Special Article

Energetics and Economics of Producing Biodiesel From Beef Tallow Look Positive

by

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Abstract: This study investigates the energetic and economic feasibility of converting beef tallow to biodiesel. An energy-profit ratio was used to measure whether tallow-based biodiesel has a net energy gain. The ratio ranged from 0.48 to 7.02, depending on the starting point of the analysis (animal growth, rendering, or transesterification) and the type of transesterification process used (batch or continuous flow). The ratio was less than 1 only when energy accounted for in the growth and maintenance of beef cattle was allocated to marketable products based on the mass of tallow in the animal. The cost of producing tallow-based biodiesel ranged from 92 cents to $1.67 per gallon, depending on the price of the tallow feedstock, the price received for the glycerine coproduct, and the type and size of the transesterification unit. With diesel prices averaging 71.2 cents during the last couple of years, biodiesel must find a market niche to compete, possibly as blends with petroleum-based diesel to meet Clean Air Act requirements.

Keywords: Biodiesel, tallow, diesel fuel, energetics, economics.

Biodiesel fuel is made by combining vegetable oils or animal fats with an alcohol, such as methanol or ethanol, and a catalyst in a process called transesterification. Production of biodiesel has the potential to partially ease U.S. dependence on fossil fuels, lessen the trade deficit associated with imported petroleum, and alleviate some of the environmental concerns affiliated with petroleum combustion.

Since 1982, domestic oil production has decreased at an average annual rate of 2 percent. During the last 12 years, petroleum imports have risen at an annual rate of 5.2 percent, resulting in a $50-billion-per-year negative petroleum trade balance. In addition, air pollution from fossil fuel combustion has come under much greater regulation since enactment of the Clean Air Act Amendments of 1990. For example, the U.S. Environmental Protection Agency's (EPA) Retrofit Rebuild Program requires urban transit fleets in heavily populated areas to retrofit engines or use alternative fuels to meet 1993 emission standards for particulate matter, carbon monoxide, nitrogen oxides, and other air pollutants (see the fats and oils section for more information).

Users of diesel fuel, such as urban transit agencies, view biodiesel as a potential option for meeting EPA's standards for urban buses manufactured in 1993 and earlier. Some industry experts believe a blend of diesel and biodiesel may be the least expensive way to meet the new air quality standards. Comparisons between biodiesel and petroleum-based diesel have shown biodiesel to be effective in reducing exhaust emissions of carbon monoxide, hydrocarbons, particulate matter, and sulfur. It may be less costly to purchase slightly more expensive biodiesel/diesel blends than to retrofit or purchase engines that burn other types of fuel, such as compressed natural gas or methanol. In addition, biodiesel can be used in existing handling facilities, unlike some other alternative fuels.

Diesel fuel accounts for over 20 percent of the transportation energy used in this country and has experienced the second largest growth rate among fuel types since 1982. On-highway diesel fuel consumption is about 21 billion gallons a year, or about 1.75 billion gallons a month (1).

Tallow Is a Potential Biodiesel Feedstock

The current tallow market favors biodiesel commercialization for two reasons. First, dietary preferences are changing toward leaner meats and less saturated fat, which has put downward pressure on tallow prices. Second, tallow is cheaper than other potential biodiesel feedstocks, such as soybean and sunflower oils (figure A-1).

The majority of tallow in the United States is generated by the meat packing, poultry, and rendering industries. Census Bureau statistics show an average of 1.328 billion pounds of edible, and 3.812 billion pounds of inedible, tallow produced between 1985 and 1991. The average quantity of tallow generated per head of cattle slaughtered is estimated to range from 120 to 148 pounds. The nine largest cattle slaughtering states--Kansas, Nebraska, Texas, Iowa, Colorado, Illinois, Wisconsin, California, and Minnesota--produce approximately 80 percent of the tallow in the United States (table A-1).

