TECHNICAL AND ECONOMIC FEASIBILITY OF BIODIESEL PRODUCTION IN VERMONT: EVIDENCE FROM A FARM-SCALE STUDY AND A COMMERCIAL-SCALE SIMULATION ANALYSIS

A Thesis Presented

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ABSTRACT

Concerns about Vermont's dairy farm viability, greenhouse gas emissions, and reliance on fossil fuels have prompted growing interest in the production of biodiesel and oilseed meal from Vermont-grown oilseed crops. The idea is that Vermont farmers could grow and harvest oilseed crops; the seed or beans could be pressed into vegetable oil and oilseed meal; and the oil could be processed into biodiesel, thereby producing both liquid biofuel and protein meal for livestock from Vermont crops. Results from this study indicate that oil, meal, and biodiesel production from sunflowers grown in Vermont is technically feasible, and may be economically feasible at both the farm and commercial scales, depending on scale and market conditions.

Farmers, entrepreneurs, and policymakers are intrigued by the potential to decrease Vermont's dependency on imported fuels and feed, reduce farms' production costs, realize local economic benefits from import substitution, and lower greenhouse gas emissions. Despite the promise of "Vermont-made" biodiesel and oilseed meal, however, it remains largely an unproven concept. Production of oilseed crops is relatively rare in Vermont, especially in quantities sufficient for biodiesel or livestock meal production. The equipment, capital, acreage, and expertise needed to successfully grow, harvest, and process these crops have not been identified, and the economic feasibility, optimal scale, and environmental and macroeconomic impacts of these new enterprises in Vermont is unknown.

This study investigates the technical and economic feasibility of producing biodiesel and livestock feed from Vermont oilseeds at a farm scale and a commercial scale. Technical feasibility at the farm scale is assessed using data from two Vermont farms. Enterprise budgets are used to assess the economic feasibility and profitability of the crop, oil and meal, and biodiesel enterprises individually and as a whole under two sets of market conditions. Economic feasibility and environmental and economic impacts of a commercial-scale biodiesel facility in Vermont are assessed using a simulation model.

None of the farm-scale enterprises were profitable as budgeted in this analysis, although the commercial-scale plant was more profitable as crude oil prices rose. The most promising enterprise at the farm scale appears to be oil and meal production. This study prompts additional questions regarding the extent to which Vermont crop production should shift to include oilseeds for biodiesel production, the net energy return to the farm, and lifecycle greenhouse gas emissions from on-farm production.

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ADDITIONAL MATERIAL

Data output from the simulation model used to evaluate commercial-scale production in this study is available on a separate disc and included with the electronic version of this thesis on file at the University of Vermont Libraries.

CHAPTER 1: INTRODUCTION

This chapter discusses the motivation and justification for this research, the broader objectives it seeks to fulfill and the specific questions it seeks to answer, and its potential significance and applications.

1.1 Research Motivation and Justification

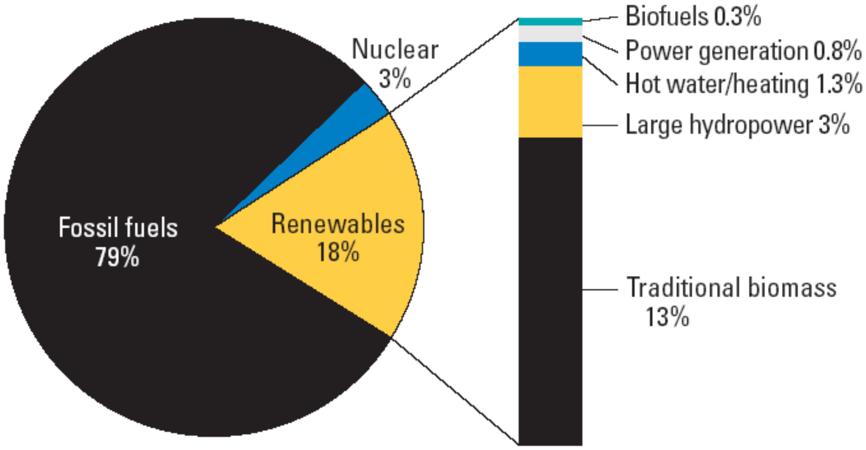
In the first half of 2008 the world experienced a “perfect storm” of record-high prices for energy, food, and other global commodities. The futures price for light-sweet crude oil on the New York Mercantile Exchange (NYMEX) passed $100 per barrel on February 19 and reached its first of several record highs at $110.93 on March 13 before peaking at $145.29 on July 3 and falling to $113.01 per barrel on August 14, 2008. The price of crude oil for most of the summer of 2008 was almost five times its level in the summer of 2003 (Energy Information Administration, 2008c). Meanwhile, public awareness of the threat of global climate change from greenhouse gas emissions continues to rise, with the awarding of the 2007 Nobel Peace Prize to Al Gore and the Intergovernmental Panel on Climate Change shining an international spotlight on the issue. Although a severe global economic recession has caused oil prices to fall to approximately $40 per barrel, the summer of 2008 provided a glimpse of what may again happen if the world’s oil capacity and reserves fail to keep up with global oil consumption.

The development of alternative energy sources is widely seen as a way to help reduce dependence on fossil fuels for both environmental and economic reasons. One source of alternative energy is biomass, plant-based organic matter such as wood, energy crops, and waste materials that can be renewably produced and converted to electricity, heat, fuels, or chemicals. The liquid biomass-derived fuels or “biofuels” currently being produced in the greatest quantity in the United States are ethanol, a gasoline substitute, and biodiesel, a substitute for petroleum-based diesel fuel.

The potential impact of these alternative fuels to reduce greenhouse gas emissions is significant, since transportation accounts for approximately 27% of worldwide energy use, and 98% of that energy is supplied by liquid, petroleum-based fuels (Energy Information Administration, 2007c). At the same time, however, because liquid biofuels in the U.S. are currently made almost entirely from food crops (corn and soybeans), the rapid growth in their production was criticized for contributing to rises in global food prices in 2008, which increased by 83% compared to the previous three years (World Bank, 2008). Corn futures, for example, which averaged $2.52 per bushel for the period 1990–2005 (Hart, 2006), reached nearly $8.00 per bushel in July 2008 (Lane, 2008). Biofuels production became a central issue in the growing debate around the tightening link between food and energy markets at a time of unprecedented global demand in both sectors.

1.1.1 Liquid Biofuels Market Trends

Liquid biofuel production worldwide has grown dramatically in recent years, with biodiesel and ethanol capacity increasing by 40% and 10%, respectively, from 2002 to 2006 (Martinot, 2008). Many nations view biofuels as a simple, renewable alternative to fossil fuels that can reduce carbon and greenhouse gas emissions, increase farm income and promote rural development, and increase energy security (Rajagopal & Zilberman, 2007). Global production of biodiesel and ethanol in 2007 was an estimated 14 billion gallons, an increase of 43% over 2005 levels. Despite this growth, however, biofuels supplied just 0.3% of the world's energy consumption in 2006 (Figure 1).

