A Critical Cost Benefit Analysis of Oilseed Biodiesel in Canada

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Table of Contents

1. Introduction...X

2. Sector Analysis Summary..X
- 2.1. Seed Production
- 2.2. Fertilizers and Farm Chemicals
- 2.3. Farming
- 2.4. Grain Storage and Transport
- 2.5. Oil Extraction and Refining
- 2.6. Biodiesel Manufacture

3. Sectors..X
- 3.1. Planting Seed Sector
- 3.2. Fertilizer and Farm Chemical Sector
- 3.3. Transportation and Storage Sector
- 3.4. Farming Sector
- 3.5. Biodiesel Manufacturing

4. Scenarios...X
- 4.1. Hub and Spoke (scenario 1)
- 4.2. Large Scale Manufacturing Plant (scenario 2)
- 4.3. Mustard Allyl Glucosinolate Biorefinery (scenario 3)
- 4.4. Solin Flax Biorefinery (scenario 4)

5. Economic Assessment of Biodiesel Production in Saskatchewan............X
- 5.1. Introduction
- 5.2. Canola Seed Supply
- 5.3. Canola Oil Extraction Coefficients
- 5.4. Canola Meal Market

6. Diesel and Biodiesel Pricing..X
- 6.1. Linear Program Model
- 6.2. Production of Biodiesel Additive Description
- 6.3. Capital Cost
- 6.4. Labour
- 6.5. Feedstock
- 6.6. Operating and Fixed Costs
- 6.7. Co-Products

7. Results..X

8. Summary X

9. References…………..X

Please note: Appendices A through N are available for download from the BIOCAP website at www.biocap.ca

Appendix A: References

Appendix B: Seed Certification Declaration

Appendix C: TUA

Appendix D: Prairie Canola Variety Trial

Appendix E: Saskatchewan Crop Production Guide

Appendix F: Hub Pro Forma Budget

Appendix G: Spoke Pro Forma Budget

Appendix H: Pro-forma analysis of various plant designs for production of biodiesel from high oil content Seeds

Appendix I: Solin Flax Biorefinery Pro Forma Budget

Appendix J: Linear Program (Objective Function)

Appendix K: Solver Tableau

Appendix L: Methods

Appendix M: Brown Soil Zone Assumptions

Appendix N: Margin Analysis of Oilseed Biorefinery Opportunities and Biodiesel Production

1. Introduction:

Production of biodiesel (and other bio-oil products) from oilseed is potentially an effective way to mitigate GHG emissions and generate environmental benefits. However, the entire supply chain and processing must be considered so that the implementation of biodiesel adds value. Biodiesel from oilseeds grown for traditional markets may prove too expensive for use as fuel but there are significant opportunities for mitigating oilseed input costs for profitable production of biodiesel. These strategies include the growth of oilseed on minimum inputs to maximize producer margins; the production of biodiesel from distressed canola and other oilseed; the production of biodiesel from weed seeds and screenings; the production of biodiesel from GMO seeds and planting seeds; and, the production of biodiesel from plants grown on land contaminated by heavy metals, hydrocarbons or other toxic compounds. Additionally, total utilization strategies for processing oilseed with advantageous chemical composition may significantly increase the ratio of benefits to costs.

Canadian producers generate far more foodstuff than can be rationally consumed as food by the populace. This resource of productive capacity is likely to be the basis of grain crop based energy production. A portion of Canadian overproduction capacity can readily and perhaps profitably diverted to domestic energy markets including biodiesel.

The goal of this study is to explore the resources in Canada that might be converted to biodiesel and through cost benefit analysis, determine those strategies that are likely to be more profitable and sustainable. In this study biodiesel threads are explored from farm production of seed to consumers. Costs and benefits of elements of the thread include 1) Producer margins to determine the costs and benefits of growing biodiesel crops. 2) Grain transportation and storage implications of various feed materials. 3) Oil extraction and refining strategies that impact on non-oil co-products. 4) Biodiesel production technology and 5) Distribution of biodiesel to the consumer.

Based on the analysis costs and benefits would accrue in a number of sectors and sub-sectors with the implementation of biodiesel manufacture in Canada: Affected sectors would include seed production, farming, farm chemicals, fertilizer, grain storage, grain transportation, crushing, biodiesel manufacture, biodiesel distribution, petroleum manufacture and distribution.

2. Sector analysis summary:

2.1. Seed production:

For the most part crops are sewn using certified seed produced by seed growers and seed companies. In Western Canada seed for a crop such as canola annual seed certified seed sales are a significant industry with seeding costs of $50 to $75 per hectare being common. The study has found that seed contribution of costs for canola produced biodiesel in Saskatchewan of $0.07 per liter of biodiesel while seed for solin flax produced biodiesel contributes just $0.03 per liter of biodiesel.

New seed types and crops are developed by Universities, Government researchers and private industry which will be licensed for sale through distributed seed growers and seed companies. Research based organizations will develop new plant varieties that have value added traits. Long term research will be performed by research leaders who will take proprietary technology positions in plant germplasm. Plant varieties are defined by superior composition and performance in the biodiesel industry may be improved in performance attributes.

A biodiesel industry may increase the demand for high value canola planting seed and increase the overall value of the seed industry. Conversely low cost seed strategies may be developed that lower net returns to the planting seed industry.

2.2. Fertilizer and Farm Chemicals:

Nitrogen fertilizer is the largest cost contributor to crop production and can contribute $0.13 per liter of biodiesel for crops such as canola and flax. For the foreseeable future it is likely that oilseed crops used for biodiesel production will use similar amounts of fertilizer and farm chemicals when compared to existing crops. No immediate benefits in fertilizer and farm chemical utilization are expected. The farm fertilizer and chemical industries will not be greatly impacted by increased oilseed and biodiesel production.

Oilseed protein content reflects the nitrogen and sulfur that is removed from the soil with the crop. Therefore, the protein content largely determines the amount of nitrogen and sulfur fertilization requirements of the plants. Canola and soybean have been bred to have a specific protein and oil content. Oilseeds are available that contain 10 percent less protein and will likely require less fertilization to produce the same or even improved yield of biodiesel available from current crops. Further improvements are possible through breeding and genetic engineering. Crops grown specifically for biodiesel production may reduce overall farm inputs and decrease the need for farm chemicals.

Canola has the highest cost for farm chemicals and thus farm chemicals would contribute significantly to biodiesel production costs if canola is used as a crop for biodiesel production.

2.3. Farming:

Biodiesel production may expand markets for producers in the short term by increasing the demand for oilseed. Biodiesel producers may utilize many forms of distressed seed and oil bearing crop waste for biodiesel production. These materials include lower grades of canola seed such as sample seed as well as weed seeds, small canola seeds and other oil bearing materials (damaged seed). The benefits of the new markets will be a competitive new market that can accept this material. Production of biodiesel from lower grades of seed and other low cost oil bearing materials is likely to provide some income to farmers.

Farmers may also participate in a variety of farmer based biodiesel production models includes, on farm, single community and hub (biodiesel plant) and spoke (crushing, feed mill and feeding) community production. Small biodiesel plants are, in general, uneconomical due to inadequate economy-of-scale. Larger biodiesel plants can produce fuel that competes with petroleum fuel prices.

New crops may be designed to cost less to grow and thus improve producer margins. These benefits will be achieved by lowered input costs including reduced seed cost, reduced fertilizer cost and/or reduced pesticide costs.

Farmers may also benefit by the development of new and stable domestic markets. Lower risks are possible where grain is not shipped across international borders. In addition, rural factories and possibly rural ownership may diversify producer risks. The use of farm land to supply new markets will also reduce overall production and may eventually contribute to increased food grain prices.

2.4. Grain storage and transport:

Land area under crop in Canada is finite and increased biodiesel production will inevitably lead to decreased production of other crops. As most Canadian grain is exported it is probable that exports would decline accordingly. In the event of a significant shift to biodiesel production there will be corresponding loss of total exports of other agriculture products. 1) Oilseed crops have considerably lower yield than cereal crops and will require significantly less storage space and fuel for transport. 2) Oilseed crops used in biodiesel production will be processed locally and not transported to ports by rail and then shipped overseas. One million hectares of canola for biodiesel production on land formerly dedicated to wheat for export will decrease Canadian wheat exports by 2,800,000 Tonnes. The cost of transporting this seed to a Canadian port is approximately $168,000,000.

In addition greater domestic markets for fuel will inevitably generate an increased supply of high protein meal. The protein meal will require transport and storage and it is expected that the availability of protein meal may 1) impact domestic production of livestock and the need to export the excess product and 2) decrease the need for less than half of the displaced grain transportation.

2.5. Oil extraction and refining:

New and established oilseed processors may both participate in building the new biodiesel industry. The Canadian Oilseed Processors Association (COPA) members may gain new demand for their spare capacity or alternatively lose access to inexpensive sources of oilseed. Similarly new opportunities may arise for established renderers as biodiesel is manufactured (eg. Rothsay) but new opportunities may attract new participants to the field of biodiesel.

2.6. Biodiesel manufacture:

Biodiesel manufacture is not yet an established industry and thus the impact on existing participants in the industry cannot be examined. However, several models of biodiesel manufacturing are available and will be explored. An analysis of the damaged seed, Mustard Allyl Gucosinolate and Conjugated Linoleic Acid biorefinery concepts will be pursued including complete budget analysis of the opportunities.

