Producing biodiesel from canola in the Inland Northwest:

An economic feasibility study

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Biodiesel has been suggested as an alternative fuel for use in urban areas with air quality concerns.

Introduction

Dryland farmers in northern Idaho and eastern Washington are somewhat limited in the number of crops they can grow economically. Many believe that adding a crop to the traditional grain-legume rotation would be desirable. Ideally, the new crop would utilize existing equipment, interrupt plant disease cycles, and be seeded and harvested at slightly different times than the traditional crops. Additionally, the crop should promote higher yields for other crops in the rotation. These are ambitious expectations.

Crops that have been tried include sunflower, safflower, chickpeas, and rapeseed. The first three are spring crops, and there are both winter and spring varieties of rapeseed, including industrial and edible (canola) varieties. Sunflower production was generally unsuccessful in the area. Safflower was grown with some success in warmer and drier areas. Chickpeas are being grown in the area on a limited acreage.

Winter rapeseed production has been successful for a few growers, especially when incorporated with government programs that require set-aside acres or fallow. Winter rapeseed is seeded during August in the Pacific Northwest, usually on fallow land. It is seeded on fallow land because most crops are not yet harvested on nonfallow fields and because seeds require high enough moisture levels to germinate and grow. Spring rapeseed and canola do not require fallow and escape winterkill problems, but yields are considerably lower than those of winter rapeseed.

Markets for rapeseed

The market for industrial rapeseed is not well developed and may be somewhat limited. Canola, on the other hand, competes in the edible vegetable oil market with soybean, cottonseed, and corn oil. In some markets, canola may command a premium because of its low saturated fat content. There is also a demand for canola meal for livestock feed.

Another potential use for edible and nonedible vegetable oils is as a fuel for combustion engines.

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There are good reasons to consider biofuel as a substitute for petrodiesel:

1. Biofuels are a renewable resource. Each year a new crop can be produced, while the supply of petroleum is finite.

2. Large quantities of petroleum and petroleum products are imported by the United States each year. Thus, our supply is somewhat vulnerable. The ability to produce ethanol and biodiesel with domestic products could be valuable if foreign sources are restricted.

3. Biofuels are more environmentally friendly than petroleum-based fuels. They are produced from biological material and are less hazardous if spilled. Biofuels also produce less air pollution and may be particularly helpful in urban areas and other sensitive environments.

Problem statement

The problem dealt with in this report consists of two parts:

1. Can rapeseed and canola be produced economically in eastern Washington and northern Idaho?

2. Under what conditions could their oils be used as a feedstock for biodiesel used in urban bus systems?

The study area is that served by the Spokane Transit Authority, and our data are partially based on a test period in which a biodiesel blend was used in several buses. Production costs were estimated for a simulated plant used to process the oil. The canola seed market price was used for the feedstock cost. This cost, added to the costs of extracting the oil and processing the oil into biodiesel, determined the estimated cost of producing biodiesel for the Spokane Transit Authority.

Background

Canola production costs in the Inland Northwest

Several studies have assessed production costs for rapeseed and canola in the Inland Northwest. Estimated costs have ranged from about 10 cents to nearly 20 cents per pound (Melfi and Withers [1993], Smathers and Withers [1993], Smathers and Foltz [1993], Hinman et al. [1991]).

Variation in production cost per pound has resulted from different climate and soil conditions, from different production practices, and from comparing winter canola with spring canola. Estimated typical yield for spring canola was 1,300 pounds per acre (Smathers and Foltz 1993) and for winter canola was about 2,000 pounds per acre (Smathers and Withers 1993). In these studies, winter canola was seeded in late summer on fallow land, while spring-seeded canola did not require fallow. Fallow costs were included in the winter canola crop estimate. The cost per pound of seed produced was 15 cents for winter canola and 19 cents for spring canola. In these estimates, all costs except management and risk were charged to the crop. Hinman et al. (1991) estimated costs a little lower, 10 cents to 12 cents per pound, in Lincoln and Adams counties of eastern Washington in a wheat, barley, fallow, canola rotation.

Canola markets

Once canola seed has been produced, it can be sold on the domestic market or exported. Oil and meal are produced by crushing the seed. Canola oil competes with soybean, sunflower, peanut, and other vegetable oils. U.S. canola also competes with Canadian canola. As soybean oil is most widely used in the United States, canola oil prices are somewhat tied to soybean oil prices. In other words, canola oil prices tend to rise and fall with soybean oil prices. The same can be said for canola meal as it tends to follow soybean meal prices.

Canola can be exported as whole seed or as oil and meal. Schermerhorn (1986) concluded that Japan would be the major importer of whole rapeseed and that U.S. access to this market would be difficult because of production in Canada, France, and Denmark. Eastern European countries could also be players in the Japanese market. However, domestic consumption of canola oil far exceeds our current production.

Vegetable oil as a fuel

Considerable work has been done on using vegetable oil as a fuel for combustion engines. Peterson (1986) found that power output, torque, and brake thermal efficiency in engines fueled with vegetable oil are equal to or very close to those using diesel. However, engine deposits, coking, and other problems result from long-term use.