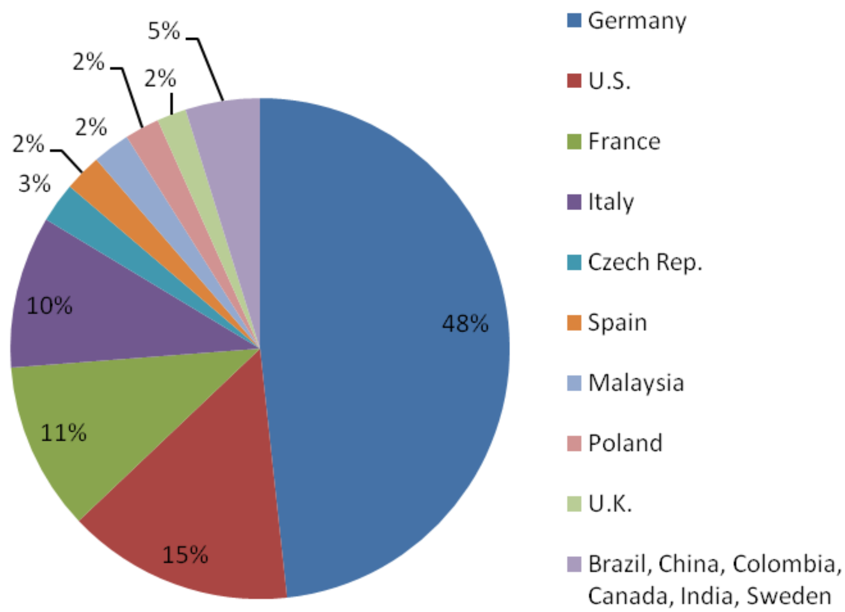


Source: (Martinot, 2008)

Figure 1: Renewable energy as a share of global energy consumption, 2006

In the U.S., factors contributing to the rapid growth of ethanol and biodiesel industries include rising oil prices, the discontinued use of methyl tertiary-butyl ether (MTBE) as a fuel additive, increased demand for low-sulfur diesel, regulatory and tax incentives, and more efficient production facilities (Eidman, 2007).

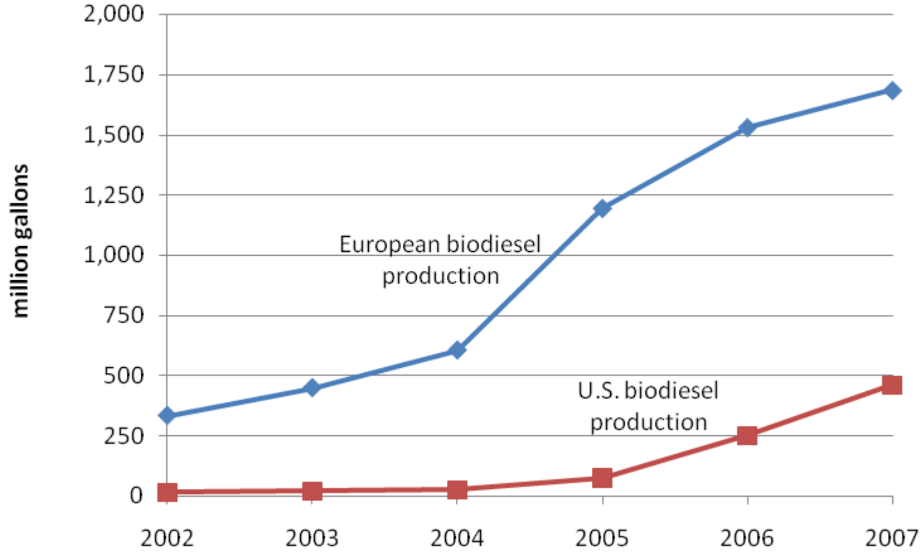
The Biodiesel Market. Biodiesel can be used as an alternative fuel for an entire group of refined petroleum products known as "distillate fuel oils," which include No. 1, 2, and 4 diesel fuels for on- and off-highway use, and No. 1, 2, and 4 fuel oils for space heating and electric power generation (Energy Information Administration, 2008a). Biodiesel can be blended with regular diesel fuel to produce concentrations of biodiesel between 2% and 99%, which are denoted B2–B99 (the number following the "B" indicates the percentage of biodiesel in a gallon of fuel). Worldwide biodiesel production was approximately 1.6 billion gallons in 2006, with over half of that amount coming from Germany, the world's leading producer. As shown in Figure 2, the U.S., France, Italy, and the Czech Republic rounded out the top five producers, while significant growth in biodiesel production is occurring in Malaysia, Indonesia, Singapore, China, Argentina, Brazil, Romania, and Serbia (Martinot, 2008). Europe's biodiesel industry is the world's largest and most mature, driven by government policies and aided by market conditions.



Source: Constructed by the author using data from Martinot (2008).

Figure 2: 2006 biodiesel production in top 15 biofuel-producing countries

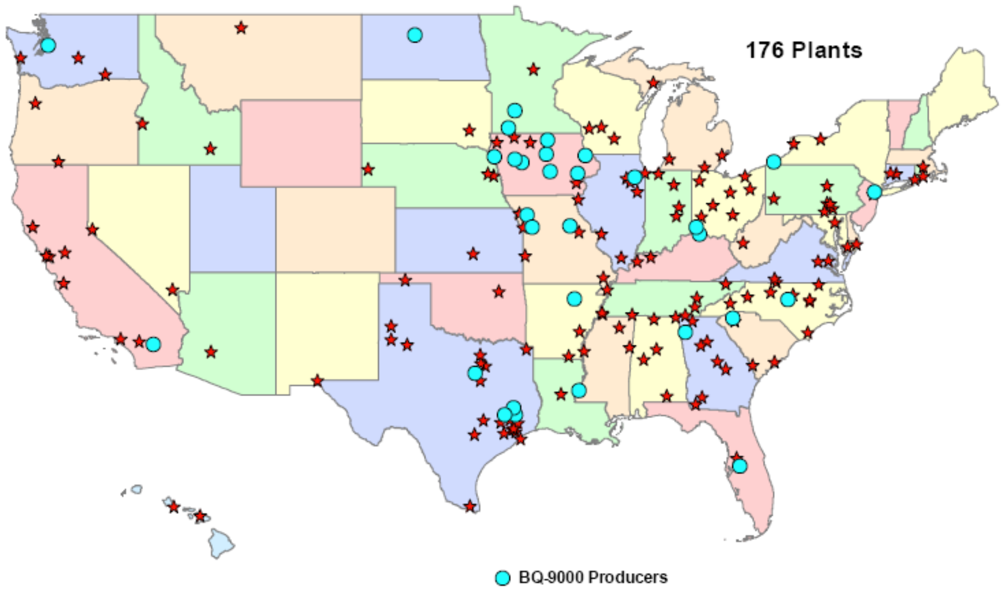
Development of the U.S. biodiesel industry was driven initially by the efforts of soybean producers who wanted to expand markets and demand for their crops, and the industry began meaningful production only after federal policies to support biodiesel production were introduced beginning in 1998. As Figure 3 shows, production of biodiesel in the U.S. has risen dramatically in the past four years, tripling from 25 million to 75 million gallons from 2004 to 2005, more than tripling again to 250 million gallons in 2006, and reaching an estimated 700 million gallons by September 2008 (National Biodiesel Board, 2008a).



Source: Constructed by author using statistics from National Biodiesel Board and European Biodiesel Board.

Figure 3: Biodiesel production in Europe and U.S., 2002–2007

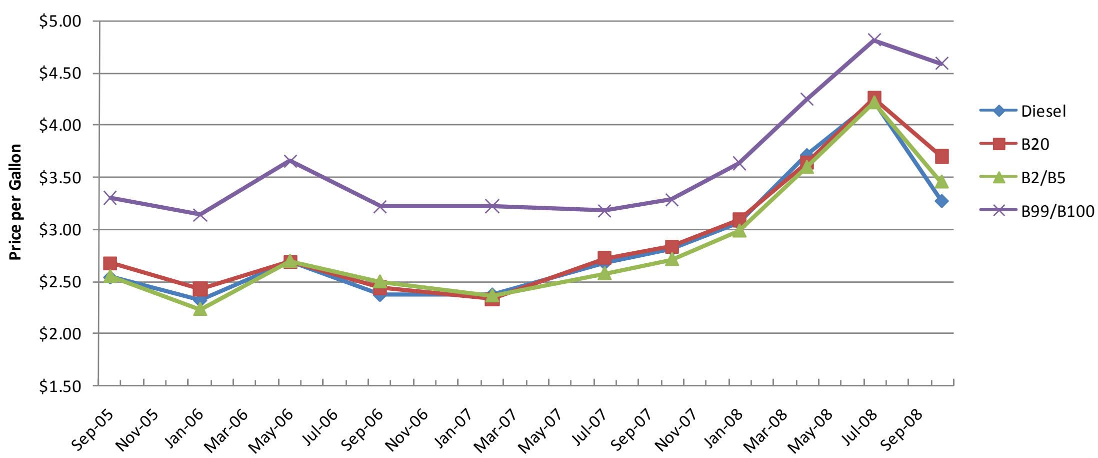
The National Biodiesel Board reported in September 2008 that 176 biodiesel plants have been constructed in the U.S. with a total annual capacity of 2.61 billion gallons (Figure 4). Even before the economic downturn, however, the U.S. biodiesel market was producing well below its capacity, with an estimated utilization rate of 43% to 57% (Carriquiry, 2007). Nevertheless, another 39 plants representing 849.9 million gallons of capacity are due to be constructed by early 2010 (National Biodiesel Board, 2008c).



