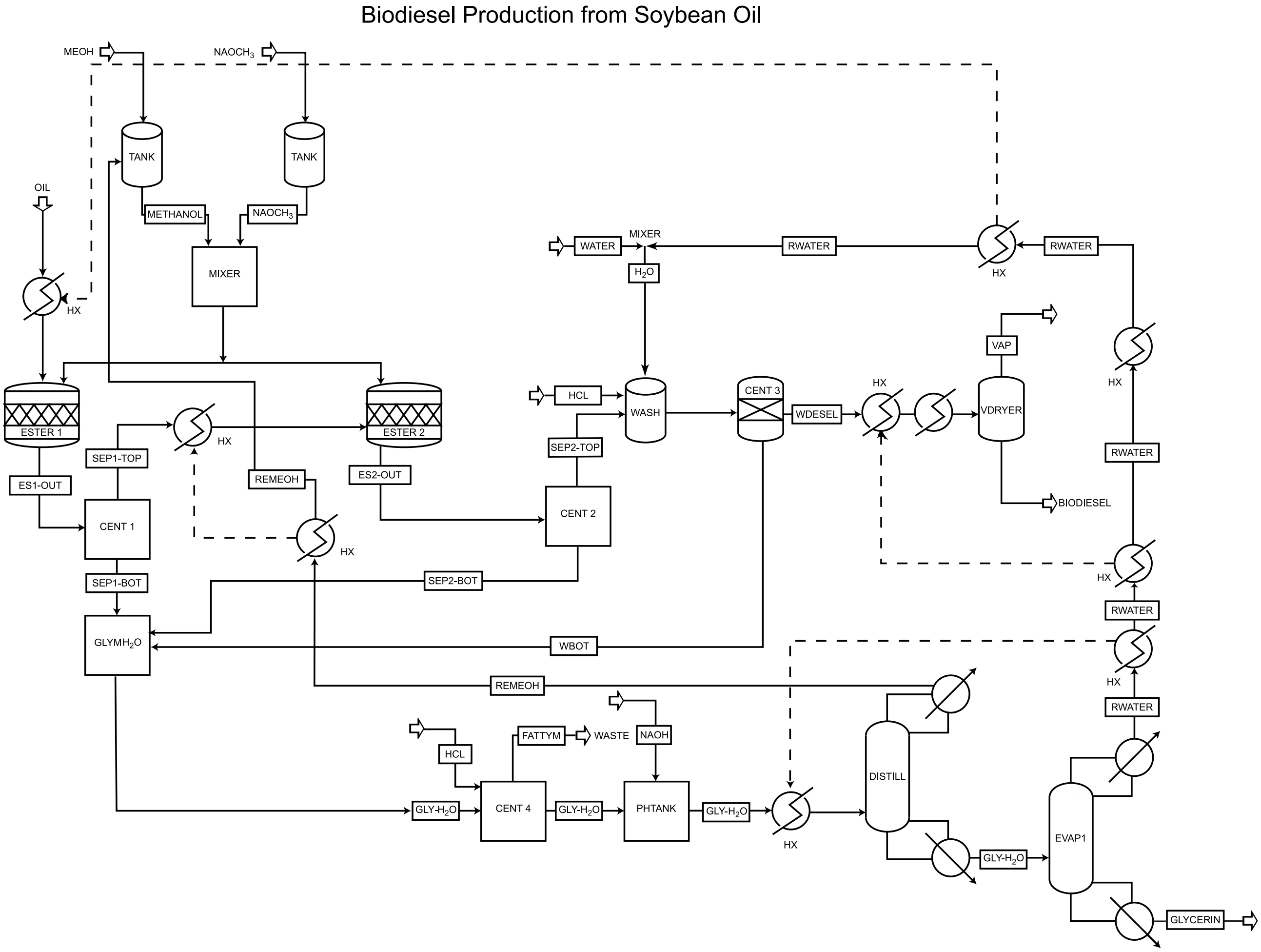

Fig. 1. Flowsheet for the modeled production of biodiesel from soybean oil. CENT: centrifuge; ES1-, 2-OUT: posttransesterification ester mixture exiting reactors 1 and 2, respectively; FATTYM: free fatty acid waste stream; GLYH$_2$O: glycerol–water stream, GLYMH$_2$O: crude glycerol accumulation tank; HX: heat exchanger; dashed lines indicate heat transfer; MEOH: methanol; NAOCH$_3$: sodium methoxide; PHTANK: pH adjustment tank, REMEOH: recovered methanol; RWATER: recovered water; SEP1-, 2-BOT: heavy (glycerol-rich) layer exiting centrifugal separators 1 and 2, respectively; SEP1-, 2-TOP: light layer (containing ester product) exiting centrifugal separators 1 and 2, respectively; VAP: water vapor; VDRYER: vacuum dryer; WBOT: aqueous stream recovered after a water wash of crude biodiesel, WDESEL: biodiesel–water mixture. Solid lines indicate the flow of liquid streams, dashed lines the flow of heat.

was subjected to chemical transesterification to produce fatty acid methyl esters (biodiesel) and coproduct glycerol, (2) a biodiesel purification section where the methyl esters were refined to meet biodiesel specifications, and (3) a glycerol recovery section.

2.2. Transesterification

Transesterification of soybean oil triacylglycerols with methanol, catalyzed by sodium methoxide, was modeled as a continuous reaction conducted in steam jacketed, stirred tank reactors at 60 °C. Alkali metal hydroxides or alkoxides can be used as transesterification catalysts. Hydroxides are cheaper than alkoxides, but must be used in higher concentrations to achieve good reaction (Freedman et al., 1984). Sodium methoxide was chosen as the catalyst for this work because it is employed by a substantial proportion of industrial biodiesel facilities. Methyl, rather than ethyl, ester production was modeled because methyl esters are the predominant product of commerce, because methanol is considerably cheaper than ethanol, and due to the greater ease of downstream recovery of unreacted alcohol.

Two sequential transesterification reactions were modeled (Fig. 1, ESTERs 1 and 2). The first reactor was continuously fed with soy oil and a 1.78% (w/w) solution of sodium methoxide in commercial grade methanol at rates of 4247 (9363) and 670 (1477) kg/h (lb/h), respectively. Product was removed from the reactor at a rate equal to the rate of charging with reactants and catalyst in such a manner as to give a residence time of 1 h in the reactor.