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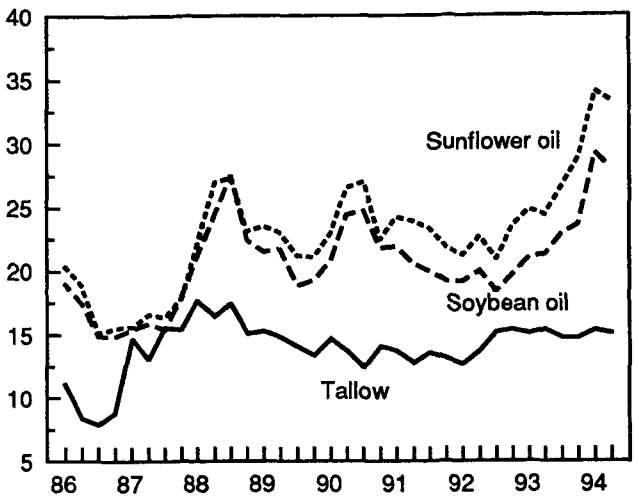
Figure A-1

Quarterly Average Price for Inedible Tallow, Soybean Oil, and Sunflower Oil 1/



1/ Tallow-Chicago, Soybean oil-Decatur, and Sunflower oil-Minneapolis.

The distinction between edible and inedible tallow is based on whether carcass parts are maintained and processed under USDA-approved conditions. Inedible tallow is most often used as a supplement for animal feed (62.4 percent), followed by use in fatty acids (22.4 percent), soap (10.4 percent), lubricants (3.4 percent), and other uses (1.4 percent).

Tallow has been used as one of the feedstocks tested in biodiesel experiments. For example, engine exhaust-emissions tests at the National Institute for Petroleum Energy Research used biodiesel made from soybean oil, beef tallow, and/or yellow grease (used fats and oils discarded by foodservice operations). In addition, the Fats and Proteins Research Foundation, which is supported by the U.S. rendering industry, and GraTech, Inc., a Kansas-based engineering company, are heading a project to commercialize GraTech's technology for turning rendered animal byproducts into biodiesel feedstocks. USDA's Alternative Agricultural Research and Commercialization Center, Minnesota's Agricultural Utilization Research Institute, and the National Livestock and Meat Board are the other participants in the project.

Does Tallow Make Sense From an Energy Perspective?

The feasibility of producing biodiesel from tallow involves, in part, comparing the quantity of energy required to transform tallow into biodiesel to the energy it contains. For tallow-based biodiesel to be feasible from an energetic standpoint, a net energy gain must be realized in the transformation process; i.e., the process must consume less energy than is contained in the fuel itself.

In this study, energetics are presented in the form of an energy-profit ratio, which is the amount of energy contained in biodiesel, divided by the amount of energy required to transform tallow into the fuel. All energies are expressed on a thermal (Btu) basis. A ratio greater than 1 indicates a favorable energy conversion, while a value less than 1 indicates an energetic liability.

Determining the energy-profit ratio associated with converting tallow to biodiesel fuel is a function of the starting point of the analysis (table A-2). Case 1 is concerned only with transesterification; both batch and continuous-flow processes are considered. It assumes that rendered tallow is available as a byproduct of beef production. Case 2 is concerned with the amount of energy required to process the animal fat into tallow at the rendering plant and then transesterify it. Case 3 deals with the growth and maintenance of the beef animal from conception through rendering and transesterification. Two separate methods are used to estimate the amount of energy allocated to tallow generation. Case 3a uses the cost of tallow as the basis for allocation, while Case 3b uses the mass of tallow in the animal.

The amount of energy needed to transform tallow into biodiesel involves accounting for both direct and indirect energy inputs. Direct energy inputs are the electrical and thermal energies required to operate the transesterification unit; process the tallow at the rendering plant; and pro-

Table A-1--Edible and inedible tallow production from cattle slaughter, by state, 1985-92

States	1985	1986	1987	1988	1989	1990	1991	1992
				Million lbs.				
California	201	190	166	152	145	147	135	112
Colorado	214	240	265	281	273	260	279	306
Iowa	249	246	267	240	233	229	207	205
Illinois	162	174	175	165	155	NA	NA	NA
Kanasa	774	812	783	788	777	782	753	757
Minnesota	128	127	125	137	126	131	135	126
Nebraska	701	713	697	731	727	735	789	823
Texas	769	776	778	745	732	710	701	712
Wisconsin	165	179	164	155	151	144	136	160

NA = Not available.

Source: Commercial Cattle Slaughter, National Agricultural Statistics Service, USDA.