Source: National Biodiesel Board

Figure 4: Commercial biodiesel plants in the U.S., September 2008

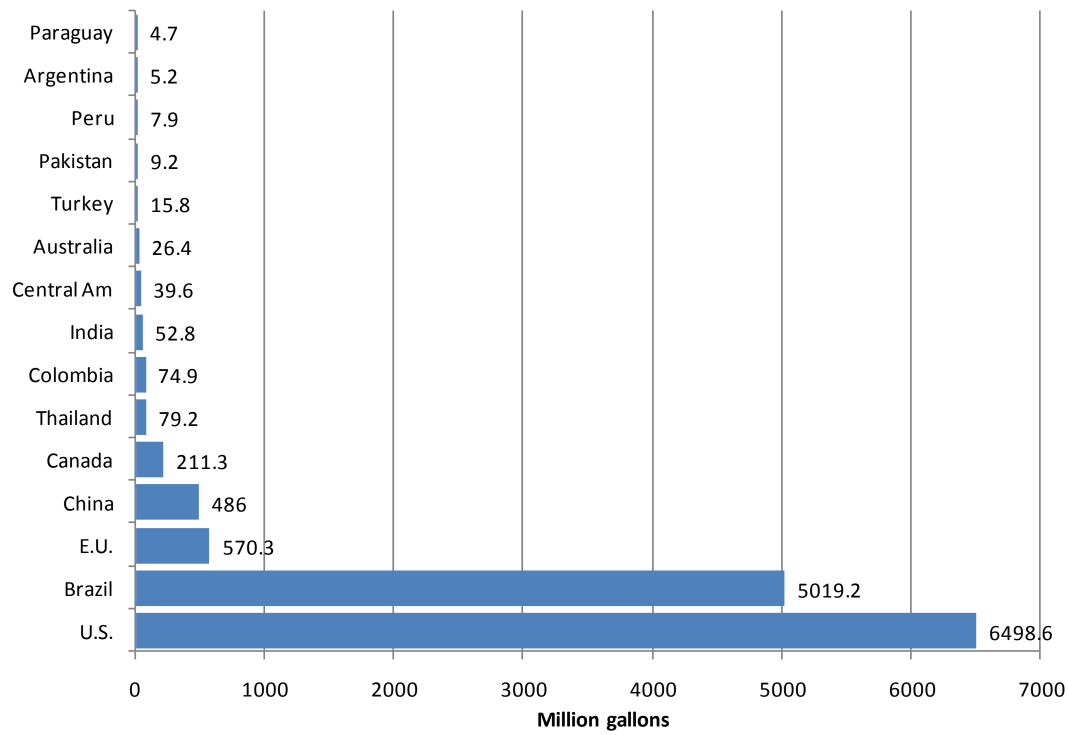
In October 2008, the U.S. DOE reported the average retail price for B20 in New England and nationally at $4.04 per gallon (U.S. Department of Energy, 2008b). DOE Clean Cities data since 2005 show that the prices of B2 and B20 historically have closely tracked the price of regular diesel fuel; B100 is more expensive, but became closer in price to regular diesel as the price of regular diesel rose (Figure 5).



Source: Constructed by author using data from Clean Cities Alternative Fuel Price Reports (U.S. Department of Energy, 2008b).

Figure 5: Historical biodiesel prices vs. conventional diesel price

The Ethanol Market. Worldwide production of ethanol, a biofuel replacement for gasoline, was 13.1 billion gallons in 2007 (Renewable Fuels Association, 2009). As shown in Figure 6, global ethanol production is dominated by the U.S. and Brazil; the U.S. overtook Brazil, the long-time leader, as the world's biggest ethanol producer in 2006 (Martinot, 2008). Ethanol in Brazil is derived from sugarcane, and replaces over 40% of the nation's gasoline consumption. Brazil is also the world's leading exporter of ethanol.



Source: Constructed by the author using data from the Renewable Fuels Association (2009).

Figure 6: 2006 ethanol production in top 15 biofuel-producing countries

U.S. production of ethanol, almost exclusively from corn, has more than doubled since 2003 to nearly 6.5 billion gallons in 2007 (Energy Information Administration, 2008b), or about 5% of U.S. gasoline consumption (Kanter, 2008). The

Renewable Fuels Association, the ethanol industry's trade group, reported in February 2008 that 139 ethanol refineries were operating in 21 states with a total annual capacity of 7.8 billion gallons (Renewable Fuels Association, 2008). Figure 7 shows the location of U.S. ethanol refineries operating and under construction as of January 2008.

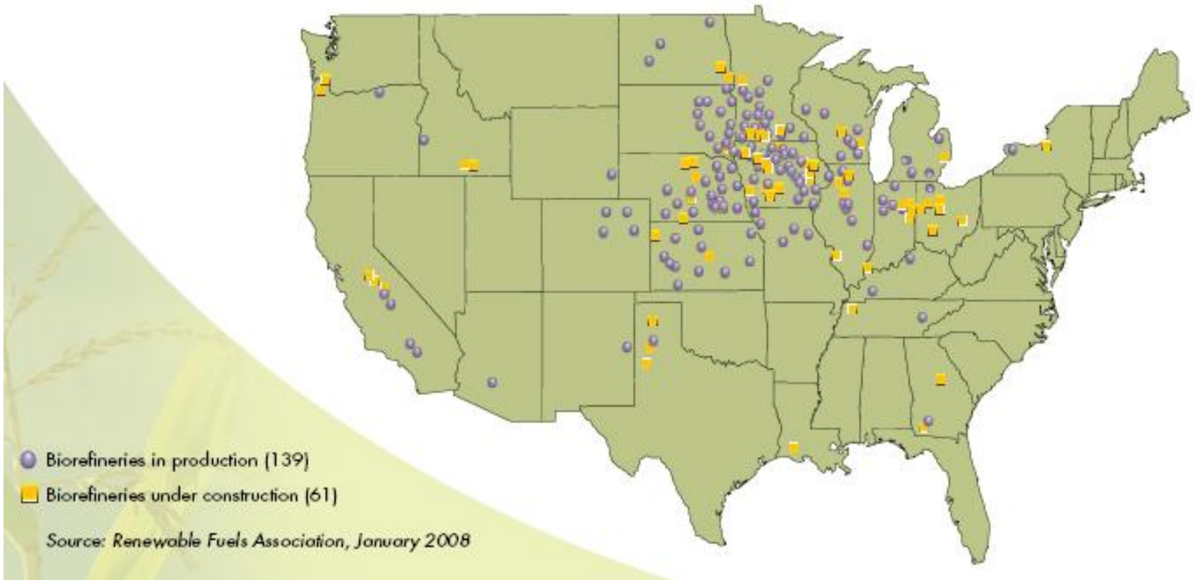
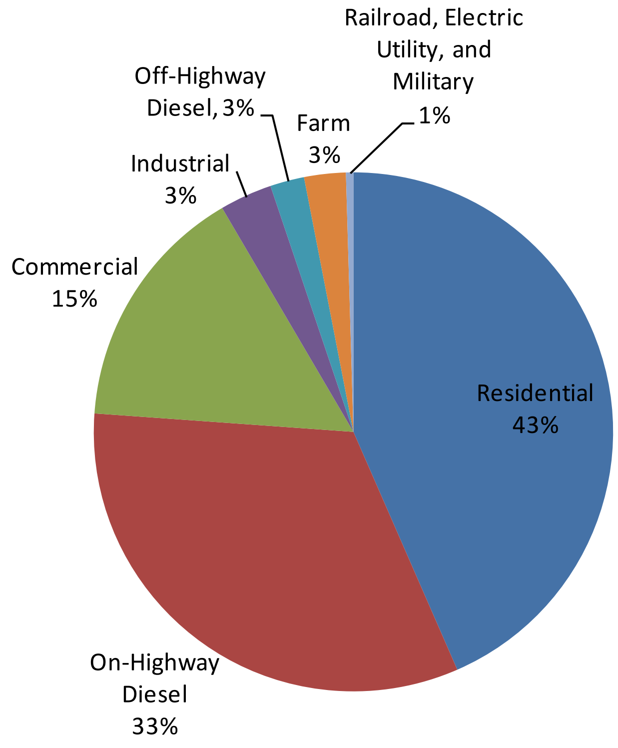