3. Sectors:

3.1. Planting Seed Sector:

Canadian planting seed production is regulated by the government and seed producer organizations, however, some unregulated seed production does occur. Most planting seed sold in Canada is certified for meeting minimum quality parameters (Appendix A). Seed growers produce seed under more stringent conditions than used in crop production so that seed is free of weed seeds, disease and other crop species. Seed certification often requires the analysis of the seed by a third party laboratory and the preparation of a pedigreed seed declaration by the grower. Pedigreed seed that meets the quality parameters may then be sold as certified seed in Canada.

Most seed in Canada is protected by plant breeder's rights and royalties must be paid for use of the seed. In many cases the seed embodies specific technology or improvements that provides crops grown from that seed specific and definable attributes or advantages. The Canadian oilseed planting seed industry is segmented into at least three broad classes. A small portion of all seed used in Canada is not protected by intellectual property rights and may be obtained from seed growers without paying royalties for use of the seed. While these unencumbered varieties may be available from certified seed producers they are often grown without a known pedigreed repeatedly by a farmer (brown bag seed) for on farm use. The cost of planting seed that is not protected by plant breeder's rights is a small portion of the overall cost of on-farm production and the revenue for seed growers for producing this seed is typically less than other more valuable seeds. Planting seed of older lines of mustard and flaxseed are often propagated on the farm. More recently seed has been protected by plant breeders rights and the use of seed varieties requires the payment of royalties to the company and/or institution that developed the seed. The known pedigreed of this seed is important in establishing its relative value in the marketplace. Planting seed of a specific variety may be called pedigreed if it meets minimum standards for genetic purity, contamination and provenance. The right to increase pedigreed seed is often made available to seed companies and organizations that increase the seed. Often pedigreed seed is grown under contract by farmers that specialize in seed production for seed companies. The bulk of seed used in Western Canada is now from varieties protected by plant breeder's rights. However, the genetic stability of many of these varieties are readily maintained by inbreeding and the seed costs reflect the vulnerability of the marketplace to “brown bag” seed. The final class of improved seed includes those seeds that contain specific high value traits and are closely protected by the industry that produced them. While the seed comprising this class may be from genetically modified crops (e.g. glyphosate tolerant canola) it may also be from a crop with a unique trait (e.g. Linola flaxseed) or a hybrid seed that is produced from inbred lines. The latter hybrid seed typically provides a significant yield advantage over other varieties. Appendix C shows a comparison of the canola varieties grown in the Prairie Canola Variety Trial.

While the area of land planted to crops does not vary significantly annually in Western Canada the varieties that are planted can change dramatically Usually in response to market forces. The impact of a growing biodiesel industry on the seed for planting industry will be related to the oilseed used in biodiesel production and the crop that is displaced. Several scenarios are proposed and discussed below to clarify the potential impact.

In one scenario existing varieties of canola are used in biodiesel production. Canola seed is amongst the most expensive used in prairie agriculture. Current canola seed costs in the Saskatchewan Crop Production Guide (appendix D) are given as $21.90 per acre ($54.12/ha) while wheat costs just $8.97 ($22.17/ha) to seed the same area. An increase in seeded canola acreage would likely lead to a decrease in other crops. The seed companies that produce canola varieties would most likely benefit directly. The seed producers for other crops would similarly lose market share for their production.

Displacing 1,000,000 hectares of wheat with 1,000,000 hectares of canola[1] for biodiesel could potentially increase the seed industry revenues by $32,000,000 dollars with the total seed costing $51 million. The resulting canola crop would produce approximately 704,000,000 liters of biodiesel, (Based on a yield of 1,370 kg/ha[2] x 1.1[3], oil content of 42%, biodiesel production efficiency of 99% and biodiesel density of 0.89 g/mL). Seed cost contributes $0.072/L of biodiesel.

Assumptions:

1 The average production of canola is 4.7 million hectares.

2 1,370 = 10 year average yield for Canada (Canadian Grains Council).

3 1.1 = Allowing a 10 percent yield increase for improved hybrid genetics.

In another scenario, that may have less impact on the seed industry, oilseeds that are less expensive to utilize may be specifically grown for biodiesel production. The seed for these crops could potentially be produced by farmers or seed growers and the royalty payment per seeded area might be held to a minimum. Such crops may include those that have smaller seeds like *Camelina sativa* and be seeded at lower rates, thus reducing seed costs. Historic trends show that newer crops decrease the net production of wheat. Similarly, an increase in the area planted with biodiesel crops will likely displace wheat production. As the proposed biodiesel producing oilseed species is selected based on minimizing relative costs to the producer it would be expected that this scenario could decrease the overall value of the seed industry if seeding rates could be lowered. However, the seed will likely be pedigreed and certified and is unlikely to be significantly less expensive than wheat.

Displacing 1,000,000 hectares of wheat with 1,000,000 hectares of the hypothetical biodiesel seed would likely have little effect on the seed industry. Based on wheat seed costs the crop seed would cost $22.17 million dollars. The resulting biodiesel crop would produce approximately 635,000,000 liters of biodiesel, (Based on a yield of 1,370 kg/ha, oil content of 42%, biodiesel production efficiency of 99% and biodiesel density of 0.89 g/mL). Seed cost contributes $0.035/L of biodiesel.

In a final scenario oilseed with an advantageous composition for processing may be grown under contract by a single source. An example of this practice is the production of high linoleic acid solin flax (Linola) under contract with Agricore United in Western Canada. In these proposed crops the value added opportunity is not biodiesel and the crop may not produce as much biodiesel as other crops. The benefits of growing these crops will be discussed separately.

Conclusions: Seed adds significantly to the overall cost of biodiesel. The income and value of the seed to the industry is highly dependent on the approach taken.

3.2. Fertilizer and Farm Chemical Sector:

Fertilization is a major input to oilseed agriculture both in terms of energy consumed and in fertilizer production and cost. Canada is a major producer of fertilizer including all of the major nutrients such as N, P, K and S. The cost of nutrients N and P are closely tied to the cost of natural gas as is the major input in fertilizer production. The Crop Production Guide for Saskatchewan (Appendix D) indicates that canola and flax require similar costs for nitrogen fertilizer while flax has lower demand for phosphate and sulfur inputs. If canola or a related oilseed species (which have similar fertilizer needs) are substituted for wheat in the production of biodiesel it is probable that a significant increase in sulfur fertilizer may occur on the land used for biodiesel production. There would be little impact on other fertilizer consumption.

One million hectares of land planted to canola or a similar high yielding oilseed crop would yield 700,000,000 L of biodiesel annually. With a projected yield of 1,490 kg/ha and a fertilizer consumption similar to that of current canola ($68/ha, $14/ha and $11/ha for N, P and S respectively) the total cost of fertilizer for the biodiesel crop will be approximately $93,000,000. For this example the cost of fertilizer will contribute $0.13 per L of biodiesel.

Farm chemicals, particularly herbicides, are also a major input cost in crop production. In general, the cost of chemicals used in canola production are greater than the costs of chemicals used in cereal cultivation. Based on the Crop Production Guide the cost of herbicide for a wheat crop (grown in the dark brown soil zone on stubble) would be $16.92 per hectare less than for a canola crop. However, options for weed control in herbicide tolerant oilseed are more simple and effective yet more costly than options for non-herbicide tolerant oilseed. For example, it is less expensive to apply farm chemicals to mustard than canola or wheat. The additional canola herbicides application costs are largely related to the herbicide tolerance trait. The more costly herbicide regimen possible in herbicide tolerant canola affords significantly better weed control than achieved in the other options. Herbicide tolerant species may be used extensively in biodiesel production. Nevertheless, growing these crops is associated with increased costs for farm chemicals.

Farm chemicals for canola direct seeded on dark brown soil are approximately $31.18/acre ($77.04/ha) and $23.82 ($58.83/ha) for canola seeded on stubble. The cost of farm chemicals for canola are likely to be similar for both hybrid and open pollinating varieties. Therefore it is expected that farm chemical costs will contribute significantly to biodiesel costs and this will range from $0.084 for hybrid canola on conventionally seeded in stubble to $0.123 for conventional canola directly seeded.

Conclusion: Fertilization costs constitute a major portion of the total costs of crop production and hence biodiesel production. The use of herbicide resistant crops for biodiesel production will require increased associated farm chemical costs.

3.3. Transportation and Storage Sector:

Oilseed crops are lower yielding than cereal crops and the transition from oilseed crop to cereal crop will result in a significantly lower mass of product for transportation. SAF maintains statistics for all crop districts (1). In districts where both canola and wheat were grown yields were compared for both crops. On a volume and mass basis the wheat crop exceeded the canola crop yield by 35% and 62% respectively. The lower mass yield is a property of oilseed crops and thus it is expected that any crop grown for biodiesel will produce a low mass yield when compared with a cereal. Transport costs are more related to mass than volume and thus the production of a lower mass crop will significantly decrease the mass of material transported. Displacing 1,000,000 hectares of wheat with a mass yield of 2,280 kg/ha with 1,000,000 hectares of canola or equivalent with a mass yield of 1,370 kg/ha will reduce the need for transport of grain by 910 thousand tonnes. Wheat from this land will no longer be transported for export and thus mass and volume requiring transport and storage will be decreased by 2,280 thousand tonnes and 824,000 cubic meters respectively. The estimated cost of moving wheat from a mid-prairie point was $65.3 or $85.7/tonne for product shipped to the pacific seaboard or the St. Lawrence respectively. Thus a cost savings of between $148 and $195 million is expected.