Table A-2--Starting points for the feasibility analysis of tallow production and transformation into biodiesel

Case	Process	Feedstock
1	Transesterification (batch and continuous flow)	Rendered tallow
2	Rendering	Animal fat
3a	Animal growth	Fossil-fuel inputs for livestock feed and transportation (allocated based on COST of tallow)
3b	Animal growth	Fossil-fuel inputs for livestock feed and transportation (allocated based on MASS of tallow)

duce, process, harvest, and transport the feed and beef cattle. Indirect energies are based on a life-cycle-inventory methodology (cradle to end use), which accounts for the energy required to produce, manufacture, process, and/or distribute the raw materials, machinery, equipment, fuels, and chemicals (such as the transesterification unit, agricultural field equipment, fertilizers, and chemicals) needed to produce methyl tallowate (tallow-based biodiesel). Indirect energy inputs also include the energy content of any raw material feedstocks sequestered in these manufactured products.

Case 1. Calculating the energy-profit ratio for transesterification depends on the type of process employed. The batch-type process requires much less thermal and electrical inputs than the continuous-flow process developed by GraTech, Inc. The energy-profit ratio was determined to be 3.06 for the continuous-flow unit and 7.02 for a batch-type transesterification unit (table A-3).

The energy-profit ratios of Cases 2 and 3 are directly affected by the type of process (batch or continuous flow) used to transesterify the tallow, because of the different amounts of energy consumed by each process.

Case 2. Rendering plant energetics quantify the electricity and natural gas used to render animal fat into tallow. Operations include crushing and/or grinding, cooking, pressing, and centrifuging the animal fat before it is acceptable for transesterification. The energy-profit ratio is 1.35, when considering the electrical, thermal, and indirect energies associated with rendering plant operations, as well as energy required in the continuous-flow transesterification process. The energy-profit ratio is 1.79, when energies associated with batch transesterification are taken into consideration.

Case 3. Energetics associated with the growth and maintenance of the beef animal from conception through transesterification involve accounting for the energy required to produce, process, and transport feed components and to transport the animal from the pasture to the feedlot and rendering plant.

Typical feed components and quantities consumed by cattle and their associated breeding stock in Kansas throughout their lifetimes are 1.24 tons of irrigated corn, 0.57 tons of dryland grain sorghum, 0.04 tons of soybean meal, 0.67 tons of irrigated alfalfa, and 1.59 tons of sorghum silage. Both direct and indirect energies were determined for the production inputs for these crops, such as machinery, fuel and lubricants, irrigation, fertilizers and pesticides, seeds, transportation, and feedlot energy. For all feed components, the energy expended per ton of feed produced was determined by dividing the energy use per acre (Btu per acre) by the crop yield (tons per acre).

In this analysis, all of the energy used to raise and maintain the beef animal was allocated to marketable products. The ratio of the market value of tallow to the total marketable value of the beef animal was estimated to be 0.022. Therefore, on a cost basis, 2.2 percent of the total energy required to raise and maintain the beef animal was allocated to tallow production. The allocation is quite different, however, when based on the mass of the animal. Approximately 63 percent of the animal's live weight at slaughter is marketable and 20.3 percent of that is edible and inedible tallow. On a mass basis, tallow received the same energy allocation as the other marketable products.

The energy-profit ratio of the animal-growth life cycle (cost-based apportioning), rendering plant operations, and transesterification is 1.13 using the continuous-flow process and 1.42 with the batch process. Considering the animal-growth life cycle (mass-based apportioning), rendering, and transesterification, energy-profit ratios were 0.48 and 0.53 for the continuous-flow and batch-type processes.

Table A-3--Direct and indirect energies and energy-profit ratios for the feasibility analysis of tallow production and transformation into biodiesel

Case	Process	Transesterification process	
		Batch	Continuous flow
		Btu per gallon	
1	Transesterification		
	Direct energy		
	Natural gas	1,402	25,451
	Electricity	1,506	1,144
	Indirect energy		
	Sodium hydroxide	964	964
	Methanol	13,865	13,865
	Process unit	314	23
	Energy-profit ratio	7.02	3.06
2	Rendering		
	Direct energy		
	Natural gas	43,857	43,857
	Electricity	8,776	8,776
	Indirect energy	83	83
	Energy-profit ratio	1.79	1.35
3a	Animal growth (cost allocation)		
	Feed ration production and transport	15,495	15,495
	Feedlot maintenance	2,276	2,276
	Animal transport	448	448
	Energy-profit ratio	1.42	1.13
3b	Animal growth (mass allocation)		
	Feed ration production and transport	143,873	143,873
	Feedlot maintenance	21,136	21,136
	Animal transport	4,532	4,532
	Energy-profit ratio	0.53	0.48

Is Methyl Tallowate Production Economically Feasible?