Figure 7: Ethanol refineries in the U.S., January 2008

The U.S. ethanol industry has several key drivers. First are federal and state incentives, including the Renewable Fuels Standard (see Section 2.2); Koplow estimates that U.S. ethanol subsidies at state and federal levels cost $5.1 billion to $6.8 billion per year and will continue to grow. Second, most gasoline sold in the U.S. now contains some percentage of ethanol as a substitute oxygenator for MTBE (Martinot, 2008). Finally, ethanol has the advantage of being the "first-mover" biofuel in the United States, with subsidies dating back to the Energy Tax Act of 1978 (Koplow, 2006). As such, the ethanol industry is larger and more mature than the biodiesel industry, with more firmly entrenched political, financial, and community support. For these reasons, demand for ethanol is better balanced with supply than in the biodiesel market; there is little idle capacity at U.S. ethanol refineries, and the U.S imported 607 million gallons of ethanol in 2006 to meet demand (Martinot, 2008).

1.1.2 Implications for Vermont

Increasing fuel and grain prices are of particular interest to Vermont for two main reasons. First, Vermont imports nearly all of its distillate fuels, and many Vermonters heat their homes with fuel oil. According to the EIA, Vermont consumed 198.1 million gallons of distillate fuel oils in 2007 (Figure 8), mostly for residential and on-highway transportation uses (Energy Information Administration, 2008d). The Vermont farm sector consumed just over 5.1 million gallons, which includes both diesel fuel used for farm equipment and fuel oil used for space heating.



Source: Constructed by author using data from Energy Information Administration, U.S. Department of Energy.

Figure 8: Vermont adjusted sales of distillate fuel oil by end use, 2007

Fuel prices in Vermont, as in the rest of the U.S., rose dramatically in 2008. According to the Vermont Department of Public Service's *Vermont Fuel Price Report* for July 2008, the average retail price of diesel fuel was $4.98 per gallon, up 67% from July of the previous year; the average retail price of No. 2 heating oil (and "off-road" diesel) was $4.65 per gallon, 82% higher than in July 2007.

The second area of concern is the impact of higher feed and fuel costs on Vermont's dairy industry. Agriculture is an important part of the state's economy, providing jobs, exports, and a working landscape that attracts tourists and contributes to Vermont's high quality of life (Wood, Halbrendt, Liang, & Wang, 2000). Dairy farming accounts for 70% of Vermont's total farm receipts (Economic Research Service, 2008a), and is estimated to contribute over $2 billion per year to the state's economy through direct payments to farmers, wages, and other agricultural-related business activity (The Vermont Milk Commission, 2008).

The number of dairy farms and cows in the state has been declining steadily, however, with the size of the state's dairy herd dropping by nearly 2,000 cows per year since 1987 (National Agricultural Statistics Service, 2007a). Since the dairy industry supports much of the infrastructure that serves all of Vermont agricultural enterprises, the decline in the number of dairy farms and cows in the state is "of great concern to milk processors, cooperatives, and the agricultural-related businesses that serve dairy farmers" (UVM College of Agriculture and Life Sciences, UVM Extension, Vermont Agency of Agriculture, Vermont Department of Economic Development, & Vermont Farm Bureau, 2005).

Vermont has approximately 140,000 dairy cows (National Agricultural Statistics Service, 2007a), of which approximately 14,000 are organic-certified (E. Wonnacott, personal communication, June 4, 2008). These animals, especially cows on dairies using conventional production techniques, consume several pounds of high-protein meal every day, or approximately 166,000 tons per year (Stebbins, 2008). Because Vermont produces very few soybeans, canola, sunflowers, or other oilseeds or meals, these grain products are imported to the state by truck and rail.

For farmers, recent market conditions mean that although the price they receive for their products generally has increased, production costs have also increased, as inputs such as fertilizer and livestock feed have become more expensive. In the spring of 2007, local feed mills quoted market prices for conventional soybean meal at $279 to $329 per ton, and for conventional canola meal at $170 per ton. Organic feed prices at that time were approximately $400–$450 per ton (Stebbins, 2008). By mid-July 2008, prices for conventional soybean meal had risen to approximately $370 per ton (AgWeb.com, 2008). Thus, although the estimated all-milk price received by Vermont farmers in July 2008 was $20.80 per hundredweight (National Agricultural Statistics Service, 2008b), the monthly cost of production for that month was $27.28 per hundredweight (Economic Research Service, 2008b).

1.1.3 Vermont's Biodiesel Market

Vermont currently produces very little biodiesel—approximately 44,000 gallons in 2006—but interest and investment in capacity is growing (Hausauer, 2007). Winooski-based Green Technologies is the only commercial-scale biodiesel producer currently in operation, with an annual plant capacity of 60,000 gallons. Green Technologies makes biodiesel from waste vegetable oil for off-road and home heating use, and plans to produce American Society for Testing and Materials (ASTM)-certified on-road biodiesel in the future (Hausauer, 2007). Biocardel Vermont, LLC, a Canadian company, has built a commercial biodiesel plant in Swanton with an initial capacity of 4 million gallons per year. The facility was scheduled to open in early 2007, but production has been delayed several times for refinements to meet quality standards for ASTM certification (McLean, 2007). Several Vermont farmers are also producing biodiesel in very small quantities for their own use.

Consumption of biodiesel in Vermont has been rising steadily since 2003, from approximately 9,000 gallons per year then to an estimated five million gallons in 2007 (Delhagen, 2006). According to the Vermont Biofuels Association, 31 Vermont fuel companies now sell biodiesel on a retail or wholesale basis (2008). Vermont companies, institutions, organizations, and individuals use biodiesel for off- and on-road transportation, home heating, farm and snowmaking equipment, and vehicle fleets (Hausauer, 2007).

1.1.4 Interest in Biodiesel Production from Vermont-grown Feedstock

As higher input costs squeeze Vermont farmers' profit margins and threaten farm viability, there has been growing interest among farmers, entrepreneurs, and policymakers in producing biodiesel and oilseed meal from oilseed crops grown in Vermont. The idea is that Vermont farmers could grow and harvest oilseed crops, such as soybeans, canola, or sunflowers; the seed or beans could be processed into vegetable oil and oilseed meal; and the oil could be processed into biodiesel, thereby producing both liquid biofuel and protein meal for livestock from Vermont crops.

In-state biodiesel and meal production from locally grown feedstocks could have several potential benefits for Vermont and its farmers. First, localized production of liquid fuel and livestock feed could lessen Vermont's dependency on fossil and imported fuels and Vermont farmers' dependency on feed imported from the Midwest or Canada. Second, access to local sources of two major inputs, feed and fuel, may allow Vermont farmers to reduce their production costs. Third, substituting Vermont-produced feed and fuel for imported products could create jobs and have other economic benefits for the state. Finally, substituting biodiesel for petroleum-based diesel fuel and No. 2 heating oil could reduce Vermont's greenhouse gas emissions.