Engine problems associated with vegetable oil fuel can be eliminated by modifying the oil into vegetable oil esters called biodiesel. Ethanol or methanol can be used for this purpose. Methanol is derived from petroleum, while ethanol is a renewable resource produced from grains and other farm products.

Peterson and his colleagues (1992) found that ethanol and methanol are quite similar in their effects on engine performance. Ethyl esters have a slightly higher viscosity than methyl esters, however, and their cloud and pour points are lower. These properties could reduce ethyl ester usability in cold weather. Fuel consumption is the same with either fuel. Ethyl esters are lower in smoke opacity and have lower exhaust temperature, lower injector coking, and fewer combustion chamber deposits.

When comparing the two esters (biodiesel fuels) with #2 diesel (D2), Peterson et al. found that the gross heat units of biodiesel were 9 to 13 percent lower than those of D2. The viscosities of biodiesel were almost twice that of D2, and D2 had lower cloud and pour points than biodiesel. Biodiesel fuels produced lower power and torque than D2. Injector coking was similar for both ethyl ester and D2, but the methyl ester showed a slightly higher coking index. The smoke opacities of biodiesel were one-third that of D2, and the exhaust temperature of biodiesel was always at least 50°C lower than that of D2 (Peterson et al. 1992).

Van Dyne and Raymer (1992) first looked at the environmental implications of biodiesel and found that the two most important factors in biodiesel's future use may be its low levels of exhaust emissions and its biodegradability. These factors may override cost considerations and performance concerns in certain niche markets such as wetlands, wilderness areas, national forests, oceans, and other environmentally sensitive areas. Biodiesel is lower than diesel fuel in three out of four categories listed in the 1993 European Economic Community emissions limits.

Biodiesel production costs

Caringal (1989) performed an economic analysis of rapeseed methyl ester and found that the cost could be broken down into the following parts: raw material cost (91.52 percent), operating cost (3.12 percent), and capital cost (5.337 percent). Due to this breakdown, Caringal determined that rapeseed methyl ester is not sensitive to either operating or capital costs because the raw materials make up the majority of the costs.

Weber (1993) determined that both feedstock and meal prices are extremely important in the cost of biodiesel. He concluded that economic competitiveness of a cooperative plant depends enormously on localized variables. Areas that offer low electrical rates, existing facilities, and large oilseed acreage would be good locations. Weber also found that without farm program benefits to minor oilseeds such as canola, soybeans and not canola is the most economic feedstock for a biodiesel facility.

Bam (1991) compared the economic viability of rapeseed ethyl ester with that of rapeseed methyl ester. He assumed that the process for making ethyl ester is essentially the same as that used for making methyl ester, so only the difference in the cost of the alcohol was considered. He found that the breakeven price of the ethyl ester was $2.00 per gallon as compared to $1.85 per gallon for methyl ester.

These studies and reports indicate that biodiesel can be used as a substitute for diesel fuel but is more expensive to produce. Up to the present, the high cost of production has prevented biodiesel from becoming a more widely used alternative fuel. In Europe, where petrodiesel is more expensive than in the United States, biodiesel has had substantial use.

A calculation of oil cost must also consider the values of meal and glycerine. When oil is extracted from canola, a protein meal is produced that can substitute for soybean meal in livestock rations. Glycerine is a by-product of biodiesel production from canola oils. These by-products help to offset the cost of biodiesel production.

The cost of canola for processing

In northern Idaho, canola was introduced as an alternative crop to peas and barley. These are crops grown in rotation with winter wheat, which is the major crop in the area. Farmers grow as much wheat as they can within the limits of rotation requirements and government programs. This means about one-half of the crop acres are seeded to wheat each year with the other half producing peas, barley, and, in some cases, lentils. It was hoped that canola would be more profitable than these traditional crops.

Crop budgets prepared by the University of Idaho Cooperative Extension System were used as a basis for estimating the profitability of canola as compared with peas and feed barley (table 1). All crops had a small return over variable costs, but when fixed costs were added, all had a negative return to risk and management. Canola experienced a loss per acre slightly greater than barley and was at an even greater disadvantage with peas. Higher prices or larger yields will be required to make canola a profitable crop. In some cases, where canola could be produced on program acres where deficiency payments could be received along with canola income, it was profitable. Also a few growers produced farm yields considerably above average for the area and enjoyed a positive net return.

The recent market price of 13 cents per pound of canola seed was used to estimate fuel costs even though this was below estimated total production costs. It was assumed that an adequate supply of seed would be available to the processor at this price.

Table 1. Estimated economic costs and returns for selected crops, northern Idaho, 1993.