The second half of the study evaluated the cost of producing tallow and processing it into methyl tallowate. Because the cost of raising and maintaining beef cattle varies within each state and throughout the nation, the cost of producing beef cattle for tallow was not included. In addition, rendering costs are embodied in the market price of tallow and were not considered separately.

Economic-feasibility analyses were conducted for three transesterification units: a batch process (173,379 gallons per year), and a 3-million- and 30-million-gallon-per-year continuous-flow process. Methodology is based on the *ANL Biomass Cost Estimation Guide* (2). Capital costs for both types of units include transesterification and glycerine-recovery equipment. Capital equipment costs are 80 cents a gallon for the batch unit, $1 a gallon for the 3-million-gallon unit, and 50 cents for the 30-million-gallon unit. Operating costs include materials and supplies, labor and fringe benefits, overhead, utilities and fuels, repair and maintenance, and insurance. State and federal taxes and distribution costs are not included.

The total cost for running a 30-million-gallon-per-year esterification unit is $43,506,900. With credit for the sale of byproducts (glycerine and free fatty acids/fat mix), the net annual cost is $36,666,900 or $1.22 per gallon (table A-4). Glycerine is used in a wide range of products, ranging from food, beverages, and pharmaceuticals to textiles, rubber, and plastics. The free fatty acids/fat mix can be used as a feedstock for making soap and detergents or as an animal feed supplement.

Cost-sensitivity analyses were performed to determine the effect of varying tallow prices, glycerine prices, and electrical and natural gas utility rates. For the continuous-flow transesterification units, the cost of producing methyl tallowate varied from a low of 92 cents per gallon for the 30-million-gallon-per-year unit to a high of $1.67 per gallon for the smaller unit (tables A-5 and A-6). The changes in cost between the two continuous-flow units at

Table A-4--Costs and coproduct credits for a 30-million-gallon-per-year continuous-flow process producing methyl tallowate

Item	Dollars
Real annual cost of capital 1/	3,255,000
Annual operating costs:	
Materials and supplies--	
2.25 million pounds of NaOH at 30 cents per pound	675,000
3,371,140 gallons of methanol at 55 cents per gallon	1,854,127
232 million pounds of tallow at 13 cents per pound	30,127,500
Operator labor, 8,000 hours per year at $15 per hour	120,000
Overhead and fringe benefits 2/	60,000
Utilities and fuels--	
3,520,000 kW-hours of electricity per year at 7.5 cents per kW-hour	264,000
763,530,000 cubic feet of natural gas per year at $3 per 1,000 cubic feet	2,290,590
26.4 million gallons of washing water per year at 50 cents per 1,000 gallons	13,200
115 million gallons of cooling water per year at 30 cents per 1,000 gallons	34,560
Maintenance 3/	300,000
Insurance 4/	150,000
Total	35,888,977
Sales and administration 5/	3,914,398
Annualized cost of working capital 6/	448,525
Total annual cost	43,506,900
Byproduct credits	
22.5 million pounds of crude glycerine at 28 cents per pound	6,300,000
6.75 million pounds of free fatty acids/ fat mix at 8 cents per pound	540,000
Total	6,840,000
Total net annual cost	36,666,900
Total transesterification cost per gallon	1.22

1/ Total capital costs are $15 million. The real annual cost of capital is a 0.217 fixed-charge rate for a 15-year-book-life nonregulated firm (30 percent equity, 10 percent debt) and no tax preferences (from ANL Biomass Cost Estimation Guide). 2/ 50 percent of direct labor. 3/ 2 percent of capital costs. 4/ 1 percent of capital costs. 5/ 10 percent of real annual cost of capital and annual operating costs. 6/ Working capital is 1/12th of the real annual cost of capital, annual operating costs, and sales and administration ($3,588,198). The annualized cost of working capital is 12.5 percent of working capital.

the same feedstock costs, glycerine prices, and utility rates can be attributed to the difference in capital costs per gallon. The batch unit had production costs that ranged from 97 cents to $1.50 per gallon (table A-7).