Despite the promise of "made-in-Vermont" biodiesel and oilseed meal, however, it remains largely an unproven concept. Some Vermont farmers have long grown soybeans for feed, but growing other oilseed crops is new in Vermont, especially in quantities sufficient for biodiesel or livestock meal production. Farmers and biodiesel enthusiasts have been excited about the potential for local oilseed products, but the equipment, capital, acreage, and expertise needed to successfully grow, harvest, and process these crops have not been identified.

In addition, the economic feasibility and optimal scale of these new enterprises in Vermont are unknown, and there are many possible ownership structures and business models. Individual farmers could process the oilseeds and make biodiesel on the farm, for example, or they could contract with a third-party entrepreneur to process the seeds or oil. Do cooperative or community-based ownership structures that allow individuals to pool resources for capital investment make sense? Is a larger, commercial-scale biodiesel operation viable in Vermont? All of these remain open questions.

1.2 Objectives and Significance of the Study

This study investigates the technical and economic feasibility of producing biodiesel and livestock feed from Vermont-grown oilseeds at both the individual-farm scale and at a small commercial scale. Technical feasibility at the farm scale will be examined by reviewing the yield and quality data, challenges, and lessons learned from the experiences of two Vermont farms that are growing and harvesting oilseed crops, processing oilseeds into meal and oil, and producing biodiesel fuel from the vegetable oil. Sample enterprise budgets for the crop, oil and meal, and biodiesel enterprises are used to assess the economic feasibility and profitability of each enterprise individually and as a whole. Economic feasibility and environmental and macroeconomic impacts of a commercial-scale biodiesel facility in Vermont are assessed using a simulation model.

This study aims to answer the following specific research questions:

1) What are the expected costs and returns for oilseed crop, oil and meal, and biodiesel production at the farm scale under both ‘normal’ market conditions and record-high conditions similar to those experienced in mid-2008?
2) How sensitive is profitability to fluctuations in market prices for the key production inputs and outputs of fertilizer, oilseeds, oilseed meal, vegetable oil, and diesel fuel?
3) What are the expected costs and returns, macroeconomic impacts, and environmental impacts of a commercial biodiesel plant producing 500,000 or 2.5-million gallons per year in Vermont?
4) How sensitive are plant profitability, macroeconomic impacts, and environmental effects to variations in plant size, diesel prices, oilseed prices,

state capacity credits, and Vermont farmers' willingness to plant oilseed crops?

The significance of this research lies in two major areas. First, this study provides much-needed technical information to Vermont farmers and entrepreneurs who are considering growing biodiesel feedstocks, processing oilseeds, or producing biodiesel as enterprises. Second, the findings of this research will improve the understanding of what role, if any, local biodiesel production could play in a sustainable and independent energy future for Vermont and in reducing costs of production and improving viability for Vermont farms.

1.3 Organization of the Thesis

This thesis contains five major chapters. Chapter 1, Introduction, discusses the motivation and justification for this research, the major questions it seeks to answer, and its potential significance and applications.

The Literature Review, Chapter 2, provides context and background, including an overview of biodiesel and the major oilseed crops considered in this project, the deepening relationship between energy and food production and its effects on Vermont dairy farmers, and previous approaches to and methodologies for evaluating technical and economic feasibility of biofuels production at the farm and commercial scale.

Chapter 3, Technical and Economic Feasibility of On-Farm Biodiesel Production in Vermont, explores whether small-scale biodiesel production is technically and economically feasible for Vermont farmers, and estimates costs and returns under a range of market conditions.

Chapter 4, Feasibility of Commercial-scale Biodiesel Production in Vermont: Results of an Economic and Environmental Simulation Model, investigates the economic feasibility of commercial-scale biodiesel production from Vermont-grown feedstocks. A simulation model is used to estimate the expected costs, returns, and greater economic and environmental impacts of two sizes of commercial biodiesel facilities in Vermont.

Chapter 5, Conclusions & Recommendations, summarizes the major findings of Chapters 3 and 4, discusses implications and limitations of this study, and suggests directions for future research.

CHAPTER 2: LITERATURE REVIEW

This chapter provides context and background for this research, including an overview of biodiesel and the major oilseed crops considered in this project, the deepening relationship between energy and food production and its effects on Vermont dairy farmers, and previous approaches to and methodologies for evaluating technical and economic feasibility of biofuels production at the farm and commercial scale.

2.1 Biodiesel: an Overview

Biodiesel is one of several liquid fuels derived from "biomass," which is defined by the U.S. DOE as "any plant derived organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials" (U.S. Department of Energy, 2008a). Biomass can be used to create myriad forms of bioenergy (energy derived from biomass) including electricity, heat, fuels, and chemicals. Other liquid biofuels include ethanol, biobutanol, biogas, and hydrogenation-derived renewable diesel.

Biodiesel is made from waste or virgin vegetable oils and animal fats, and can be used as an alternative fuel for an entire group of refined petroleum products known as "distillate fuel oils," which include No. 1, 2, and 4 diesel fuels for on- and off-highway use, and No. 1, 2, and 4 fuel oils for space heating and electric power generation (Energy Information Administration, 2008a). In a process called transesterification, oils or fats are reacted with alcohol (such as ethanol or methanol) by a catalyst (usually potassium or sodium hydroxide) to break the long-chain fatty acids in the oil, separating the straightchain methyl or ethyl esters from the glycerin in the oil or fat. The reaction has two products: (1) the biodiesel—a pale yellow, medium-light, combustible fuel, and (2) glycerin. It takes just over 1 gallon of oil to produce 1 gallon of biodiesel; Table 1 shows the relative levels of inputs and outputs.

Table 1: Biodiesel production input and output levels

Process Input Levels		Process Output Levels	
Input	**Volume percentage**	**Output**	**Volume percentage**
Oil or fat	87%	Biodiesel	86%
Alcohol	12%	Alcohol	4%
Catalyst	1%	Fertilizer	1%
		Glycerin	9%

Source: (Methanol Institute and International Fuel Quality Center, 2006)

2.1.1 Feedstocks

Most biodiesel produced in the United States is made from soybean oil, but canola oil, sunflower oil, waste vegetable oil, and animal fats are also used (U.S. Environmental Protection Agency, SmartWay Transport Partnership, 2006). Biodiesel can be made, however, from any lipid or fat, including algae or vegetable oils derived from oilseed crops such as sunflowers *(Helianthus annuus)*, flax *(Linum usitatissimum)*, mustard *(Brassica hirta)*, cottonseed *(Gossypium hirsutum)*, peanuts *(Arachis hypogaea)*, and castor beans *(Ricinus communis)*.

This study focuses on soybeans, canola, and sunflowers because these crops can be grown in Vermont’s climate, yield a high-value livestock feed as a co-product, and have a sufficiently high oil content to be an efficient feedstock for biodiesel production. Table 2 summarizes the basic characteristics of these three oilseed crops.

Table 2: Basic characteristics of soybeans, canola, and sunflowers

Attribute	Soybeans	Canola	Sunflower
Sold by:			
Seed	Bushel	Ton	Hundredweight
Meal	Ton	Ton	Ton
Oil	Pound	Pound	Pound
Pounds per bushel (avg)	60	50	28–32
Bushels per ton (avg)	33	40	62.5-71
Yield/acre	1–1.1 tons	0.85 tons	1–1.1 tons
	35–40 bushels	32–35 bushels	66–73 bushels
Oil content	13–18% oil	40% oil	39–49% oil
Oil yield/acre	48 gallons	127 gallons	102 gallons
Oil yield/bushel	1.5 gallons	2.8 gallons	1.7 gallons
Biodiesel/acre	56 gallons	70 gallons	70 gallons

Sources: (Christmas & Hawkins, 1992; Journey to Forever, 2008; Putnam et al., 2000; Tyson, Bozell, Wallace, Petersen, & Moens, 2004).