New transportation costs associated with the production of biodiesel will, of course, displace some of the former costs associated with exporting grain. The cost of gathering grain in terminals and pooling the grain for shipment will be decreased due to the lower mass and volume of the oilseed crop (when compared with the cereal crop that has been displaced). The oilseed crop will be moved to oil extraction facilities for separation of oil and meal. These facilities will be significantly closer to agriculture land than ports used for export. Canola meal is in oversupply in Canada and much of it is shipped to markets in the US (in spite of Canadian demand for soy meal from the US). Meal arising from the production of biodiesel, 60 to 70 percent of the mass of the seed, will likely be shipped to the same markets that currently consume canola meal including the US (Unless the meal can be used to displace US soy meal). Biodiesel will likely be sold to markets throughout Canada and perhaps even sold internationally.

The transportation of methanol and catalyst used in production of biodiesel and the co-product glycerin are relatively small in total volume and mass. Catalyst represents just 1% of the biodiesel mass or 0.4 % of the oilseed mass. Glycerin and methanol are 4% of the seed mass. Methanol and catalyst are manufactured in Alberta but glycerin refineries are are located in the US and southern Ontario.

Assuming shipping costs are similar for both biodiesel and wheat shipping biodiesel to the Pacific coast of the St. Lawrence will contribute $0.058 or $0.076 /liter of biodiesel.

Conclusions: Production of biodiesel crops that displace other oilseed crops will have little effect on transportation. However, it is expected that production of a biodiesel crop that displaces cereals will significantly decrease the demand for transportation and storage of grain. The need to transport meal, biodiesel and glycerin to remote markets will represent a new role for the transportation sector. The combined mass of the meal and biodiesel is significantly less than the mass of cereal for export. An in depth study is required to determine the impact on the sector. Biodiesel transport to large markets in Western or eastern Canada will cost $0.058 to 0.076/liter.

3.4. Farming Sector:

The cost of farming in Canada is tightly linked to the costs of fuel, chemicals and seed and the potential benefits of biodiesel are unlikely to change these input costs quickly. In the future crops may be designed to significantly lower input costs. Desirable traits may include: small seeds or exceptional seed vigor so that seed cost is minimized; low fertilizer consumption (a high ratio of oil to N, P, K and S inputs); disease tolerance; herbicide tolerance for inexpensive herbicides. A targeted economic study could that includes input from plant breeders, agronomists and processing expertise could lead to the design of crop that maximize producer margins.

Canadian agriculture output is not sufficient to affect prices of commodities on world markets. Therefore, changing the utilization of land from food to non-food production may not affect the value of the agriculture output. Small decreases in the world supply of grains possible through a Canadian agriculture shift from cereal production to oilseed production will not impact the prices of these commodities significantly. However, the global trend to increase the use of crops as fuels and other non-food products is of sufficient magnitude to significantly change the nature of commodity pricing. It is likely that biodiesel production abroad will have more impact on farm gate prices than domestic biodiesel production. It would be possible to establish the likely magnitude of the transition to biofuels on a global basis and determine the impact on farming in Canada. However this topic is beyond the scope of this analysis.

Oilseed often loses value due to conditions encountered during the growing season, during harvesting and storage. The damaged or degraded seed is either sold at a discount or not sold at all. The Economic Assessment of Biodiesel Production in Saskatchewan chapter of this document describes the economic viability of producing biodiesel employing a strategy that consumes some low grade seed. Farmers may significantly benefit from the establishment of a biodiesel industry that consumes lower grades of oilseed. While the model show excellent potential for economically sustainable production of biodiesel it does not address the fact that farming in Canada under the current paradigm is unsustainable.

The farm margin analysis tool provided by the Saskatchewan Agriculture Development Fund can be used in extensive sensitivity analysis of farm inputs and the costs of biodiesel crops. While sensitivity analysis is not part of the current study it could be incorporated in a future project.

2006 Dark Brown Soil, Conventional Seeded Stubble Crop	**27bushels** **Conventional seed** Canola	Cost of expense per Biodiesel ($/L) **27bushels** **Conventional seed** Canola	**30 bushels** **Hybrid seed** Canola	Cost of expense per Biodiesel ($/L) **30 bushels** **Hybrid seed** Canola
Estimated Yield (Kg/ha)	1370.0		1507.0	
Biodiesel produced from yield (Litres)	626.00		688.65	
Variable Expenses/hectare				
Seed	22.21	0.04	54.09	0.08
Fertilizer - Nitrogen	56.81	0.09	56.81	0.08
- Phosphorus	13.83	0.02	13.83	0.02
- Sulfur & Other	8.15	0.01	8.15	0.01
Chemical - Herbicides	71.63	0.11	71.63	0.1
- Insecticides/Fungicides	2.91	0.01	2.91	0.01
Machinery Operating - Fuel	27.42	0.04	27.42	0.04
- Repair	16.40	0.03	16.40	0.02
Custom Work & Hired Labour	12.35	0.02	12.35	0.02
Crop Insurance Premium	3.05	0.01	3.05	0.01
Utilities & Miscellaneous	12.58	0.02	12.58	0.02
Total		**0.40**		**0.41**
Other Expenses/hectare				
Building Repair	2.96	0.01	2.96	0.01
Property Taxes	12.89	0.02	12.89	0.02
Insurance & Licences	4.94	0.01	4.94	0.01
Machinery Depreciation	41.00	0.06	41.00	0.06
Building Depreciation	2.96	0.01	2.96	0.01
Machinery Investment	20.08	0.03	20.08	0.03
Building Investment	2.91	0.01	2.91	0.01
Land Investment	37.79	0.06	37.79	0.05
Total		0.21		0.2

4. Biodiesel Manufacturing:

4.1. Hub and Spoke (scenario 1):

The hub and spoke concept was designed to maximize rural development in the Canadian oilseed utilization industry while providing the highest quality of biodiesel. The concept includes several oil extraction plants that focus on producing value added meal products (that increase the value of canola meal to compete with soy meal) and selling all or a portion of their oil product to biodiesel production. The biodiesel plant is centrally located to take advantage of economy of scale considerations and to provide for maximum product quality. A hub and spoke project design is being tested to utilize distressed (wasted) canola seeds. For the purposes of determining costs and benefits of the hub and spoke model assumptions will be based on the near and long term roll out plans stated by Milligan Biotechnology Inc. (MBTI), the company currently implementing the hub and spoke project. The project will first be set up in Foam Lake, Saskatchewan (the hub), with a 50 T/day (seed) portable crushing unit and a permanent biodiesel production facility. The approach (foot print), hub and spoke, will then be sold to other canola producing rural communities across Canada and later other canola producing countries.

The hub and spoke commercial approach currently under way includes the commissioning and optimization of a portable mechanical oil seed crushing system (spoke) having an approximate capacity of 50 T/day (each unit) one in Manitoba and one in Alberta, and a permanent biodiesel (esterification) plant to be set up in Foam Lake (hub) which will process seed oil from several satellite crushing plants. The project plans to test AAFC technologies for extraction of oil from distressed seed and for conversion of the oil to biodiesel at the producer community level. The budget model assumptions provided as appendix ? regarding oil extraction are all based on pilot runs using full scale equipment. Research funding for oilseed extraction studies was provided by Agriculture and Agri-Food Canada, the Saskatchewan Canola Development Commission and MBTI.

The oil extraction plant will be both portable and self sufficient. It will be readily moved to communities where significant supplies of distressed seed are available. The portable unit will increase the efficiency of the planned business with the proprietary method of oilseed augmented crushing, developed by AAFC, that results in the recovery of most of the seed oil, without the need for additional solvent extraction. It is performed using standard crushing equipment, and the process is readily scaled for use within small processing plants.

The fuel will be produced by the esterification or transesterification of vegetable fats oils to produce a fuel suitable for compression ignition (diesel) engines. Biodiesel substitutes directly for diesel fuel and may be used in varying portions as a blend with diesel fuel. The efficiency of biodiesel production was determined in large scale pilot plant processes conducted under the supervision of Dr. Martin Reaney. Milligan Biotechnology has the license from AAFC to commercialize the hub and spoke process. The AAFC biodiesel synthesis process consistently meets European and US standards, utilizes low quality oils, minimizes solvent evaporation demands and completely avoids the use of water.

MBTI biodiesel plant design can accommodate expansion and will have considerable excess capacity upon installation. It will be installed to process the oil from up to 5 spokes and a local pressing plant. The cost of this extra capacity is minimal but allows for huge savings in labour as the plant needs only to be operated 1 shift per week at minimum capacity and increased to 5 shifts per week at full capacity.