Glycerol, a coproduct of acylglycerol transesterification, separates from the oil phase as the reaction proceeds. Following the first transesterification reaction, continuous centrifugation (Fig. 1, CENT1) is employed to remove the glycerol-rich coproduct phase (Fig. 1, SEP1-BOT), which is sent to the glycerol recovery unit (Fig. 1, GLYMH_2O). The methyl ester stream (Fig. 1, SEP1-TOP), which also contains unreacted methanol and soy oil, and catalyst, is fed into a second steam jacketed, stirred tank reactor (Fig. 1, ESTER 2) at a rate of 4439 kg/h, accompanied by the addition of sodium methoxide, 1.78% (w/w) in methanol, at a rate of 75 kg/h. Again, a continuous stirred reaction is conducted at 60 °C, with the crude ester product being removed from the reactor at a rate equal to that of reagent addition and in such fashion as to produce a reactor residence time of 1 h.

A transesterification efficiency of 90%, well within the range of reported values (Freedman et al., 1984; Noureddini and Zhu, 1997), was assumed for each of these two transesterification reactions, for an overall efficiency of 99%.

The mixture of methyl esters, glycerol, unreacted substrates and catalyst (Fig. 1, ES2-OUT) exiting the second reactor was fed to a continuous centrifuge (Fig. 1, CENT2). Typical municipal quality water is used for this, and all subsequent, washes. The glycerol-rich aqueous stream from this operation (Fig. 1, SEP2-BOT) is sent to the glycerol recovery section (Fig. 1, GLYM-H_2O) while the impure methyl ester product (Fig. 1, SEP2-TOP) goes to the biodiesel refining section for purification and dehydration (Fig. 1, WASH).

2.3. Methyl ester purification

The crude methyl ester stream (Fig. 1, SEP2-TOP) is washed with water at pH 4.5 to neutralize the catalyst and convert any soaps to free fatty acids, reducing their emulsifying tendencies (Fig. 1, WASH). Centrifugation is then employed (Fig. 1, CENT3) to separate the biodiesel from the aqueous phase. The latter (Fig. 1, WBOT) is cycled to the glycerol recovery section.