Soybeans. Approximately 90% of the oilseeds produced in the United States are soybeans. Soybeans are one of the most important commodity crops grown in the U.S., second only to corn in farm production value and acres planted. The production value of soybeans was $16.9 billion in 2005, with 72.1 million acres under production (Ash, Livezey, & Dohlman, 2006).

Demand for soybeans is driven by demand for soybean meal, the most important high-protein feed for livestock worldwide, and the main byproduct of crushed soybeans. Soybean meal is a highly desirable protein source because of its complete amino acid profile, which is high in lysine, lower in methionine, and especially well-suited for poultry and swine feeding. Growth in the poultry industry has fueled high demand for soybean meal, which has increased soybean crop production steadily in the last 10 years. Soybeans' other byproduct, soybean oil, is typically used in salad and cooking oils, other foods, and industrial applications. A relatively small amount of whole soybeans are grown in the U.S. for food use in tofu, edamame, soymilk, or other edible soy products.

Canola. Canola is a genetic variation of rapeseed developed by Canadian plant breeders specifically for its nutritional qualities, particularly its low level of saturated fat and low eicosenoic and erucic acid contents. Canola seeds grow in small pods that are similar in shape to pea pods, but are about one-fifth the size. The tiny, round seeds are crushed to obtain canola oil. The remainder of the seed is processed into canola meal, which is used as a high-protein livestock feed.

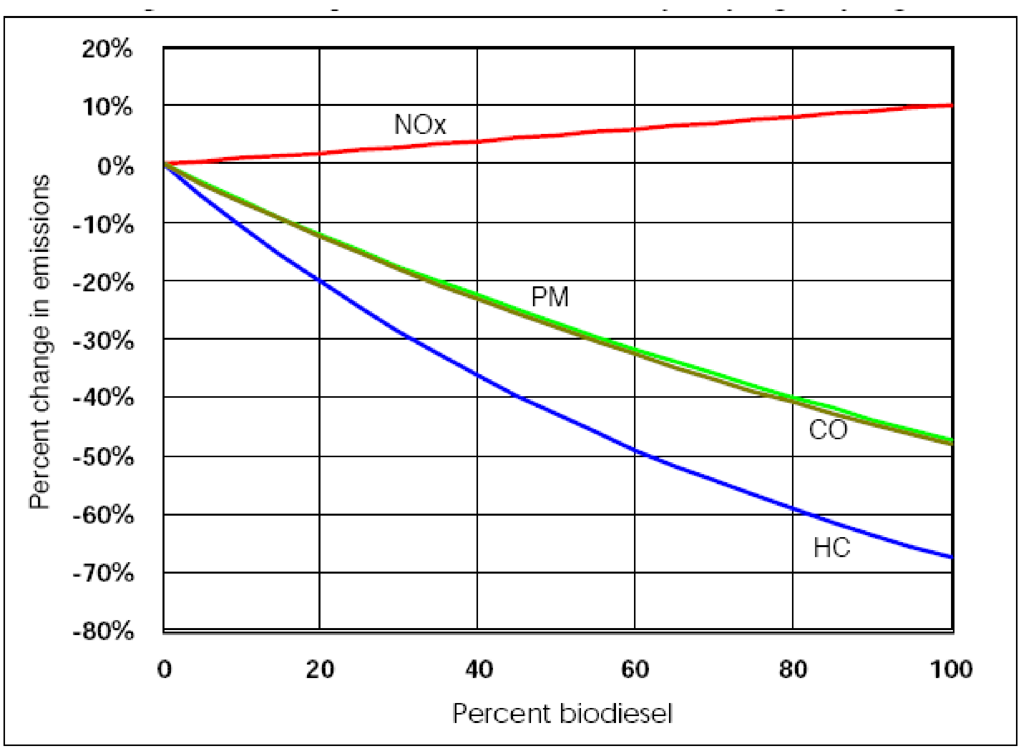
Canola is Canada's first or second-most valuable agricultural commodity (depending on the year), and the U.S. is its largest canola customer, importing approximately 500,000 tons of canola oil, 255,000 tons of seed, and 1.1 million tons of meal from Canada each year (Canola Council of Canada, 2005). The price of canola is driven primarily by vegetable oil markets, and is also affected by the price of soybeans.

Sunflowers. Sunflower varieties fall into two major categories: oilseed and confectionery. Confectionery seeds are only 10–20% of the U.S. crop each year, and are a premium product used for snack food, processed foods, and baking. Oilseed sunflowers are grown for birdseed or crushed primarily for their vegetable oil, with the meal as a secondary product for livestock feed (Thomas Jefferson Agricultural Institute). In 2007–2008 the U.S. produced 192,900 tons of confectionery sunflower seed and 1.24 million tons of oilseed sunflower seed (National Sunflower Association, 2008).

Sunflower varieties range widely in their seed oil content, from 39% to 49%. Sunflower oil is considered premium oil because of its light color, high level of unsaturated fatty acids, and clean, light flavor. Non-dehulled or partly dehulled sunflower meal has been substituted successfully for soybean meal in isonitrogenous (equal protein) diets for ruminant animals, as well as for swine and poultry feeding. Sunflower meal is higher in fiber, has a lower energy value, and is lower in lysine but higher in methionine than soybean meal. The protein percentage of sunflower meal ranges from 28% for non-dehulled seeds to 42% for completely dehulled seeds (Thomas Jefferson Agricultural Institute).

2.1.2 Advantages and Disadvantages

Biodiesel has several advantages over regular diesel fuel. From an environmental perspective, biodiesel is a non-toxic, biodegradable substance that can be made from waste products or renewable resources. Furthermore, as shown in Figure 9, burning biodiesel instead of petroleum-based diesel fuel in a regular diesel engine reduces emissions of most regulated air pollutants, including unburned hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). Biodiesel use also reduces emissions of unregulated pollutants, including sulfates, polycyclic aromatic hydrocarbons (PAHs), nitrated PAHs, and ozone potential of speciated hydrocarbons (U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, 2002). Biodiesel is one of the seven alternative fuels commercially available for vehicles identified by the 1992 Energy Policy Act, along with electricity, ethanol, hydrogen, methanol, natural gas, and propane (U.S. Department of Energy, 2007a).



Abbreviations: CO, carbon monoxide; HC, unburned hydrocarbons; NOx, nitrous oxide; PM, particulate matter.
Source: (U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, 2002)

Figure 9: Average emission impacts of biodiesel for heavy-duty highway engines

Biodiesel can be substituted directly for or blended in varying proportions with regular diesel fuel or heating oils, requiring no changes to existing infrastructure, engines, or equipment. (Biodiesel blends are concentrations of biodiesel between 2% and 99%, denoted B2–B99, with the number following the "B" indicating the percentage of biodiesel in a gallon of fuel.) Biodiesel's performance advantages over regular diesel fuel include a higher cetane index and greater lubricity (especially compared to low-sulfur diesel) (Radich, 2004). Biodiesel also has a higher flashpoint than regular diesel fuel, making it less combustible and therefore safer to store, use, and transport (U.S. Department of Energy, 2007b).

Biodiesel also has several disadvantages. First, as Figure 9 shows, biodiesel produces slightly higher emissions of nitrous oxide (NOx). Second, because biodiesel contains approximately 8% less energy per gallon than petroleum-based diesel, its use reduces fuel economy slightly. Finally, at cold temperatures, pure biodiesel will "gel" or form wax crystals that can clog fuel lines and slow engine performance, an especial concern in northern regions such as Vermont (Radich, 2004). These problems can be largely avoided by blending biodiesel with regular diesel fuel at concentrations of 20% or less (B1–B20).

2.2 Biodiesel Policy Environment

The U.S. currently has several policy incentives in place to promote biodiesel production. Support for biofuels demand began with the Energy Policy Act (EPAct) of 1992, which mandated that a share of the new vehicles purchased by certain fleets be alternative fuel vehicles. At first, biodiesel was not included, but EPAct was amended in 1998 to allow fleet managers to meet up to half of their alternative fuel requirement for heavy-duty vehicles by using biodiesel. Biodiesel is also included in the U.S. Environmental Protection Agency's Renewable Fuels Standard (RFS), which requires a minimum portion of all transportation fuels to be renewable. The RFS was raised to 7.76%, or 9 billion gallons of renewable fuel, in 2008, rising over time to 36 billion gallons per year by 2022 (U.S. Department of Energy, 2008c).