It is also the plan of the hub and spoke model that as supply is assured near the original hub and spokes that the first spokes will potentially become hubs on their own. New spokes will be established around each provincial hub as needed. According to MBTI plans Alberta and Saskatchewan need at least 2 hubs each. The hubs will accept a wide variety of oils as they become available. They will be able to process rendered products and waste restaurant grease, etc. An important attribute of the the model is the flexibility of the spokes to pursue certain value added practices. Spokes will also accept canola fines (screenings), pesticide laden planting seed, mustard, GMO seed and weed seed as necessary and will focus on adding value to these materials.

Objectives: The overall objective of this segment of the analysis is to determine the budget of the novel biorefinery technology that profitably utilizes low-grade canola seed as a resource for biodiesel production. The overall objective could be stated as : "Develop a detailed budget of a biorefinery process that utilises lower grades of canola seed for the production of biodiesel fuel and a soy equivalent canola meal product".
Sub-objectives:

- Determine the budgets of the spokes that feed value of canola meal for use in feeds (Technology developed by funding from AAFC and Milligan MBTI).
- Determine the budget of the hub capable of processing of vegetable oils with between 0 and 15% fatty acids (FFA) into biodiesel at 50 tonnes per day (Technology developed by funding from AAFC, SCDC, and MBTI).
- Determine the costs and benefits of the hub describing a technology for the processing of vegetable oils with between 0 and 15% free fatty acids (FFA) into biodiesel at 30 tonnes per day (Technology developed by funding from AAFC, SCDC and MBTI).

Implementation of the hub and spoke design will also have a social and economic impact by adding value to damaged crops and by creating high quality jobs in rural areas where they are much needed. Ongoing AAFC and NRCan funded projects are investigating the ability of the hub and spoke model to be replicated and support sustainable development. These studies will predict if a significant amount of Canada's present fuel needs can be satisfied from renewable resources, without compromising the demand of future generations. Furthermore the projects will demonstrate if sound economic performance can be balanced with appropriate consideration of the environment. Optimum resource recovery is a primary benefit whenever seed waste and other biomass residues are utilized for the economical production of green biodiesel. In lieu of the completion of these studies in Appendix F and Appendix G are provided as complete budgets for a spoke and hub extraction and biodiesel plant respectively. These budgets demonstrate the predicted performance of the plant over the period of 10 years.

GHG Emissions: Biodiesel production, in general and the hub and spoke model will have a major environmental impact and result in significant GHG emissions reduction. Some benefits to GHG emissions are related directly to biodiesel consumption and displacement of diesel fuel, others are related to above ground disposal of damaged oilseed which is a common practice.The GHG emissions reductions will result from:

- Reduction of emissions due to the decomposition of wasted distressed seeds will be achieved with the elimination of seed dumping and incineration practises (methane and CO_2).
- Reduction in biogenic NOx is also possible as oilseed contains considerable protein and will release nitrogen compounds if dumped or incinerated.
- Reduction of diesel engine CO_2 emissions by 3% when 1% biodiesel is used as a fuel additive have been reported due to improved lubricity.

- Reduction in emissions due to transport of only the oil fraction (not the seeds) and use of the meal in the area where crushing takes place.
- Cattle methane emissions decrease in response to inclusion of fat in their diet. A reduction in cattle methane emissions is anticipated by using meal that contains approximately 5% oil.
- Reduction of emissions by fully utilizing a crop.
- Reduction of energy inputs and solvent loss when compared to conventional oilseed processing operations that use solvents.

Biodiesel increases fuel lubricity, and even when used at low levels, it directly decreases total GHG emissions as fuel consumption is decreased. When used as a fuel additive, enhanced fuel efficiency is the predominant impact. Fuels with enhanced lubricity extend engine life and decrease engine oil consumption. The result is an enhanced reduction in GHG and other environmental emissions. The augmented crushing technology is less energy intensive than is the industry method of mechanical seed crush with subsequent hexane extraction of residual oil. Hexane evaporation is an energy intensive step in the process, but this step will be eliminated with augmented crushing.

Biodiesel will displace petroleum-based diesel fuel, and thus have an indirect impact on GHG emissions. Similarly, biodiesel reduces the emissions of many potentially toxic components of diesel fuel exhaust. Specifically, biodiesel reduces emissions of carbon monoxide, polyaromatic hydrocarbons, sulfur and particulates when compared to conventional diesel. However, biodiesel can increase the emission of nitrous oxides. This impact on NOx emissions is eliminated when biodiesel is used in the fuel at less than 5%, as increases in fuel efficiency offset NOx production.

An ancillary benefit can be anticipated from this technology. The augmented crushing process produces a meal product with higher fat content than is attainable from other protein meal sources. Fat in oilseed meals fed to ruminants is known to suppress methane emissions.

Scenario Function and Purpose: The technology will process seed that is distressed. The compact design allows the oil extraction to be executed in a small portable oilseed extraction plant that is readily placed on a site that has undergone minimum preparation. The extraction requires only a temporary building, grain bins, and road or rail access. The facility may be powered by biodiesel powered electric generators. As biodiesel plants cannot be easily moved, it is proposed that larger biodiesel plants will receive oil supplied from several smaller extraction plants. The biodiesel plant design is based on a robust technology developed by AAFC.

The proposed technology model contrasts with the current Canadian situation where the Canadian oilseed processing industry, which is sometimes called the crushing industry, currently consists of 13 crushing and refining/packaging plants, owned by five companies. There are currently no commercial mobile crushers, and this presents an important innovation for local canola producers.

Through years of research in biodiesel production, AAFC has developed both efficient oilseed extraction and biodiesel production technologies. The biodiesel production has been demonstrated repeatedly at full pilot scale and the oilseed recovery technology has been tested at pilot scale in prior work.

4.2. Large Manufacturing Plant (scenario 2):

The Canadian oilseed crushing industry is dominated by multinational corporations that have constructed large oilseed crushing plants. The plants extract oil in a multistage process as shown in a flow diagram in figure ? . Large oilseed extraction facilities have considerable on site oilseed storage and may have cleaning facilities as well. The extraction facilities can usually receive seed by truck and rail car from farmers and inland terminals. Canadian based facilities have the advantage that they are close to the source of canola and the canola exceeds the domestic crush capacity. In most years this provides an abundant supply of oilseed at a competitive price. The existing crushing facilities have typically operated below their rated capacity but in 2006 they have reported to be operating at 90 percent of capacity (http://news.tradingcharts.com/futures/8/1/76964618.html).

The crushers process canola seed by two processes to separate oil and meal. In the plant in Ste. Agathe MB the canola is processed by a direct crush and the oil is currently sold unrefined. A model budget of this type of operation is included in appendix ? for purposes of comparison. All other large crush facilities operate a process which involves oil reduction by pressing followed by extensive oil extraction with solvents. The latter process, called “pre-press by solvent extraction”, is economically very efficient. A model budget of this operation is included as appendix K.

Once oil is separated from the meal it may be refined for food use. Many of the Canadian crush facilities do not have the capacity to refine all of the oil produced in Canada and ship crude unrefined oil to the US for further processing. Bunge, for example, has reported plans to expand capacity in Nipawin, SK (http://www.bungenorthamerica.com/news/06_01_10.htm)

The costs and benefits of operating large canola crushing facilities in Canada are dealt with below in the Economic Assessment of Biodiesel Production in Saskatchewan. Significant production of biodiesel might affect the crushers depending on the circumstances. Increased biodiesel production may be coupled with increased canola production and the surplus canola may remain constant. In this case canola seed supply will not be affected. However, margins may be affected if the result is competition for domestic canola meal markets which will be potentially oversupplied.

If special non-food oilseed crops are utilized in biodiesel production they may be processed in existing large scale crushing plants operating below capacity, however, there are significant limitations. The large scale plants are producing food products that should not be contaminated with non-food streams. The large plants do not easily switch between feed materials and must be cleaned in the transition from food to non-food operations and re-cleaned in the reversion to food production. The combined transition would result in a loss of 1 day of production. Petros Loutas believes that the larger crushers can in fact conduct full production runs of novel materials if the process fills the plant for at least 10 days (20 to 25,000 tonnes). Smaller volumes may not be economically processed. Furthermore, the design of the larger facilities does not allow for the optimization of processes to the needs of specific materials. For example, processes that require low temperature processes cannot be conducted in existing extraction large scale facilities.

Conclusions: The current large scale crushers can produce large volumes of oil at the lowest cost from canola oil. These crushers may not be able to access opportunities for smaller volume oilseeds as their capacity is dedicated to processing canola for existing markets. Adding crush volume to this sector may be necessary to produce biodiesel.

4.3. Mustard Allyl Glucosinolate Biorefinery (scenario 3):

The MAG biorefinery produces two environmentally friendly products that contribute to improving air and environmental quality. The process converts mustard seed to a biopesticide that is used to control nematodes (a plant pest that causes millions of dollars of damage to crops, lawns and other forms of land use), and biodiesel used as an additive and replacement to petroleum-based diesel. The MAG biorefinery is based on a series of commercially proved technologies. The mustard nematocidal product is manufactured by a joint venture of Peacock Industries, of Hague Saskatchewan, and Nematrol Inc., of Vineland, ON. The consortium has been expanded to include a partnership with Milligan Biotechnology Inc. which has access to technology for oil extraction (a necessary step in production of the biopesticide) and conversion of mustard oil to biodiesel.