The crude, washed methyl ester product (Fig. 1, WDESEL) may contain several percent of water. This must be lowered to a maximum of 0.050% (v/v) to meet United States biodiesel specifications (Anonymous, 2002). Water is removed in a vacuum dryer (Fig. 1, VDRYER) from an initial value of 2.4% to a final content of 0.045%.

2.4. Glycerol recovery and purification

The glycerol liberated during transesterification has substantial commercial value if purified to USP grade. However, this process is expensive. Small and moderately sized operations, including those of the scale modeled here, often find it most cost effective to partially purify the glycerol, removing methanol, fatty acids and most of the water, and selling the product (80% glycerol by mass) to industrial glycerol refiners. We included the production and sale of such a partially pure glycerol coproduct in the model, assigning it a value of US$0.33/kg ($0.15/lb) consistent with recent prices for this material.

In the model, the impure, dilute, aqueous glycerol streams exiting the transesterification reactors and the biodiesel wash process are pooled (Fig. 1, GLYMH_2O). The mixture is then treated with hydrochloric acid to convert contaminating soaps to free acids, allowing removal by centrifugation (Fig. 1, CENT4). This fatty acid waste is presumed to be destined for disposal as sewage in our model, although in some contemporary industrial settings it has market value. The glycerol stream is then neutralized with caustic soda (Fig. 1, PHTANK). Methanol is recovered from this stream by distillation (Fig. 1, DISTILL) and is recycled into the transesterification operation (Fig. 1, REMEOH). Finally, the diluted glycerol stream is distilled to reduce its water content (Fig. 1, EVAP1). At this point the glycerol concentration is 80% (w/w), suitable for sale into the crude glycerol market.

Water recovered during drying of the ester and glycerol fractions is recycled into wash operations (Fig. 1, RWATER). The model includes maximum recovery of the heat present in condensates, transferring it via heat exchangers to the material feedstreams entering reactors.

Since environmental pollution regulations vary from location to location, no precise calculation of waste stream treatment costs was attempted. However, in the annual operating budget, US$50,000 was allocated for waste stream disposal charges.

3. Analysis and discussion

Based on contemporary production processes and using current best values for reagent, equipment, and supply costs, a computer model of a biodiesel production facility was designed, and employed to estimate the capital and production costs for the synthesis of fuel grade biodiesel from soybean oil. This model is relatively preliminary in regard to the level of its detail. It is not meant to replace the thorough engineering analysis that is required in the final design and construction of such a plant, but rather is meant for use as a tool in estimating capital and operating costs. The model is flexible, and is meant for use in assessing the effects on estimated biodiesel production costs of changes in feedstock, in feedstock and glycerol prices, in chemical or process technology employed, or in equipment specified for the facility.

Based on the process flow diagram shown in Fig. 1, capital and production costs were calculated. Capital costs are summarized in Table 2 (Details of the facility specifications are available from the authors). The estimated total capital cost was approximately US$11.3 million. One third of this was for actual hardware, and two thirds was based on our assumption of a construction cost roughly double the equipment costs. Of the equipment costs, nearly one third is for feedstock and product storage tanks. These were modeled at a 25 day working supply capacity. Substantial savings would accrue from reducing storage capacity, as in the case of colocating a facility at an oil production site, arranging for timely removal of product by rail, or accepting smaller inventory holding capabilities.

Table 2
Capital costs for the construction of a 37,854,118 l (10×10^6 gal)/year soy oil-based biodiesel facility