Supply-side federal incentives include tax credits for producers, blenders, and infrastructure investments. Small producers making fewer than 60 million gallons of "agri-biodiesel" (derived solely from virgin oils or animal fats) per year are eligible for an income tax credit of $0.10 per gallon on the first 15 million gallons produced. Biodiesel blenders can claim a volumetric excise tax credit of $1 per gallon of B100 “agri-biodiesel” or B100 made from other sources blended with petroleum diesel. The tax credit applies proportionally to lower biodiesel blends, and the biodiesel must meet ASTM specifications in order to qualify. The producers’ and blenders’ credits are set to expire on December 31, 2009. Finally, installers of refueling infrastructure for alternative fuels including biodiesel blends of B20 or above are eligible for a tax credit of up to 30% of the cost, not to exceed $30,000 (U.S. Department of Energy, 2008c).

In addition, approximately 36 states have acted to promote biodiesel through producer or consumer incentives, mandates that require all diesel fuel sold contain a certain percentage of biodiesel, or a combination thereof (Koplow, 2006). Minnesota, for example, which enacted a B2 mandate in 2005, recently passed legislation to increase that mandate to B20 by 2015 (National Biodiesel Board, 2008b). Koplow (2006) finds that the many subsidies at the federal and state levels are uncoordinated and poorly targeted, and cost approximately $500 million per year for biodiesel.

2.3 Previous Feasibility Studies of Biodiesel and Biofuels Production

Previous studies have investigated many aspects of the technical and economic feasibility of biodiesel and biofuels production, including profitability at various scales and ownership structures (Bender, 1999; Carter, 2006; Eidman, 2007; Kenkel & Holcomb, 2006; Kingwell & Plunkett, 2006; Paulson & Ginder, 2007; Van Dyne & Blase, 1998; Weber & Van Dyne, 1992; Whittington, 2006), using different feedstocks (Duffield, Shapouri, Graboski, McCormick, & Wilson, 1998; Nelson & Schrock, 2006; Shapouri & Duffield, 1993), and in a variety of regions, states, and nations worldwide (Lee & Han, 2008; Meyer, Strauss, & Funke, 2008). Additional studies address the broader economic and environmental impacts of biofuels production, including macroeconomic impacts on local communities (Fortenberry & Deller, 2008; Meyer et al., 2008; Parcell & Westhoff, 2006), effects on food and agricultural prices (Babcock, 2008; Rosegrant, 2008; Walsh et al., 2007), and changes in land use and greenhouse gas emissions (Carriquiry, 2007; Coyle, 2007; Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008; Hill, Nelson, Tilman, Polasky, & Tiffany, 2006; Marshall, 2007; Rajagopal & Zilberman, 2007; Searchinger & Heimlich, 2008; Searchinger et al., 2008). This section first reviews the methodologies used in previous economic feasibility assessments and summarizes their results, and then reviews previous studies of biofuels impacts.

2.3.1 Methodologies for Economic Feasibility Assessment

An economic feasibility analysis has been defined as "a comparison of anticipated costs and returns associated with a planned business enterprise" (Dobbs, 1988, p. 1). Dobbs outlines four components of an economic feasibility analysis, as follows: (1) estimating costs; (2) analyzing potential markets, demand, and competition; (3) estimating revenues; and (4) calculating expected profit (or loss) and break-even points. At the microeconomic scale, this method results in an enterprise budget, or statement of costs and returns, for a proposed line of business. The partial budget method takes a similar approach, but considers only changes to expected costs or returns based on the introduction of a new technique or technology (Norman, Worman, Siebert, & Modiakgotla, 1995).

Additional tools are used to evaluate risks associated with the uncertainty of the assumed market conditions, such as those caused by weather, external shocks, and other factors. Sensitivity analysis using partial budgets can estimate how sensitive profitability is to variations in costs or revenues.

Previous economic feasibility studies of biodiesel production show that the primary determinants of profitability are (1) the cost of the feedstock, (2) the value of and access to markets for biodiesel, (3) the value of and access to markets for the co-products (glycerin and oilseed meal), (4) government support policies, and (5) utility costs.

2.3.2 Farm- and Community-Scale Feasibility

The Department of Agriculture and Food for Western Australia has conducted three economic feasibility studies of farm-scale biodiesel production from farm-produced canola (Carter, 2006; Kingwell & Plunkett, 2006; Whittington, 2006). All use relatively straightforward spreadsheet budgets, and all find that biodiesel production at the farm-scale (2,650–10,600 gallons/year) is not economically feasible. Estimated biodiesel production costs ranged from $1.23 to $1.55 per liter, or $4.66 to $5.87 per gallon, well above the approximate price of regular diesel fuel in Australia at that time, $0.90 per liter or $3.40 per gallon. Using a partial budget technique, Carter (2006) calculated a break-even biodiesel price of $1.31 per liter ($4.96 per gallon), and concluded that petroleum-based diesel prices would have to rise by more than 70% in order for canola-based, farm-scale biodiesel production to achieve a return on investment comparable to the then-current bond rate.

Several studies have also reviewed the economic feasibility of community-scale, cooperatively owned biodiesel production. Weber, Van Dyne, and Blase contributed to early work in this area, using spreadsheet simulation models to estimate costs and returns for a 500,000-gallon biodiesel plant owned by a farmer cooperative similar to those in

Austria (Van Dyne & Blase, 1998; Weber, 1993; Weber & Van Dyne, 1992). Van Dyne and Blase found that transaction costs avoided by the "closed loop" cooperative model reduced the cost of biodiesel production by $0.83 to $0.97 per gallon compared to costs incurred using the conventional soybean marketing system. Despite these savings, however, all three analyses showed that biodiesel produced by the cooperative-owned plant was not competitive with regular diesel fuel. Similarly, Bender's (1999) meta-analysis of 12 biodiesel economic feasibility studies found that none were yet feasible; all projected biodiesel production costs above the then-current price for regular diesel fuel. Weber (1993) concluded that the cooperative model of biodiesel production would be most viable for farmers who had diversified livestock and oilseed crop operations, since they would benefit from the reduced price of the biodiesel feedstock and the high replacement value of the oilseed meal.

According to these three studies, the most important variables in the cost of biodiesel production are the price of the feedstock (soybeans were determined to be the most cost-effective in all three studies) and the value of the meal co-product. Key cost and revenue components of small-scale production are shown in Table 3.

Table 3: Cost and revenue components of farm-scale oil and biodiesel production

Costs	Co-product Credits/Revenues
Fixed	Biodiesel
Oilseed/biodiesel processing building	Oilseed meal
Seed storage	Glycerine
Seed press	Government credits/subsidies
Oil storage	
Meal storage	
Biodiesel reactor	
Electrical work and pumps	
Insurance	
Maintenance	
Variable	
Oil	
Methanol	
Catalyst (KOH)	
Electricity	
Labor	
Testing fees and supplies	

2.3.3 Commercial-Scale Feasibility

Several recent studies have evaluated the economic feasibility of larger, commercial-scale biodiesel production in the United States (Eidman, 2007; Kenkel & Holcomb, 2006; Paulson & Ginder, 2007). These analyses conclude that biodiesel production on a scale sufficient to displace a significant share of U.S. diesel consumption is not economically feasible, primarily because of the high cost of feedstocks in relation to the price of conventional diesel fuel.