Technology/Process: Mustard seed contains a non-toxic compound (allyl glucosinolate) that is broken down by an enzyme (myrosinase) that is also present in the seed. When the allyl glucosinolate and myrosinase are combined in the presence of water a chemical reaction occurs that converts the glucosinolate to glucose and allyl isothiocyanate. It is this latter compound that has nematocidal activity. Therefore processing of mustard seed must be preformed on dry seed and as requires the preservation of both the allylglucosinolate and the myrosinase. A different oil extraction technology is required to remove oil from mustard seed and produce a biopesticide. The de-oiling technology, developed by Agriculture and Agri-Food Canada (AAFC), utilizes a cold-press process that preserves the active ingredient used to make biopesticide.

The biopesticide product can best be described as an environmentally friendly natural nematicide, and has been officially designated as a "biochemical pesticide" by the U.S. Environmental Protection Agency (EPA). This superior Canadian technology provides Canada with a unique commercial opportunity. Saskatchewan is the primary location for mustard production in North America and thus has access to mustard crops required to develop this technology. The AAFC biodiesel production technology has been tested on mustard oil products. Mustard oil is suitable for inclusion in biodiesel but as it produces a product with an elevated boiling point it may only make the European standard if it is blended with other source materials.

The pesticide application of mustard represents an entirely new market for this crop. The potential exists to expand mustard acreage. However, the mustard crop is well established and it has traditionally provided good returns to farmers in Saskatchewan. The costs of expanding acreage of this crop and potential benefits include:

- Sustainable development: Mustard seed is a renewable resource.
- Social benefits to Canada: This project will have a positive impact on rural communities. Many dryer regions are not able to grow high value crops such as canola. Mustard seed grows best in dry climates, and demand for mustard would increase significantly.

Environmental benefits to Canada:

- Increased sustainable crop production by utilizing more mustard plants in Western Canada. Crop rotation is a critical process of alternating crops produced to reduce soil erosion, pest problems and crop loss. Mustard grows well in drier areas, and increased mustard seed demand would allow for more sustainable crop rotation and reduced summer fallow acreage. By avoiding summer fallow it is possible to increase the carbon content of soils and store significant amounts of atmospheric carbon in agricultural land.
- This environmentally friendly biopesticide will replace existing toxic synthetic pesticides such as Methyl Bromide. The product is totally biodegradable and non-hazardous, and safe to the environment and humans.
- These products will reduce greenhouse gas emissions and ozone depleting chemicals via the use of a natural product, grown and processed in Canada.
- Replacing Methyl Bromide as a pesticide.
- Eliminating the natural gas used for producing Methyl Bromide.
- Biodiesel additives will improve the efficiency of diesel combustion.

- Biodiesel fuel production will replace fossil diesel used.
- Provide crop rotation options, increasing soil's carbon content.

Economic benefits to Canada:

- Create high-skilled rural jobs with production of biopesticide and biodiesel.
- Value-added production of biopesticide and biodiesel will be kept within Canada rather than selling low-value crops abroad such as wheat. These high-value products may be sold abroad, generating large amounts of foreign exchange.
- Production of higher-value crops benefits farming communities.

4.4. Solin Flax Biorefinery (scenario 4):

Biodiesel production with alkali catalyst produces a solution of alkaline glycerin as a waste product. The solution has sufficient catalyst and solvent capacity to converts oils, soapstocks, fatty acids, soaps and esters rich in linoleate moieties to conjugated linoleic acid by reacting the same in a crude alkaline glycerol solution. The process is novel in that the crude alkali glycerol solution is prepared as a by-product of biodiesel production. The recycled alkaline solution has sufficient reactivity to isomerize linoleate to conjugated linoleate moieties. The oils such as solin oil may be added to the alkaline glycerol solution directly.

The conversion of solin oil to conjugated linoleate is achieved by mixing the linoleate containing material with the alkaline glycerol solution and increasing the temperature to above 170^{o}C. The reaction proceeds with the alkali present in the glycerol solution alone and additional alkali added to augment the reaction. The reaction proceeds at temperatures above 170^{o} C and accelerates with increases in temperature.

Conjugated linoleic acid is liberated after the reaction from the solution by cooling the mixture to between 20 and 150^{o}C, and adding acid. The glycerol separated by this method is readily recovered and refined. When phosphoric acid is used the waste solution can be neutralized and used as a surface applied fertilizer and there are no disposal costs for discarding this product.

Conjugated linoleic acid is the trivial name given to a series of eighteen carbon diene fatty acids with conjugated double bonds. Applications of conjugated linoleic acid vary from treatment of medical conditions such as anorexia (U.S. Pat. No. 5,430,066) and low immunity (U.S. Pat. No. 5,674,901) to applications in the field of dietetics where CLA has been reported to reduce body fat (U.S. Pat. No. 5,554,646) and to inclusion in cosmetic formulae (U.S. Pat. No. 4,393,043).

CLA shows similar activity in veterinary applications. In addition, CLA is effective in reducing valgus and varus deformity in poultry (U.S. Pat. No. 5,760,083), and attenuating allergic responses (U.S. Pat. No. 5,585,400). CLA has also been reported to increase feed conversion efficiency in animals (U.S. Pat. No. 5,428,072). CLA-containing bait can reduce the fertility of scavenger bird species such as crows and magpies (U.S. Pat. No. 5,504,114).

Industrial applications for CLA also exist where it is used as a lubricant constituent (U.S. Pat. No. 4,376,711). CLA synthesis can be used as a means to chemically modify linoleic acid so that it is readily reactive to Diels-Alder reagents (U.S. Pat. No. 5,053,534).

5. Economic Assessment of Biodiesel Production in Saskatchewan:

A general cost benefit analysis of biodiesel production in Saskatchewan is the focus of the economic assessment in this report. The revenues minus the variable costs from the sale of biodiesel and the co-products produced in an integrated oilseed crushing biodiesel manufacturing industry are the benefits and costs used in this analysis. A linear programming model is used to generate the estimates of the gross returns for the base case and four scenarios. The different scenarios are used to examine some of the economic factors that will influence the production of biodiesel using Canola as a feedstock. The price of feedstock, efficiency of the oil extraction technology, and the selling price of biodiesel are the main factors that are examined.

5.1. Introduction:

A linear program model is used to assess the economics of biodiesel production using Canola seed in Saskatchewan. The background data used in the model is presented first followed by a description of the model. The results of the model for a base case and four scenarios are then presented.

5.2. Canola Seed Supply:

A step supply function is used in the model as a means to differentiate the different qualities and quantities of Canola seed available in Saskatchewan. The step supply function is estimated by adding search and transportation costs to the base cost for each seed quality. First, estimates of the search costs for various hauling distances are calculated from the marginal labour and advertising costs of increasing the targeted area (Table1). Transportation cost estimates are based on commercial trucking rates for the average distance hauled for each category of distance.

Table 1: Search & Transportation Cost ($ tonne^{-1})

	Hauling Distance			
	<100	**101< >200**	**201< >500**	**501< > 1000**
Search Cost[1]	$ 2.47	$ 2.71	$ 3.03	$ 3.45
Transport Cost[2]	$ 8.21	$ 8.84	$ 16.79	$ 31.78
Total Cost	**$ 10.68**	**$ 11.55**	**$ 19.82**	**$35.23**

(Assumes: Search costs based on advertising and labour costs. Transportation costs are calculated from Trimac Consulting Services 1999 adjusted for changes in the price of diesel.)

The 10-year average price of #1 Canola is used as the base price from which the base grade prices for #2, #3 and sample can be estimated (Table 2). The discounts for the lower grades are $8:00 tonne^{-1}, $13:00 tonne^{-1} and 50% of #1 price; for #2, #3 and sample grade, respectively[1]. The costs for search and transportation for the hauling distances are then added to the net price for Canola for each grade to determine the price for the grade of Canola and associated quantity at that distance.

The 10-year average (1995 to 2004) grade distribution and production of Canola for Saskatchewan is used to calculate the average quantity available for each grade of Canola. A step supply function for Canola is estimated using the quantities supplied at each price level for each grade/transportation category given the costs from Table 2 and are presented in Table 3 for low quality seed and Table 4 for high quality seed. The

[1] Winnipeg Commodity Exchange and Saskatchewan Agriculture and Food. These discounts are expected to hold for most years with a typical grade distribution.

quantity of sample grade Canola ranged from zero to 551,570 tonnes with 4 years of no sample grade Canola over this 10-year period.

Table 2: Price[1] of Canola Seed ($\$\text{ tonne}^{-1}$)

Canola Grade	Discount[2] $\$\text{ tonne}^{-1}$	Net Price[3] $\$\text{ tonne}^{-1}$	Hauling Distance (KM) <100	101< >200	201< >500	501< > 1000
#1	$ -	$ 313.49	$ 324.17	$ 325.04	$ 333.31	$ 348.72
#2	$ 8.00	$ 305.49	$ 316.17	$ 317.04	$ 325.31	$ 340.72
#3	$ 13.00	$ 300.49	$ 311.17	$ 312.04	$ 320.31	$ 335.72
Sample	$ 156.75	$ 156.75	$ 167.42	$ 168.29	$ 176.56	$ 191.98

1. The 10-year average price of seed is adjusted for quality, search cost, and transportation cost.
2. Long term average discounts ($\$\text{ tonne}^{-1}$) for Canola from Winnipeg Commodity Exchange and Saskatchewan Agriculture and Food, #2 $8.00 tonne^{-1}, #3 $13.00 tonne^{-1} and Sample 50% of #1 price.
3. Net Price of the Canola at the plant gate by grade of Canola.