Item	Cost (US$, thousands)
Storage facilities	
Oil storage tank	506
Biodiesel storage tank	447
Crude glycerol storage tank	22
Loading/unloading stations	50
Pumps to/from storage (5)	22
Subtotal storage facilities	1047
Process equipment	
Methanol storage tank	24
Sodium methoxide tank	25
Methanol/catalyst mixer	7
Reactor #1 preheater	3
Reactor #1	70
Glycerol biodiesel separator #1	311
Reactor #2 preheater	9
Reactor #2	61
Glycerol biodiesel separator #2	315
Biodiesel/HCl mixer	7
Biodiesel wash tank	35
Biodiesel wash water separator	328
Biodiesel final water removal preheater	9
Biodiesel final water removal heater	2
Biodiesel final water removal flash tank	15
Biodiesel final water removal vacuum system	75
Glycerol/methanol tank	6
Methanol distillation tower preheater	4
Methanol distillation tower	95
Distillation reboiler	5
Distillation condensor	13
Glycerol/fatty acid separator	174
Fatty acid storage tank	10
NaOH mix feeder	5
Glycerol/NaOH mix tank	6
Glycerol distillation tower	16
Glycerol distillation reboiler	26
Glycerol distillation condenser	2
Glycerol distillation postcondenser	13
Pumps (12)	62
Additional process equipment	433
Subtotal processing	2166
Utility equipment	
Cooling tower system	174
Steam generation system	104
Instrument air system	25
Electrical distribution system	100
Subtotal utility equipment	403
Total equipment cost	3616
Other costs	
Installation, @ 200% of equipment costs	7232
Rail siding and miscellaneous improvements	500
Total other costs	7732
Total costs	11,348

The projected annual operating costs for the modeled biodiesel production facility are shown in Table 3. This analysis calculates a final biodiesel production cost of US$0.53/l ($2.00/gal). Raw materials costs constitute the greatest component of overall production costs, and of these the cost of the soy oil feedstock is the biggest contributing factor, itself constituting 88% of the overall production cost. These values are consistent with the results of other analyses of the costs of biodiesel production from refined soy oil (American Biofuels Association & Information Resources Inc., 1994; Bender, 1999; Graboski and McCormick, 1998). In the US, bulk petroleum diesel fuel prices during 2003 were generally in the range US$0.20–0.25/l ($0.76–0.95/gal), considerably lower than the cost of biodiesel production estimated here. In fact, the calculated biodiesel production cost exceeds even recent US retail prices of US$0.37–0.48/l (1.40–1.80/gal) or more. This substantial price differential, and the large contribution of feedstock cost to the cost of biodiesel, highlight the potential value of low cost alternatives to virgin vegetable oils in improving the economic viability of biodiesel.

Crude, degummed soybean oil, for use as the feedstock for biodiesel production, was assigned a cost of US$0.052/kg ($0.236/lb), which is in line with recent trends, though as much as 25% below very recent prices. Using the process model developed here, we calculated the impact of fluctuations in the cost of the oil feedstock on the predicted price of biodiesel production (Fig. 2). Product cost is predicted to vary linearly with soy oil cost, with each change of US$0.022/kg ($0.01/lb) in feedstock costs causing a roughly US$0.020/l ($0.075/gal) increase in the production cost of biodiesel. This response is as one would expect, given the approximately 1:1 ratio between feedstock mass input and biodiesel mass output, and a soy oil density of approximately 7.8 lb/gal. Note that Fig. 2 cannot be used to predict the cost of biodiesel made from feedstocks other than crude degummed triacylglycerols. Other feedstocks generally have free fatty acid levels appreciably higher than those in virgin vegetable oils, and must therefore be subjected to more involved and expensive processing technologies for conversion to biodiesel. The model developed here does not represent these processes, and thus cannot be used to estimate capital or production costs.

Table 3
Annual and unit costs for the annual production of 37,854,118 l (10×10^6 gal) of biodiesel from soybean oil

Description	Annual use (thousands)	Annual cost (US$/year, thousands)	Unit cost (US$)	
			(/gal)	(/l)
Raw materials				
Soy oil—degummed	74,152 lb	17,507		
Methanol	7422 lb	966		
Sodium methoxide	927 lb	412		
Hydrochloric acid	529 lb	32		
Sodium hydroxide	369 lb	103		
Water	2478 lb	0.4		
Subtotal raw materials		19,022	1.89	0.50
Utilities				
Natural gas	66.9.8 cu. ft.	321		
Wastewater treatment		50		
Electricity	1008 kW	50		
Subtotal utilities		406	0.042	0.011
Labor				
Operating		198		
Maintenance		45		
Supervisory		126		
Fringe benefits		148		
Subtotal labor		517	0.051	0.013
Supplies				
Operating supplies		40		
Maintenance supplies		113		
Subtotal supplies		153	0.015	0.004
General works				
General and administration		57		
Property taxes		11		
Property insurance		56		
Subtotal general works		125	0.012	0.003
Depreciation				
@10% capital cost/year		1130		
Subtotal depreciation		1130	0.113	0.03
Subtotal operating costs		21,329	2.123	0.561
Coproduct credit				
80% glycerol		1288	0.128	0.034
Gross operating costs		20,041	1.995	0.527