	Canola	Peas	Feed barley
Yield per acre	1,300 lb	1,700 lb	1.5 ton
Price per unit	$0.13	$0.09	$91.00
Gross receipts per acre	$169.00	$148.75	$136.50
Total variable costs	$149.37	$131.91	$128.55
Return above variable costs	$19.63	$16.84	$7.95
Total fixed costs	$106.18	$91.28	$89.10
Total costs	$255.55	$223.19	$217.65
Return to risk and management	$(86.55)	$(74.44)	$(81.15)
Price needed to cover all costs	$0.20	$0.13	$145.10
Yield per acre needed to cover all costs	1,966 lb	2,551 lb	2.39 ton

Feasibility of rapeseed oil as a feedstock for biodiesel

All three varieties of rapeseed (spring canola, winter canola, and winter rapeseed) grown in the study area could be used for biodiesel because of their high oil contents. The largest portion of the cost to produce biodiesel is the feedstock cost. The cost of producing feedstock has been the major obstacle to the economic feasibility of biodiesel.

The Clean Air Act of 1990 established stricter emissions regulations for urban transit systems (Caro 1994). Urban transit directors may have to find ways to reduce emissions either with cleaner engine operation or with pollution reducing fuels. Some alternative fuels competing with biodiesel include compressed natural gas, electricity, ethanol, methanol, and others. The expense of converting buses to use these alternative fuels or of purchasing new fleets to meet the federal emissions standards imposes a financial hardship on urban transit systems. Biodiesel can be used in existing diesel engines without expensive conversion changes. One merely changes from diesel to biodiesel. Therefore, Spokane Transit Authority and other transit systems have been looking into biodiesel as a viable alternative to diesel fuel. The Spokane Transit Authority system was chosen for this feasibility study as it serves the urban center of the northern Idaho and eastern Washington region and has tested biodiesel blended with diesel fuel.

Spokane Transit Authority fuel use

Spokane Transit Authority (STA) is the urban transit system for Spokane, Washington, and the surrounding area in Spokane County. STA serves a 371-square-mile area that has a population of about 331,000 people. STA operates several services including 36 bus routes, paratransit services for persons with disabilities, carpool and vanpool matching, as well as transportation consulting services (Spokane Transit Authority 1993).

Eighteen buses were used for a biodiesel experiment from September 1993 to February 1994. These buses ran on a blend of 70 percent diesel and 30 percent biodiesel. The biodiesel used soybean oil as a feedstock and was supplied by the Iowa Soybean Association. At the end of the six-month experiment, STA reported reduced fumes, lower particulate levels, and increased fuel economy for the buses using the blend.

At the time of their experiment, STA utilized 157 coaches each of which used about 1,100 gallons of diesel per month (Caro 1994). This is a total of 172,700 gallons of diesel required per month or 2,072,400 gallons per year for the fleet of coaches alone. Considering that Spokane is a major center in the Inland Northwest, it would be reasonable to look at area rapeseed/canola producers as a source of fuel for the STA.

Plant site analysis

A linear programming model was used to select an optimal plant site based on the transportation cost of moving seed and its three co-products—meal, biodiesel, and glycerine—to and from the plant. Regional trucking firms were contacted for custom hauling rates between possible plant sites, canola-producing areas, and product markets.

Six possible plant sites were selected. The sites include five cities from the five seed-producing areas (Moscow and Craigmont, Idaho, and Steptoe, Ritzville, and Dayton, Washington) and Spokane, Washington. The five cities were chosen as possible sites because they are located in canola- or rapeseed-producing areas and are accessible to Spokane by major highways. Spokane was chosen as a possible site since it was the target market for both biodiesel and glycerine (figure 1).

The meal co-product was to be hauled back to the seed-producing areas or to one of four cities in central Washington. The four cities considered as potential meal markets were Pasco, Yakima, Ellensburg, and Moses Lake. All of these cities are major trading centers for the surrounding counties, and there are many livestock enterprises in each area. Canola meal can be fed to any livestock species in the area.

Custom hauling rates for seed and meal transportation were based on belly dump trucks capable of hauling 70,000 pounds or more of seed. The rates for glycerine were based on a minimum tanker truck load of 48,000 pounds. The plant was estimated to be able to produce one truck load of glycerine every two weeks (Northwest Agricultural Cooperative Association 1994).

The transport cost of shipping the meal to market was subtracted from the total value of meal produced per day. The base model assumed that the meal was to be shipped to the seed-producing areas. Base model calculations revealed that the optimal plant site was Steptoe, Washington. Transport costs at this location totaled $942.69 per day. The second best location for the biodiesel plant was Spokane, Washington, with transport costs of $1,141.64 per day.

The alternate meal transport site model utilized the same assumptions except that all meal produced by the plant would be shipped to one of four central Washington cities. The model again chose Steptoe, Washington, as the plant site with all meal produced being shipped to Moses Lake, Washington (figure 2). The total cost for shipping meal with this option was $1,066.03 per day. The total cost for custom hauling meal from Spokane, the second plant site choice, again to Moses Lake was $1,092.42 per day.

Based on these models, the Steptoe plant site was chosen as the least-cost location for the biodiesel plant. Moses Lake was chosen as the destination for the meal.

Cost to produce biodiesel

Canola procurement costs—As explained previously, it was assumed that all of the seed needed to supply the market could be purchased for 13 cents per pound at the local storage sites.