Table 3: Canola Price[1] and Supply[2] of Low Quality Seed (LQS)[3]

Category	Canola Price $\$\text{ tonne}^{-1}$	Sample Tonnes	Grade #3 Tonnes	#2 Tonnes	Total Tonnes
LQS Trans 4	340.00		38,004	154,595	192,599
LQS Trans 3	330.00		38,004	154,595	192,599
LQS Trans 2	320.00		57,007	206,126	263,133
LQS Trans 1	310.00		57,007	-	57,007
LQS Sample	195.00	125,608			125,608
Total Tonnes		**125,608**	**190,022**	**515,315**	**830,946**

1. Price of Canada #2, #3 and Sample grade Canola Low Quality Seed (LQS) adjusted for transportation and search costs where Trans 1 = $10.68; Trans 2 = $11.55; Trans 3 = $19.82; Trans 4 = $35.23 per tonne.
2. Supply of Seed is from the 10-year average grade distribution and production of Canola from Agricultural Statistics Handbook various years, Saskatchewan Agriculture and Food.
3. All sample grade Canola is allocated to the LQS Sample category subsequent categories are allocated the remaining quantities based on Table 2.

Table 4: Canola Price[1] and Supply[2] of High Quality Seed (HQS)[3]

Category	Price $ $tonne^{-1}$	Quantity Tonnes
HQS Trans 4	350.00	836,421
HQS Trans 3	340.00	597,444
HQS Trans 2	330.00	477,955
HQS Trans 1	320.00	477,955
Total		**2,389,774**

1. Price of Canada #1 grade Canola High Quality Seed (HQS) adjusted for transportation and search costs where Trans 1 = $10.68; Trans 2 = $11.55; Trans 3 = $19.82; Trans 4 = $35.23 per tonne.
2. Supply of Seed is the 10-year average grade distribution and production of Canola from Agricultural Statistics Handbook various years, Saskatchewan Agriculture and Food.
3. Categories are allocated Canola quantities based on Table 2.

5.3. Canola Oil Extraction Coefficients:

The oil content for the various grades of canola from the Canadian Grain Commission Annual Harvest Surveys 1998-2005 are used to adjust the base coefficient of 2.322 kg of seed $Litre^{-1}$ of oil.[2] The coefficients for the grade/transportation categories used in the model for three oil extraction rates are presented in Table 5.

Table 5: Canola Oil Extraction Coefficients[1] kg seed $litre^{-1}$ Oil

Seed Category	92% Oil Extraction	95% Oil Extraction	98% Oil Extraction
LQS Trans 4	2.4968	2.4179	2.3439
LQS Trans 3	2.4997	2.4208	2.3467
LQS Trans 2	2.5009	2.4220	2.3478
LQS Trans 1	2.5483	2.4678	2.3923
LQS Sample	2.6215	2.5387	2.4610
HQS Trans 4	2.4246	2.3480	2.2761

1. The kilograms of canola seed required to produce a litre of biodiesel, adjusted for the oil content of the seed and technology used to extract the oil. Base coefficient of 2.322 kg seed $Litre^{-1}$ of oil for a 41.5% oil content.

5.4. Canola Meal Market:

The net price received at the plant gate and the expected quantity to be sold in each of the markets is presented in Table 6. The net price adjusted for inflation accounts for the transportation of the meal to the selected markets. On average Canada has produced 1,833,929 tonnes of canola meal over the 1996-97 to 2004-05 crop years with the United States accounting for 97% of the exports with domestic utilization at 34.9% of production in recent years. Canola meal is mainly valued for its protein and is used in swine, poultry and dairy rations.

[2] Base coefficient calculated as 1000/(1000*0.415/0.963894), for a standard oil content of 41.5%.

Table 6: Price[1] and Quantity[2] of Canola Meal

Market	Meal $ tonne^{-1}	Quantity Tonnes	%
Local	$ 190.00	36,678	2%
Saskatchewan	$ 180.00	147,628	8%
Domestic (ROC)	$ 165.00	476,811	26%
Export (U.S)	$ 146.00	1,172,812	64%
Total		**1,833,929**	**100 %**

1. Inflation adjusted price of meal plus transportation costs to the selected markets.
2. Quantity of meal for selected markets, export market accounts for 65% of production with the U.S. taking 97%.

6. Diesel and Biodiesel Pricing:

The retail price of diesel can be calculated from crude oil prices plus refining and marketing margins and taxes (MJ Ervin & Associates).

Crude Oil Price ($/barrel) / (159 litres) +
Processing Margin (8.35 cents/litre) +
Marketing Margin (7.42 cents/litre) +
Taxes (Federal Excise 4 cents per litre + GST + Provincial)
=Retail Diesel Price

Biodiesel can replace the cetane-enhancing additive used in diesel in Western Canada, which costs about 0.2 cents per litre ((S&T)[2] and MNP 2004). The cetane value of vegetable oil diesel is 0.4 cents per litre and animal fat biodiesel is 1.2 cents per litre. Lubricity value of biodiesel has been estimated at 2.5 to 5.0 cents per litre for B2, 1.0 to 2.0 cents per litre B5 and 0.25 to 0.5 cents per litre B20. Cold weather properties of biodiesel may require the addition of cold flow improvers for Western Canada ranging in cost from 0.3 to 4.0 cents per litre ((S&T)[2] and MNP 2004). The need for cold flow improvers varies by the feedstock used to make biodiesel (less for vegetable based), it increases with increased blend levels and differences in diesel fuel quality. The cost of blending biodiesel will depend on where the biodiesel is blended and the blend (B5 or B20). A summary of the positive and negative attributes associated with the use of biodiesel is presented in Table 7. Increasing the amount of biodiesel in a blend reduces the contribution per unit of biodiesel added of the positive aspects as most of the benefits are achieved at low rates of biodiesel. However, the cost increases to maintain cold flow ability as the blend percentage increases. Although, Schmidt 2004 states that tests of a B20 blend at temperatures of 20 to 40 C had almost no problems it remains to be seen whether a cold flow additive will be needed for Western Canada.

Table 7: Economic Value of Biodiesel Attributes of Different Blends[3]

	Additive	Farm Gate	B5	B20
	Cents/litre	Cents/litre	Cents/litre	Cents/litre
Cetane Value[1]	0.4 to 1.2	0.4 to 1.2	0.4 to 1.2	0.4 to 1.2
Lubricity Value	2.5 to 5	.25 to .5	1.0 to 2.0	.25 to .5
Blending Cost	-3.0	-1.0	-2.0	-1.0
Cold Weather Properties[2]	0	-0.3	-1.0 to -2.0	-1.5 to -3.0
Total	-.1 to 3.2	-.65 to 0.4	-1.6 to -0.8	-1.85 to -2.3

Source: Adapted from (S&T)[2] and MNP 2004.

Cetane Value 0.4 to 1.2 cents per litre higher value in western Canada due to less heating fuel being produced. A cetane number is determined by an engine test using two reference fuel blends with known cetane numbers. A cetane index is a calculated value, derived from fuel density and volatility that gives a reasonable approximation of the cetane number.

Schmidt 2004, claim that B20 demonstrations in 20 to 40 C had almost no problems.

Blends of biodiesel; Additive 1% biodiesel; Farm Gate (produced on farm) up to B100; B5 5% biodiesel; B20 20% Biodiesel.

Historic prices of North American biodiesel can be obtained from the Energy Management Institute, Alternative Fuels Index www.energyinstitution.org. The price of biodiesel used in this study is calculated as the cost of diesel plus the federal excise tax of $0.04 per litre and adjusted for biodiesel attributes (Table 7). The price of biodiesel before retail margin, provincial tax and GST for a number of markets is presented in Table 8. The biodiesel prices as presented here reflect the value of the biodiesel relative to the value of diesel. A biodiesel additive can be priced higher than regular diesel as the attributes of the additive are positive. On farm production of biodiesel has a slightly higher relative value than diesel. Biodiesel used in a B5 or B20 blend has a lower value relative to diesel.

Table 8: Wholesale Price of Biodiesel

					Diesel	Biodiesel[3]			
Price of Crude Oil		Processing[1]	Marketing[1]	Tax[2]	Price	Additive	Farm	B5	B20
$/barrel	$/litre	$/litre	$/litre	$/litre	$/litre	$/litre	$/litre	$/litre	$/litre
20	0.126	0.084	0.074	0.04	0.323	0.355	0.327	0.315	0.300
25	0.157	0.084	0.074	0.04	0.355	0.387	0.359	0.347	0.332
30	0.189	0.084	0.074	0.04	0.386	0.418	0.390	0.378	0.363
35	0.220	0.084	0.074	0.04	0.418	0.450	0.422	0.410	0.395
40	0.252	0.084	0.074	0.04	0.449	0.481	0.453	0.441	0.426
45	0.283	0.084	0.074	0.04	0.481	0.513	0.485	0.473	0.458
50	0.314	0.084	0.074	0.04	0.512	0.544	0.516	0.504	0.489
55	0.346	0.084	0.074	0.04	0.544	0.576	0.548	0.536	0.521
60	0.377	0.084	0.074	0.04	0.575	0.607	0.579	0.567	0.552
65	0.409	0.084	0.074	0.04	0.607	0.639	0.611	0.599	0.584
70	0.440	0.084	0.074	0.04	0.638	0.670	0.642	0.630	0.615
75	0.472	0.084	0.074	0.04	0.669	0.701	0.673	0.661	0.646
80	0.503	0.084	0.074	0.04	0.701	0.733	0.705	0.693	0.678

1. Processing and marketing costs from Ad Hoc Report- MJ Ervin & Associates.
2. Federal excise tax.
3. Blends of biodiesel; Additive 1% biodiesel; Farm (produced on farm) up to B100; B5 5% biodiesel; B20 20% Biodiesel.