The glycerol coproduct generated during biodiesel production from a triacylglycerol feedstock was assigned a market value of US$0.33/kg ($0.15/lb) in this model, representative of its recent value when sold as a crude 80% aqueous solution. Income from the sale of this material resulted in an estimated 6% reduction in production costs (Table 3). As biodiesel production volumes increase in the future it is expected that the concomitant increase in glycerol supplies will reduce its market value. The impact of changes in the glycerol credit price on the production cost of biodiesel also was examined (Fig. 3). Decreases in the value of glycerol are linearly correlated with an increase in biodiesel production costs, with each US$0.01 reduction in glycerol value causing an approximately $0.008 rise in production cost. Since the amount of glycerol produced from a fixed amount of biodiesel feedstock, as well as the cost of glycerol production, purification, storage and etc. are constant irrespective of its selling price, the market value of glycerol would be expected to impact the net biodiesel production price solely in the context of a financial return at sale. As glycerol market value increases, a comparable increasing amount will be subtracted from the biodiesel production cost, with no increase in the cost

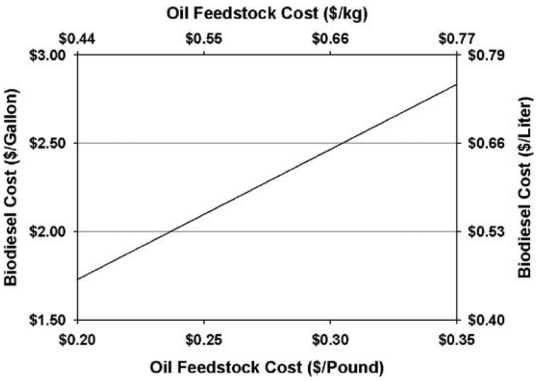

Fig. 2. The impact of feedstock prices on the predicted unit cost of producing biodiesel from crude degummed soybean oil, based on a process model plant producing 37.8 million l (10 million gal) annually, and with the crude glycerol coproduct assigned a value of $0.15/lb ($0.33/kg).

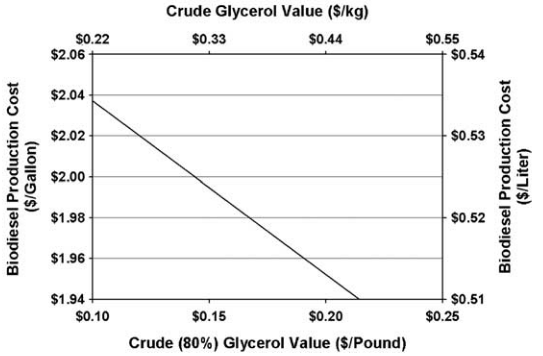

Fig. 3. Impact of the market value of 80% (w/w) glycerol on the unit cost of biodiesel production, as predicted by a process model for a 37.8 million l (10 million gal)/year facility, and with the soy oil feedstock assigned a value of $0.236/lb ($0.520/kg).

of biodiesel production. Thus, one would expect a linear relationship between glycerol market price and net biodiesel production cost, as is observed (Fig. 3).

This model is meant as a research and planning tool. It is flexible in that elements of the scale, process or physical plant can be modified by the user to estimate the effects of changes in these parameters on capital and production costs. Also, it serves as the basis for future work, presently underway here, to estimate the cost of production of biodiesel from other feedstocks. The model is available at no charge from the corresponding author in either the Aspen version or after conversion to SuperPro Designer v. 5.5 software (Intelligen Inc., Scotch Plains, NJ 07076).

3.1. Disclaimer

The spreadsheet model described here was developed to be used for research only. The authors and the Agricultural Research Service of the US Department of Agriculture do not accept responsibility for the accuracy of this program or decisions taken based on the model results. For specific applications of this spreadsheet, users should contact the authors for more detailed information, and information regarding the limitations and scope of the model.

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