The structure needed to store the canola seed and meal for the extraction plant was an underutilized grain elevator at the processing site. A grain elevator was considered to be a reasonable site because necessary equipment such as augers,

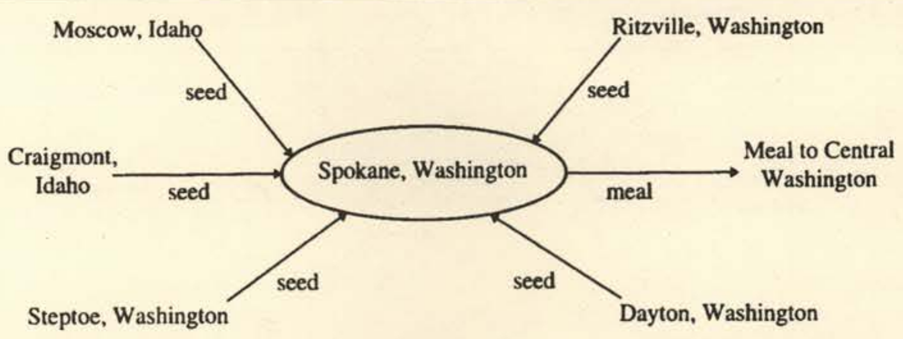

Figure 1. Seed and meal flows with Spokane, Washington, as the processing location. Spokane is also the market for products except meal, which is shipped to central Washington for livestock feed. Possible destinations for meal include one or more of the following cities: Pasco, Yakima, Ellensburg, and Moses Lake.

bins, conveyors, scales, and loading areas were all available. Local grain cooperatives owned these grain elevators. The assumption made for this study was that the biodiesel plant was operated by one of these grain cooperatives using an elevator owned by the cooperative. A per bushel rental fee was assumed to be paid for storage.

A plant with a capacity of 75 metric tons of seed per day would be large enough to produce adequate biodiesel for the target area. It was assumed that the plant would process an average of 71.43 metric tons of seed per day for 300 days per year for a total of 21,429 metric tons of seed processed per year. Assuming a typical 1,000-acre farm producing 100 acres of spring canola per year and further that the average yield was 1,300 pounds per acre, it would take 36,330 acres of canola per year, or about 364 farms to supply the market.

Oil yield estimates were based on a 40 percent oil content in the seed and an extraction rate of 91 percent of the oil. An acre producing 1,300 pounds of seed would contribute about 473 pounds of oil and 827 pounds of canola meal. Table 2 gives a breakdown of the costs required to extract the oil and produce biodiesel from canola oil.

Extraction costs—Two companies were contacted about extraction plant costs. Each of these companies is prominent in the extraction equipment supplier industry. They supplied written bids on equipment used, costs, utilities, and installation.

The detailed extraction process in figure 3 was taken from information provided by Anderson International Company. The end products are filtered oil and oil meal.

A separate building was needed to house the extraction and transesterification systems since they involve the use of alcohol, heating elements, and steam and could not be located in the preexisting

Table 2. Estimated annual biodiesel production costs and cost per gallon.

	($)	(%)
Procurement costs		
Canola seed (@ 13 cents/pound)	6,139,702	
Transport cost	129,936	
Elevator rental cost	22,890	
Storage cost	161,235	
Total procurement costs	6,453,763	70.1
Extraction costs		
Depreciation expense	62,500	
Equipment loan payment	219,263	
Electricity	21,276	
Water	473	
Labor	144,000	
Repairs	62,500	
Total extraction costs	510,012	5.5
Transesterification costs		
Depreciation expense	157,292	
Equipment loan payment	219,564	
Electricity	16,640	
Water	357	
Waste water	468	
Labor	187,200	
Repairs	17,391	
Materials	695,336	
Transport cost	55,637	
Total transesterification costs	1,349,885	14.7
Overhead costs		
Insurance	106,481	
Sales and administration	36,000	
Operating loan payment	631,130	
Total overhead costs	773,611	8.4
Opportunity cost of equity capital	115,684	1.3
Total biodiesel cost	9,202,955	100.0
Credits		
Net meal value	2,349,761	
Net glycerine value	904,493	
Net biodiesel cost	5,948,701	
Net cost of biodiesel per gallon	2.56	

Note: Annual acres required 36,330 acres
Annual canola seed required 47,228,481 pounds
Annual canola oil production 17,191,167 pounds
Annual biodiesel production 2,327,000 gallons

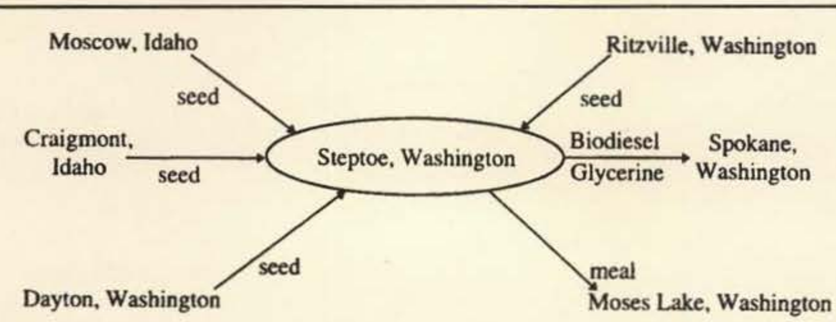

Figure 2. Seed, meal, biodiesel, and glycerine flows with Steptoe, Washington, as the processing site and Spokane as the product market for biodiesel and glycerine. Meal is shipped to Moses Lake to be used as livestock feed.

grain elevator. It was assumed that an 8,000-square-foot building would be adequate and would cost \$51.39 per square foot. This cost includes required piping, electrical installation, central air conditioning, fire alarms, and sprinkler system. This building would be used for both oil extraction and transesterification of the fuel.