6.1. Linear Program Model:

The linear program model used to analyze the production of biodiesel in the province of Saskatchewan maximizes the net returns of producing biodiesel and the associated co-products. A flowchart of the model is presented in Figure 1 and a formal statement of the model and the Solver Tableau for the base case is in Appendix A. Feedstock enters the model using a step supply function in a sequential manner as the quantity for the highest net return for a grade/transportation category is used first. Coefficients in the model are used to calculate the amount of biodiesel, meal, glycerine and Free Fatty Acids produced from the grade/transportation category of seed. The model maximizes the net returns of the products produced subject to the constraints on seed quantity by grade/transportation category, demand for meal in each market category, and size of the biodiesel market.

Figure 1: Linear Program Flowchart

LQS Low Quality Seed graded as sample, #3 or #2 Canola.
HQS High Quality Seed graded as #1 Canola.

Feedstock Step Supply Function
LQS Quantity available differentiated by grade, transportation cost and search cost

Conversion Coefficients
Coefficients for oil and meal produced from each quality of seed

Biodiesel (Litres)

Free Fatty Acids

Meal (tonnes)

Glycerine (tonnes)

Net Return for Each Product
Selling price of each product minus the variable cost of producing

Objective Function Value
The feedstock with the highest net return is brought into the model
Subject to the constraints:
- Quantity of seed in a grade/transportation category,
- Demand for meal in each market category,
- Size of the Biodiesel market.

6.2. Production of Biodiesel Additive Description:

Biodiesel additive for this study is manufactured from refined vegetable oil in an integrated oilseed crushing and biodiesel production and packaging facility. The consistency of the final product is important so only one feedstock is used in the manufacture of the additive. Since, canola oil has the best properties for use as an additive when compared to other vegetable and animal oils its the only feedstock used in this analysis.

A flowchart of the integrated process used as the basis for the analysis of this technology is presented in Figure 2. The oilseed crushing facility produces crude oil for biodiesel manufacture and meal to be sold in the feed market. A Biodiesel plant produces biodiesel and the co-products of glycerine and free fatty acids.

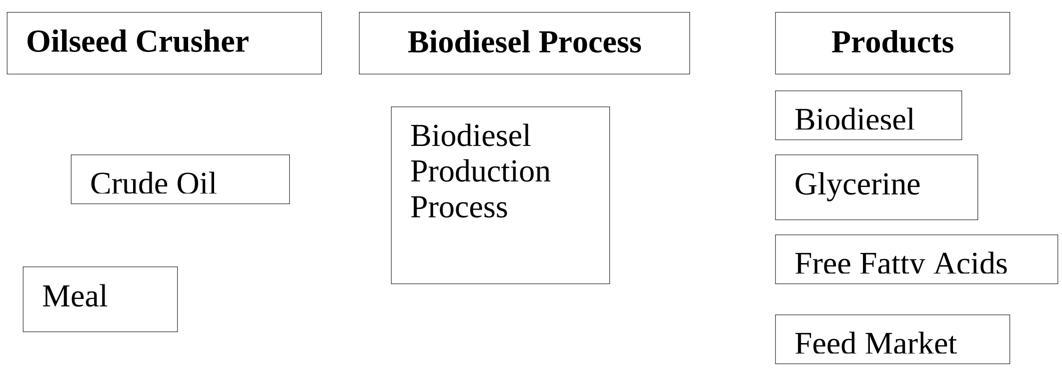

Figure 2: Process Flow Integrated Canola Crushing and Biodiesel Production

6.3. Capital Cost:

The manufacturing process requires a building for oilseed crushing and extraction, and for the manufacture of biodiesel. Infrastructure costs consist of site land cost and preparation, gas, electricity, water, and sewer. Feedstock storage, grain cleaning, cold press oil extruder, oil expeller, oil storage tank, meal processing and storage and various material conveyors are the equipment needed to crush and process the oilseed. The production of biodiesel additive requires a batch processor, storage tanks and packaging equipment.

The capital per litre of output for a biodiesel plant of various capacities is presented in Table 9. The amount of capital used as a base to calculate other costs in the model is $.32 per litre for the biodiesel plant and $.145 per litre for the oilseed crushing plant for a total capital requirement of $.465 per litre of biodiesel produced.

Table 9: Integrated Canola Crushing and Biodiesel Plant Capital ($ litre^{-1})

Plant Size	Biodiesel $ litre^{-1}	Crusher $ litre^{-1}	Integrated Total
1.9 million litre[1]	0.70	0.34	1.040
11.3 million litre[1]	0.42	0.230	.650
56.7 million litre[1]	0.24	0.150	.390
113 million litre[1]	0.19	0.140	.330
Lurgi 60 million litre[2]	0.32	0.145	.465
Lurgi 120million litre[2]	0.23	0.140	.370
BIOX 60million litre[2]	0.25	0.145	.395

1 Source: (S&T)^2 and MNP 2004.
2 Source: Envirochem Services Inc.

6.4. Labour:

Direct labour is required for the canola crushing and biodiesel manufacture consisting of operators and maintenance personnel with some labour savings if it is an integrated plant. The rates for direct labour costs of Employment Insurance, Canada Pension Plan and Workmanâ€™s Compensation are from the respective government agencies. A holiday pay rate of 5.8% is also included in the direct labour costs. The per litre cost of direct labour and benefits are .0157 and .002 $ / litre^{-1} biodiesel, respectively for the biodiesel plant. This is based on the labour cost factor from ((S&T)^2 and MNP 2004) using a base labour cost of $32,000 per worker per year. The direct labour cost for a canola crushing plant is based on the labour requirements from Georgia Oilseed Initiative 2001 for a 700 tonne per day plant and benefits are .01 and .0013 $ litre^{-1} biodiesel, respectively.

6.5. Feedstock:

Biodiesel additive manufacture can use any grade of canola as the feedstock. Canola oil is produced from canola seed using cold press extruder and oil expeller technology, which extracts 95% of the oil contained in the seed. The cost allocation of the feedstock to oil and meal is 40% and 60%, respectively. This is based on the market value of canola seed as calculated by the Winnipeg Commodity Exchange.

6.6. Operating and Fixed Costs:

The operating costs per litre of biodiesel produced to crush and refine the feedstock are presented in Table 10. Labour and benefits (CPP, EI, WC), natural gas and administrative expense account for over 75% of the total operating cost. The operating and fixed expense of crushing the oilseed is allocated to the cost of making biodiesel and meal at the 40-60 split, respectively.

Table 10: Cost of Oilseed Crushing ($ Litre^{-1} Biodiesel)

Operating Expense	$ litre^{-1} BD	%
Natural Gas[1]	0.0091	24.1%
Electricity[2]	0.0039	10.2%
Water & Sewer[3]	0.0011	3.0%
Direct labour[4]	0.0100	26.6%
Direct labour Benefits[4]	0.0013	3.4%
Maintenance[5]	0.0015	3.9%
Administrative[6]	0.0100	26.6%
Processing Supplies	0.0009	2.3%
Total Operating Expenses	**$ 0.0377**	**100%**
Fixed Expenses	**$ litre^{-1} BD**	
Depreciation	0.008	
Interest on LTD	0.008	
Total Fixed	**$ 0.016**	

1. Natural gas use rates from Agri-industry Modeling and Analysis Group, 2003. Price from Sask Energy.
2. Electricity use rate from ENVIROCHEM Services Inc, 2005. Price from Sask Power.
3. Water and Sewer use rates from Georgia Oilseed Initiative, 2001.
4. Direct labour and benefits - number of workers from Georgia Oilseed Initiative, 2001. Canada Pension Plan 4.95%, Employment Insurance 1.95%, Workman's Compensation - $1.40/$1000 income, Holiday Pay 5.8%.
5. Maintenance 1% of plant capital cost (S&T)[2] and MNP 2004.
6. Administrative includes office costs, marketing, local tax and insurance.

Biodiesel operating costs consist of methanol, catalyst, labour (CPP, EI, WC), repairs, natural gas, electricity, water and sewer plus any interest on an operating loan and long-term debt. Methanol cost adjusted for freight to arrive at a Saskatchewan price of $0.278 per litre[3] is used at a rate of 0.11 litre litre^{-1} biodiesel. Energy in the form of natural gas is required at 1.4 MJ litre^{-1} biodiesel and electricity at 0.27 KWHr litre^{-1} biodiesel both priced at the commercial rate. Packaging costs for the biodiesel sold by retailers consist of the capital equipment and containers. The fixed costs consist of depreciation, and principle repayment. The operating and fixed costs for biodiesel manufacture are in Table 11. The cost per litre of biodiesel produced at $0.1047 is in the range estimated by LevNRCan in Schmidt 2004 at $0.098 and Wise 2004 at $0.12. Differences in the costs of natural gas, electricity and methanol account for most of the variation in cost between the studies.