The price of tallow as the feedstock had the greatest impact on costs. Production costs for both types of transesterification units rose an average of nearly 26 cents per gallon when tallow prices increased from 10 to 13 cents per pound, and rose an average of 43 cents per gallon when tallow prices increased from 10 to 15 cents per pound. When glycerine prices ranged from 20 to 33 cents per pound, production-cost changes averaged slightly less than 10 cents per gallon, given set feedstock costs and utility rates.

Utility rates within the range specified did not have a pronounced effect on production costs. For specific tallow and glycerine price combinations, the difference in production costs between low and high utility rates averaged slightly greater than 2 cents per gallon for the continuous-flow units and was negligible for the batch unit.

The Outlook for Tallow-Based Biodiesel

The rendering industry in the United States generates a significant amount of tallow, approximately 5 billion pounds per year. The conversion of beef tallow into biodiesel fuel has a favorable energy balance. Production costs in this analysis ranged from 92 cents to $1.67 per gallon, depending upon the cost of the feedstock tallow (10 to 15 cents per pound), prices for the byproduct glycerine (20 to 33 cents), and type of transesterification used (batch or continuous flow).

In the past few years, diesel fuel at retail outlets has sold for an average of 71.2 cents per gallon, excluding state and federal taxes (figure A-2). For biodiesel to compete, it will have to find a market niche--possibly as a blend with petroleum-based diesel to meet Clean Air Act emission requirements.

Table A-5--Estimated cost of methyl tallowate from a 3-million-gallon-per-year continuous-flow process, with varying tallow feedstock costs, utility rates, and prices for the glycerine coproduct

Glycerine prices per pound	Tallow prices per pound		
	10 cents	13 cents	15 cents
	Dollars per gallon		
With low utility rates 1/			
20 cents	1.21	1.47	1.64
28 cents	1.15	1.41	1.58
33 cents	1.12	1.37	1.54
With high utility rates 2/			
20 cents	1.24	1.49	1.67
28 cents	1.18	1.43	1.61
33 cents	1.14	1.40	1.57

1/ 6 cents per kW-hour of electricity and $2.75 per 1,000 cubic feet of natural gas. 2/ 7.8 cents per kW-hour of electricity and $3.50 per 1,000 cubic feet of natural gas.

Table A-6--Estimated cost of methyl tallowate from a 30-million-gallon-per-year continuous-flow process, with varying tallow feedstock costs, utility rates, and prices for the glycerine coproduct

Glycerine prices per pound	Tallow prices per pound		
	10 cents	13 cents	15 cents
	Dollars per gallon		
With low utility rates 1/			
20 cents	1.02	1.27	1.44
28 cents	0.96	1.21	1.38
33 cents	0.92	1.18	1.35
With high utility rates 2/			
20 cents	1.04	1.30	1.47
28 cents	0.98	1.24	1.41
33 cents	0.94	1.20	1.37

1/ 6 cents per kW-hour of electricity and $2.75 per 1,000 cubic feet of natural gas. 2/ 7.8 cents per kW-hour of electricity and $3.50 per 1,000 cubic feet of natural gas.

Table A-7--Estimated cost of methyl tallowate from a 173,379-gallon-per-year batch process, with varying tallow feedstock costs, utility rates, and prices for the glycerine coproduct

Glycerine prices per pound	Tallow prices per pound		
	10 cents	13 cents	15 cents
	Dollars per gallon		
With low utility rates 1/			
20 cents	1.07	1.33	1.50
28 cents	1.01	1.27	1.44
33 cents	0.97	1.23	1.40
With high utility rates 2/			
20 cents	1.07	1.33	1.50
28 cents	1.01	1.27	1.44
33 cents	0.97	1.23	1.40

1/ 6 cents per kW-hour of electricity and $2.75 per 1,000 cubic feet of natural gas. 2/ 7.8 cents per kW-hour of electricity and $3.50 per 1,000 cubic feet of natural gas.

Figure A-2

U.S. Average Price of No. 2 Diesel Fuel Sold Through Retail Outlets[1/]

1/ Excludes state and federal taxes.

Source: Department of Energy, Energy Information Administration.

References

1. Davis, S. C. and M. D. Morris. *Transportation Energy Data Book: Edition 12*, ORNL-6710. Oak Ridge National Laboratory, Oak Ridge, TN, 1992.

2. Jaycor Corporation. *ANL Biomass Cost Estimation Guide, Review of Cost Estimates for Two Transesterification Processes*. McLean, VA, 1987.