Extraction plant installation costs—Installation costs include all costs required to get the capital equipment running to its capacity. Both companies stated that the installation costs for an extraction plant equal roughly the cost of the equipment. The equipment cost was \$1,250,000, making the finished plant cost about \$2,500,000 (Anderson International Co. 1993, French Oil Mill Machinery Co. 1993).

Utilities costs—Electricity requirements for the extraction process were estimated at 325.14 kWh per day based on written bids provided by the manufacturers. This includes power for all the equipment used in the extraction plant. The plant also has a steam boiler that would require 1,447.74 kWh per day. The rate of 4 cents per kWh was quoted by Washington Water Power and was used to calculate the electricity cost per day.

The heat exchangers utilize 100 gallons of water per minute to help cool the oil after it has been extracted. The water is recycled through a cooling tower with only about a 3 percent loss due to evaporation and drift. This estimate of water loss results in the extraction plant requiring 4,320 gallons per day to replace the lost water. Steptoe water users were charged \$13 for the first 5,000 gallons used each month. From 5,000 to 10,000 gallons the rate was 55 cents per 1,000 gallons, and above 10,000 gallons the rate was 30 cents per 1,000 gallons (Steptoe Water and Sewer District 1994). The extraction water cost was estimated by multiplying the total plant water usage by the percentage of water used in the extraction process.

Labor costs—Labor requirements for this size of an extraction plant are minimal because of the automation of the plant. Only two people were needed per shift at a semi-skilled labor rate of \$10 per hour. This rate included a base wage plus a percentage for Social Security, Medicare, unemployment insurance, and other employment expenses.

Maintenance and repair costs—Because maintenance costs were not included in the written bids, an estimate of 5 percent of the capital costs was used. This rate was based on a telephone conversation with a representative of French Oil Mill Machinery Co. (French Oil Mill Machinery Co. 1993).

Canola meal adjustment—Canola meal value was subtracted from total costs of producing biodiesel in order to estimate the net cost. The market price for canola meal was based on prices paid in the Portland, Oregon, market. Canola meal prices tend to follow soybean meal prices according to available price data for recent past years.

Canola meal has about three-fourths the protein of soybean meal, and the Portland price for

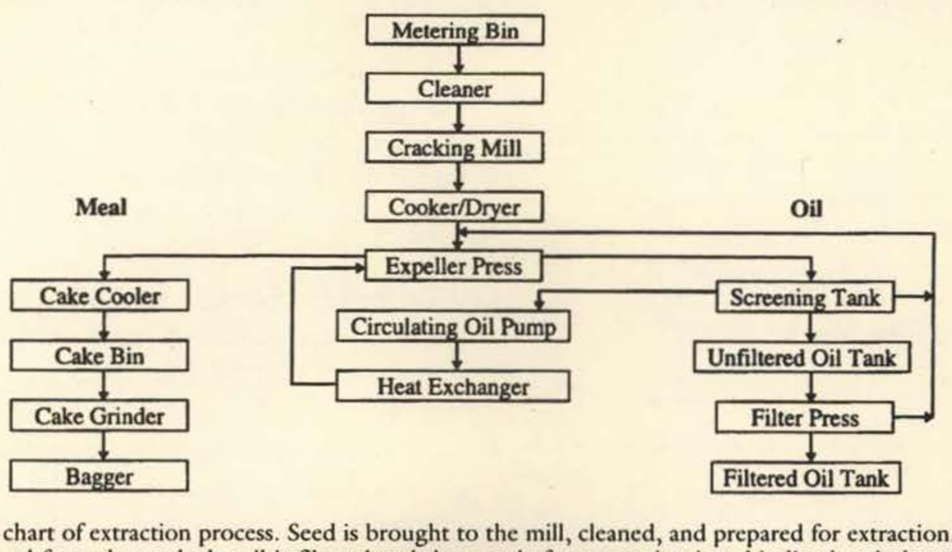

Figure 3. Flow chart of extraction process. Seed is brought to the mill, cleaned, and prepared for extraction. After oil is removed from the seed, the oil is filtered and then ready for processing into biodiesel and glycerine. Meal is diverted, cooled, ground for a more uniform product, and stored in bulk or put into bags.

canola meal was about 70 percent of the Portland soybean meal price. This relationship was fairly constant for the nine years of available price data (figure 4). Other areas of the nation may have a different relationship between soybean and canola meal depending on demand and proximity to the source.