[3] Methanex monthly average regional posted contract price adjusted for freight and exchange rate May-2001 to Feb 2006.

Table 11: Cost of Biodiesel Manufacture ($ Litre^{-1} Biodiesel)

Operating Expenses	$ litre^{-1} BD	%
Natural Gas[1]	0.0049	4.7%
Electricity[2]	0.0013	1.2%
Methanol[3]	0.0306	29.2%
Direct labour[4]	0.0157	15.0%
Direct labour Benefits[4]	0.0020	1.9%
Maintenance[5]	0.0032	3.1%
Administrative[6]	0.0180	17.2%
Processing Supplies	0.0290	27.7%
Total Operating Expenses	**$ 0.1047**	**100%**
Fixed Costs	**$ litre^{-1} BD**	
Depreciation	0.018	
Interest on LTD	0.018	
Total Fixed	$ 0.036	

1. Natural gas use rates from (S&T)[2] and MNP 2004. Price from Sask Energy.
2. Electricity use rate from Radich, 2003. Price from Sask Power.
3. Methanol prices from Methanex monthly average regional posted contract price adjusted for freight and exchange rate May- 2001 to Feb 2006.
4. Direct labour and benefits - number of workers from (S&T)[2] and MNP 2004. Canada Pension Plan 4.95%, Employment Insurance 1.95%, Workman's Compensation - $1.40/$1000 income, Holiday Pay 5.8%.
5. Maintenance 1% of plant capital cost (S&T)[2] and MNP 2004.
6. Administrative includes office costs, marketing, local tax and insurance.

6.7. Co-Products:

A number of co-products are produced when biodiesel is manufactured. The production of biodiesel results in 0.079 kg glycerine per litre of biodiesel (Dalai 2000). Glycerine can be marketed as crude glycerine, which sells for between 11.5 and 16 cents per kilogram (Wise 2004). It is not expected that it would be profitable given the amount of glycerine produced for a company to further process the glycerine. There is one glycerine plant in Saskatchewan, Akzo Nobel in Saskatoon, with an annual capacity of .6 kilotonnes (Wise 2004). However, if there is an oversupply of glycerine on the market due to increased biodiesel production the glycerine may have no market value. In which case it can be burned as a process heat source and valued as a replacement for natural gas or composted. Other markets for glycerine may develop as the production of biodiesel increases i.e. use as an antifreeze propylene glycol (McClinton 2006), construction industry as a form oil (Wise 2004). A cost of $.112 per kilogram is attributed to glycerine handling and marketing.

Free Fatty Acids (FFA) can be burned as a process heat source, sold as an ingredient for animal feed, or composted. FFA is produced at 0.004 kg FFA per litre of biodiesel (Dali 2000) and can be sold for $.01 per kilogram with a cost of selling at $.005 per kilogram. Sodium Phosphate/Potassium Phosphate can be marketed as a fertilizer or composted.

7. Results:

The operating costs as calculated for producing biodiesel additive are used to determine the net returns for the biodiesel and co-products of meal, glycerine and Free Fatty Acids. In the base case scenario the seed cost is approximately 70% of the total variable costs of producing biodiesel except for sample grade Canola (58%). The range in the percentage of feedstock to variable cost calculated in other studies is from 70% to 90%. Recycled oils, animal fats and low grade oilseeds are on the low end of the estimates while use of high quality seed or using toll processed vegetable oil is on the high end.

Four biodiesel scenarios were developed from the base case. In scenario 1 the cost of Canola seed was increased by $100 tonne^{-1} and the selling price of meal was also adjusted to reflect the increased seed cost. In scenario 1 the cost of seed accounts for 75% of the variable costs of producing biodiesel. In scenario 2 the extraction rate of oil from canola seed was decreased from 95% in the base case to 92%. In scenario 3 the extraction rate of oil from canola seed was increased from 95% in the base case to 98%. The price of biodiesel additive was reduced to the rack price of diesel in scenario 4. The assumptions used in the scenarios are outlined in Table 12.

Table 12: Assumptions Used in the Scenarios

	Oil Extraction	Biodiesel Price[2]	Seed Cost[3]
Scenarios[1]	%	\$ $Litre^{-1}$	\$ $tonne^{-1}$ difference
Base Case	95%	0.5442	-
Scenario #1	95%	0.5442	+ $100
Scenario #2	92%	0.5442	-
Scenario #3	98%	0.5442	-
Scenario #4	95%	0.4722	-

Scenarios are Base Case,
Scenario #1- cost of seed increased by $100 per tonne over the base case.
Scenario #2 oil extraction rate decreased by 3% from the base case to 92%.
Scenario #3 oil extraction rate increased by 3% from the base case to 98%.
Scenario #4 biodiesel sold at wholesale for the rack price of diesel plus federal excise tax.
Biodiesel price is from table 8 for the $50 per barrel price of crude row.
Seed Cost difference in the cost of seed from the base.

A summary of the results for the base case and four scenarios are presented in Table 13. The base case objective function value is $23 million with a fixed cost of $12 million for a net return of $11 million. The meal that is produced is sold at a loss of $8 million while glycerine and Free Fatty Acids add little to the net return. An increase in the price of Canola seed by $100 per tonne reduces the production of biodiesel from 237 million litres to 76 million litres as it becomes only profitable to crush sample grade Canola. However, the net return is only $2 milllion less than in the base case as meal sales are a positive contribution to the net return. The increase in the price of meal as a result of higher Canola seed cost accounts for most of the positive contribution of meal in this scenario. Lowering the extraction rate to 92% reduces the net return to $8 million as more seed is crushed to produce the same quantity of biodiesel and more meal is sold at a loss. Increasing the extraction rate to 98% resulted in the highest net return at $26 million. The higher net return is due to the lower amount of seed purchases to produce the same amount of biodiesel and lower amount of meal that is sold at a loss. Reducing the price for biodiesel to the rack price of diesel results in the lowest net return for the scenarios at $6 million. Meal produced only from low quality seed makes a $179,000 contribution to the net return.

Table 13: LP Biodiesel Base Case and Scenarios Results

	Model Base Case	Increased Seed Cost[8]	Oil Extraction Rate[9] 92%	Oil Extraction Rate[9] 98%	Diesel Rack Price[10]
Objective Function Value[1]	$ 23,304,544	$ 12,870,485	$ 20,178,674	$ 26,239,230	$ 10,087,891
Fixed Cost[2]	$ 12,360,920	$ 3,945,025	$ 12,360,920	$ 12,360,920	$ 3,945,025
Net Return[3]	$ 10,943,624	$ 8,925,460	$ 7,817,754	$ 13,878,310	$ 6,142,866
Seed Crushed (Tonnes)	572,608	192,599	590,808	555,522	192,599
Biodiesel Produced (Litres)	237,710,000	75,865,864	237,710,000	237,710,000	75,865,864
Meal Produced (Tonnes)	343,482	119,473	361,681	326,395	119,473
Meal Contribution ($)[4]	(8,260,854)	1,118,210	(9,057,168)	(7,513,244)	179,021
LQS Sample Crushed (Tonnes) [5]	192,599	192,599	192,599	192,599	192,599
HQS Trans 1 Crushed (Tonnes)[6]	380,009	-	398,209	362,923	0
Glycerine ($/kg)	0.003	0.003	0.003	0.003	0.003
Quantity (Kilograms)	600,000	600,000	600,000	600,000	600,000
Total Contribution ($)	$ 1,800.00	$ 1,800.00	$ 1,800.00	$ 1,800.00	$ 1,800.00
FFA[7] ($/kg)	0.005	0.005	0.005	0.005	0.005
Quantity (Kilograms)	950,840	303,468	950,840	950,840	303,468
Total Contribution ($)	$ 4,754.20	$ 1,517.34	$ 4,754.20	$ 4,754.20	$ 1,517.34

Objective Function Value the Selling price of the biodiesel, meal, glycerine, and FFA minus the respective variable costs times the quantities produced.
Fixed Cost the costs of depreciation and interest on long-term debt for the integrated oilseed crushing and biodiesel manufacturing plants.
Net Return the value for the objective function minus the fixed costs.
Meal Contribution the dollar value of the meal sold in all markets.
LQS Sample amount of sample grade canola seed that is crushed.
HQS Trans 1 amount of #1 grade of canola from the local market that is crushed.
FFA Free Fatty Acids.
Cost of Seed increase the cost of seed by $100 tonne^{-1} over the base case, selling price of meal is also increased.
Oil Extraction Rate 95% in the base case.
Rack Price biodiesel priced at the rack price of diesel calculated as crude oil price + processing cost + marketing cost.

8. Summary:

The quantity of low priced Canola that is available in a given year and the value of meal are the main factors driving the profitability of a biodiesel industry in Saskatchewan. Although the canola market does not price the seed on the basis of oil content the profitability of biodiesel manufacture depends on the price of the seed and oil content.

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