In the absence of a canola meal price for areas of the Pacific Northwest, one can estimate its value to be about 70 percent of the soybean meal value.

The transesterification process—Once the feedstock has been crushed and the oil extracted, the transesterification of the oil into biodiesel takes place. Transesterification is the process of reacting a triglyceride, such as one of the vegetable oils, with an alcohol in the presence of a catalyst to produce glycerol and fatty acid esters.

The processing plant was set up to manufacture a canola methyl ester rather than an ethyl ester, since methanol has historically been the lower priced alcohol.

Two catalysts commonly used in transesterification are sodium hydroxide (NaOH) and potassium hydroxide (KOH). The catalyst chosen in the initial case was KOH.

The transesterification process begins with filtered canola oil from the extraction plant. The oil is added to the reactor from its storage tank. The alcohol and catalyst are combined in a mixing tank and then added to the reactor. After mixing, the ester separates from the glycerol. The raw ester is left in the reactor for washing, and the glycerol is drained off. After washing, the methyl ester is approximately 99 percent pure. The conversion rate of oil to methyl ester was calculated at 98.3 percent (Caringal 1989).

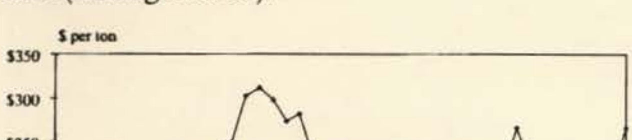

Figure 4. Price of feed meals, Portland, Oregon, 1985-95. (Prices quotes for January, April, June, and October of each year. Only the first two quarters were available for 1995.) Source: USDA 1985-94.

The glycerol phase is flash distilled to vaporize the remaining methanol, which is then condensed and recycled for reuse in the reactor. After the methanol has been recovered, the glycerol phase is vacuum evaporated to recover and refine the glycerol present. The glycerine recovered has a glycerol content of 98.2 percent. The glycerol recovery rate at the evaporator was 86.29 percent (Caringal 1989).

Methyl ester was to be stored for delivery to STA in tanks with a capacity of one week's production. Glycerine would also be stored on site since it would require two weeks of production to fill a truck for transportation to market.

The entire transesterification process requires 24 hours to complete. Therefore, the transesterification plant costs were calculated at 24 hours per day, and the volume of methyl ester needed to supply STA would require production for 260 days per year.

The flow chart in figure 5 illustrates the materials used and the products that result from the transesterification process on a daily basis. Recycling of the methanol reduces the consumption of this raw material by 26 percent.

Transesterification equipment costs—The estimated equipment cost for a transesterification facility that can process 30 metric tons of canola oil per day was $695,656.

Equipment required was estimated using scale-up techniques of Caringal (1989). The cost of the equipment was determined using Caringal's estimate with an adjustment for size and a 3 percent per year adjustment for inflation.

Transesterification installation costs were calculated at 50 percent of the total transesterification equipment cost. Installation costs include freight charges, labor, electrical set-up, spill control dikes around storage tanks, and all other costs necessary to have the plant running at or near capacity.

Transesterification operating costs—Electrical costs were based on a total daily usage and were estimated using the scale-up techniques of Caringal (1989).

The water usage of the transesterification process was estimated to be 187,710 gallons per day. However, most of this water was recycled and reused in the washing process. The water usage costs were allocated between the extraction and transesterification processes based on the percentage of total water use by each system. The transesterification process was estimated to use 43 percent of the total water consumed by the plant.

Of the water used, all could be recycled except for about one-third of a gallon for each gallon of fuel produced, which was considered waste water. At a level of 2,983 gallons of waste water produced per day, the plant produces 775,580 gallons per year. The City of Steptoe had a waste water rate of $39 per month for industrial uses with water requirements at the level of the processing plant.

Labor required for the transesterification process was estimated at three people for each eight-hour shift. Semi-skilled labor was used and was paid $10 per hour. The labor rate included a base wage plus a percentage for Social Security, Medicare, unemployment insurance, and other overhead expenses.

Repairs and maintenance costs for each year were estimated at 2.5 percent of the equipment costs. This was below the rate for the extraction process because the equipment had a higher value and less deterioration.

The price of methanol used in this study was $1.44 per gallon (Van Waters and Rogers, Inc. 1994). This price was based on the market price for methanol with a quantity purchase discount included. The plant uses 1,479 gallons per day and has the methanol delivered to the plant in truckloads of 9,600 gallons each.

Potassium hydroxide (KOH) pellets were valued at 70 cents per pound (Van Waters and Rogers, Inc. 1994). The plant used 778 pounds per day and had the KOH delivered in 400-pound drums once a week.

When NaOH was used as the catalyst, it had a cost of 44 cents per pound (Van Waters and Rogers, Inc. 1994). NaOH beads were used in the same amount as KOH pellets. The plant received the NaOH beads in shipments of 500-pound drums once a week.

Transport costs for shipping biodiesel to Spokane from the plant site in Steptoe totaled $213.99 per truckload (JJW Trucking Limited 1994). The biodiesel was assumed to be shipped using tanker trucks at the rate of one truckload per day.

Glycerine co-product adjustment—Industry processing methods for crude glycerine include distillation and ion exchange. Caringal (1989) studied two methods for glycerol recovery from the biodiesel process. Method A utilized a series of filtration steps to separate the glycerol from the glycerol phase. Method A yielded a condensate that was 90.1 percent glycerol, not technical grade. Method B used vacuum evaporation to separate the glycerol and resulted in a condensate of 98.2 percent glycerol, which is technical grade. Caringal (1989) recommended vacuum evaporation because of the higher purity and recovery rate of the glycerol and the fewer steps in the process. Caringal's vacuum evaporation method appears to be similar to the distillation process widely used in industry. The vacuum evaporation method was assumed for this study because of its high glycerol recovery rate, lower labor requirement, and resulting purified glycerine to be sold at the refined glycerine price.

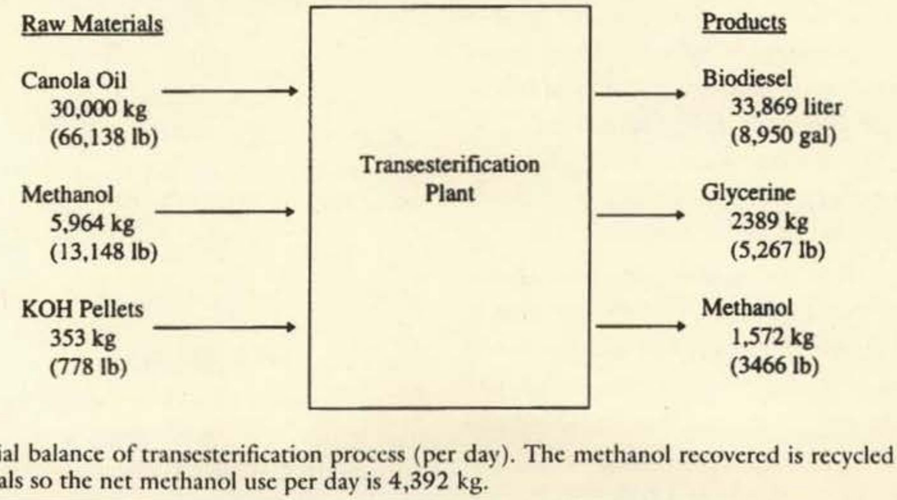

Figure 5. Material balance of transesterification process (per day). The methanol recovered is recycled back to the raw materials so the net methanol use per day is 4,392 kg.

Glycerine is recovered at the rate of about 5,270 pounds per day. Glycerine prices were based on the prices reported for 96 percent glycerol in the *Chemical Marketing Reporter* 1985-94 series. Value of glycerine produced per day of processing was estimated to be \$3,531 using the five-year average glycerine price of 67 cents per pound.

The cost of hauling glycerine to Spokane from the plant site at Steptoe was subtracted from the value of glycerine produced. Transport cost was estimated to average \$52.08 per day including cleaning the truck tanks after delivery. One truckload of glycerine was shipped to Spokane every two weeks and sold to regional chemical companies. Selling crude unprocessed glycerine was not considered in this study as no accessible market was found in the area.

Transesterification overhead costs—Insurance costs for the plant were estimated by a local commercial insurance agency. The insurance costs include both property and liability coverage.

Sales and administration of the plant are handled by the plant manager. The manager was to be paid for an eight-hour day at a labor rate of \$15.00 per hour. The labor rate includes a base wage plus a percentage for Social Security, Medicare, unemployment insurance, and other overhead expenses.

A revolving operating loan was needed to cover the first month of cash expenses for the plant. This loan is assumed to be for one year at 8 percent interest.

Other assumptions for the cost analysis—Depreciation expense for the extraction equipment was based on a 40-year useful life using the straight-line method and assuming no salvage value. It was assumed that the cooperative of growers running the biodiesel plant would borrow 90 percent of the capital needed to purchase the equipment. The long-term fixed interest rate loan payment was calculated at 9 percent per year for 30 years with equal amortized payments.

The transesterification equipment had an assumed useful life of seven years, while the building constructed to house the plant has an estimated life of 50 years. Depreciation expense for the transesterification equipment and the building was calculated using the straight-line method assuming no salvage value. As with the extraction equipment, it was assumed that the cooperative would require a loan worth 90 percent of the capital needed to purchase the equipment and the building. The equipment loan was for seven years and was calculated using an 8.5 percent per annum interest rate and equal total payments. The building had a long-term loan of 30 years with a fixed interest rate of 9 percent per annum and equal total payments of principal and interest. The operating costs were calculated as described in the transesterification cost analysis section.

Cost allocation—The cost of procuring canola seed was, by far, the largest single cost of producing biodiesel (table 2). At 70 percent of total costs, it is obvious that as the price of canola seed fluctuates, it will greatly impact the price per gallon of biodiesel fuel.

Transesterification accounted for nearly 15 percent of the total cost. More than half of this was for materials. Overhead costs made up 8.4 percent of the total.

The co-product credits played a large role in the reduction of these total costs. The canola meal adjustment offset 26 percent of total costs, while the glycerine adjustment offset 10 percent of total costs. Combined, the two co-product credits offset 36 percent of total costs, leaving the sale of biodiesel to recover only 64 percent of the total.

Sensitivity analysis

Canola seed—The cost of canola seed makes up a large portion of the total cost of biodiesel, so the price of the seed could have great impacts on the cost per gallon. The cost estimate was used to do a sensitivity analysis of how price changes in canola would impact biodiesel's cost per gallon. At a price of 9 cents per pound of seed, the cost of biodiesel was \$1.69 per gallon. At 15 cents per pound the cost per gallon of biodiesel was \$2.91 per gallon. On average, a 1 cent per pound increase in the price of canola seed increased the price per gallon of biodiesel by 20 cents.

Meal—The meal adjustment accounted for 26 percent of total costs, reflecting the importance of the meal sales price to the cost of biodiesel per gallon. When the price of meal increases by \$10 per ton the cost of biodiesel decreases around 6 cents per gallon. As has been shown, canola meal prices closely follow the soybean meal price and can be expected to fluctuate in a similar way.

Glycerine—The glycerine adjustment accounted for 10 percent of total costs. Since glycerine prices are quite volatile, the cooperative will need to develop a market strategy to obtain the best possible price. A price sensitivity analysis showed that as glycerine prices increase 5 cents per pound the cost per gallon of biodiesel decreases by about 3 cents.

Diesel-biodiesel blend

The estimated cost of $2.56 per gallon to produce biodiesel assumes 100 percent biodiesel used to power the buses. A more likely scenario would be a blend of biodiesel and diesel fuel. For example, an 80-20 blend of diesel and biodiesel was found to reduce air pollution substantially and its cost would be about the following:

$$
\begin{aligned}
0.8 \times 0.90 &= 0.72 \\
0.2 \times 2.56 &= \underline{0.51} \\
&\$\ 1.23 \text{ per gallon}
\end{aligned}
$$

This price is higher than straight diesel but may be justified in areas where pollution reduction is critical.

If the blend were used instead of total biodiesel, the amount of biodiesel required by STA would be reduced. In this case, a larger market would be required to use the production from the proposed processing plant. An alternative would be to sell canola oil on the market except for a reduced amount to be used in a smaller transesterification facility. Costs for a smaller facility may differ from those estimated in this study.

Another alternative would be to buy canola or other vegetable oils from a larger extraction plant located in another area and process the biodiesel locally.

Summary and conclusions

A limited acreage of industrial winter rapeseed has been grown for several decades in the Palouse region of Idaho and Washington. Recently canola types of rapeseed have been introduced into the area as an alternative to barley, peas, and other crops grown in rotation with wheat. Unlike industrial rapeseed, canola produces an edible oil and a good-quality protein meal for livestock. Canola competes with other edible vegetable oils such as soybean, cottonseed, and others.

Vegetable oil can also be used as a feedstock for biodiesel. With that in mind, this study estimated the cost of producing biodiesel in eastern Washington and northern Idaho using locally grown canola. Studies of canola production costs and returns have shown that returns can cover all economic costs only if excellent yields are obtained. In this study, estimated economic costs of producing spring canola seed amounted to about 20 cents per pound based on a yield of 1,300 pounds per acre. The biodiesel cost estimates used a price of 13 cents per pound to more nearly reflect the market price for canola seed.

Costs were estimated for extracting oil from the seed and for processing the oil into biodiesel. Seed procurement cost, including seed at 13 cents per pound, transport, and storage, was 70 percent of the final cost of biodiesel. Oil extraction was another 5.5 percent of the cost. The other 24.5 percent of costs were for transesterification of the oil, transportation, equity capital, and overhead.

The estimated cost of a gallon of biodiesel was $2.56 when canola seed cost 13 cents per pound. When the price of canola was raised to 15 cents, the estimated cost of each gallon of biodiesel was $2.91. When the price of canola was dropped to 9 cents per pound, the estimated cost of one gallon of biodiesel was only $1.69. Clearly, seed cost is a big factor in the final price of biodiesel.

Blended fuels afford most of the advantages of biodiesel at a much lower cost than straight biodiesel. With the cost of diesel at 90 cents per gallon and the cost of biodiesel at $2.56 per gallon, a gallon of blended fuel composed of 20 percent biodiesel and 80 percent diesel would cost about $1.23.

While canola produces an adequate quality of biodiesel, a canola-based biodiesel is expensive in comparison with diesel. Therefore, except for specialized uses, a less expensive feedstock will be needed to make biodiesel a competitive fuel. There may be specific circumstances where it would be feasible to use a blended canola fuel, however, such as in environmentally sensitive areas, including congested urban areas. The Spokane Transit Authority, however, decided in 1994 that the cost of its diesel-biodiesel blend exceeded the benefits, and decided against its further use in buses for the near future. For the present, at least, the vegetable oil market will be the preferred market for canola. Industrial rapeseed, on the other hand, must compete in the more limited industrial oils market.

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