Paulson and Ginder's (2007) study is significant in reporting on actual operating costs and conversion rates at plants currently in production, rather than engineering estimations. They report that rapid changes in U.S. biodiesel production have rendered many previous studies obsolete, as production has shifted from smaller, batch-based plants to larger, continuous flow facilities. Using a spreadsheet-based capital budgeting model, Paulson and Ginder found that although a larger, 60-million gallon plant realized marginal decreases in production costs from returns to scale, overall return on investment was sensitive to feedstock and biodiesel prices. Similarly, according to Eidman (2007), the profitability of a commercial biofuel plant depends primarily on three key factors: (1) the price of petroleum, (2) the price of the feedstock, and (3) government support policies. Kenkel and Holcomb's (2006) analysis adds access to markets for co-products and biofuels and utility costs and availability to the list of important profitability factors.

In their survey of challenges to producer ownership of biodiesel and ethanol facilities, Kenkel and Holcomb also identify special factors for biofuels projects located in grain-deficit areas such as Vermont. First, farmers would face a learning curve in growing new crops for biofuel feedstocks, making it "difficult to develop a critical mass of planted acres and producer investment to support a processing facility" (374). Second, biofuels plants in grain-deficit regions may be viewed as competing for local grain crops and driving local prices higher.

2.3.4 State-Level Feasibility

There has been substantial interest in biodiesel production at the state level, as policymakers have wondered about its potential to increase economic development and farm viability, as well as to produce environmental benefits. Biodiesel feasibility studies have been conducted for states including Georgia (Shumaker, McKissick, Ferland, & Doherty, 2003), Iowa (Hayes, 1995), New York (Urbanchuk & LECG LLC, 2004), North Dakota (VanWechel, Gustafson, & Leistritz, 2002), Oregon (Jaeger, Cross, & Egelkraut, 2007), Vermont (Mulder, 2004), and Wisconsin (Fortenberry, 2005). These analyses use a combination of market assessment, capital and enterprise budgets, and input-output modeling to assess microeconomic feasibility of the plant and its macroeconomic effects.

Mulder’s study goes further by using a dynamic and stochastic model that also estimates ecological effects.

All of these state-level studies found that commercial-scale biodiesel production was technically feasible, but all except Oregon also found that it was not yet economically viable, citing the need for growth in the biodiesel industry to lower operations costs; high biodiesel production costs relative to the price of conventional diesel (primarily due to the high price of feedstocks); and the high level of risk, which discourages necessary investment. All studies further agreed that without government incentives to create demand, such as a mandate that all diesel fuel contain a certain percentage (typically 2%) of biodiesel, large-scale biodiesel production would be risky and unprofitable.

Mulder’s study on Vermont (2004) found that although a privately owned facility was projected to lose money, a cooperatively owned plant supported by producer tax incentives and strong local market demand for the feed and biodiesel could be profitable and produce direct and induced local economic benefits, reduce greenhouse gas emissions, and yield a net positive energy return. Mulder further recommends public policy incentives that require some portion of the biodiesel feedstock to be grown in Vermont in order to maximize potential economic and environmental benefits.

The most recent study, for Oregon, found that biodiesel production from canola seed could be commercially viable under current market conditions and existing government subsidies, including an indirect “blender’s credit” of $1.00 per gallon. The Oregon study also finds, however, that the biodiesel production would offer the state a relatively small measure of energy independence, and would require 100 times more canola than is currently grown in the state. Finally, on a combined net-energy-and-cost basis, the study finds that canola biodiesel is estimated to cost 125% more than petroleum diesel (Jaeger et al., 2007).

2.3.5 Environmental Impacts

More recent studies have begun to address the feasibility of biofuels production in a broader context, considering biodiesel's relationship to other biofuels and alternative energy sources, food and agricultural prices, and land use changes and environmental impacts (Carriquiry, 2007; Coyle, 2007; Hill et al., 2006; Rajagopal & Zilberman, 2007). Giampietro et al. (1997) propose that large-scale biofuel production is a feasible and sustainable substitute for fossil fuel energy only if biofuel production is biophysically feasible (i.e., land and water resources are sufficient), environmentally sound, and compatible with the society's socioeconomic structure (i.e., is consistent with the society's labor supply and per capita energy use). Similarly, Hill, Nelson, et al. (2006) assert that an alternative fuel is a viable substitute for fossil fuels only if it has superior environmental benefits, is economically competitive, can be produced in sufficient quantities to meaningfully impact energy demand, and provides more energy than is required to produce it.

One of the first questions considered when evaluating the net benefit of biofuel production is the biofuel's net energy balance (NEB), the difference (positive or negative) between the energy derived from the fuel and the energy required to produce the fuel, including crop production and fuel processing. Hill, Nelson, et al. (2006) found "no support" for a negative NEB for either ethanol or biodiesel. In an analysis that expanded energy accounting to include energy costs of farm machinery and processing facilities, they found a 25% NEB for corn grain ethanol and a 93% NEB for soybean biodiesel. Biodiesel from soybeans achieved a higher NEB due to (1) relatively lower agricultural inputs for soybeans versus corn, (2) the lower energy input required to convert soybean oil to biodiesel compared to that required to convert corn to ethanol, and (3) the high value of the co-products of the biodiesel production process, including soybean meal and glycerine.

A second important question in determining the overall value of biofuel production is the net change in greenhouse gas (GHG) emissions from producing and consuming biofuels as a substitute for fossil fuels. In a lifecycle analysis that includes fertilizer inputs, pesticide use, and emissions of GHG and other pollutants, Hill, Nelson, et al. find that the production and combustion of ethanol results in 88% of the net GHG emissions of gasoline, and that soybean biodiesel's net GHG emissions are 59% of regular diesel fuel.

Many studies of GHG emissions from biofuels, however, do not account for the impacts of any land use changes occurring as a result of biofuel production. As Hill, Nelson, et al. report, their findings "assume that these biofuels are derived from crops harvested from lands already in production; converting intact ecosystems to production would result in reduced GHG savings or even net GHG release from biofuel production" (p. 11207). If food crops such as corn and soybeans are used for biofuels production, additional land may be brought under cultivation to meet demand either for biofuels or for food crops to replace the supply diverted to biofuels. It is feared that these shifts may be most dramatic in developing nations, where environmental and land use restrictions may be fewer and the need for food greater.

As Searchinger and Heimlich (2008) explain, such shifts can increase GHG emissions in three ways: (1) loss of carbon in vegetation if forest or grassland is cleared for food or biofuel crop production, (2) loss of carbon in soils from conversion to cropland, and (3) loss of ongoing carbon sequestration from the lost forest or grasses. Findings from recent studies reporting that biofuels production actually increases GHG emissions (Fargione et al., 2008; Searchinger et al., 2008) have been disputed by the U.S. DOE (U.S. Department of Energy, 2008d).

Biofuels production has also been criticized for contributing to rises in global food prices, which have increased by 83% over the past three years (World Bank, 2008). It is generally agreed that food prices have risen due to a combination of factors, including growth in demand for food, especially protein, as a result of rising incomes in emerging economies such as China and India, which has depleted global food stockpiles; higher fuel and energy costs; droughts and other severe weather events that have affected production; and price volatility caused by increased speculation in agricultural futures markets; as well as biofuels production and the tightening link between food and energy markets (Sheeran, 2008; U.N. Food and Agricultural Organization, 2008). The U.N. Food and Agricultural Organization (2008) emphasizes, however, that “there is no single factor that can be identified as being the main one responsible” (2).

Although higher petroleum prices make biodiesel production more economically feasible, higher global food prices also mean higher prices for biodiesel feedstocks. According to Carriquiry, “in contrast to cornbased ethanol, in which the price of the main feedstock (corn) seems to be determined by its value in the energy market, biodiesel feedstock prices are largely determined in the markets for food” (22). The tightening relationship between energy and food markets may make it more difficult for biofuels produced from food crops to be economically competitive against fossil fuels.

While debate in the literature continues about how worldwide land, energy, and food markets will respond to biofuels production, and the true impacts of such changes on GHG emissions, land use, and food prices, a consensus is beginning to emerge. Most researchers agree that although indiscriminately sited large-scale biofuels production will have adverse environmental impacts in the loss of forest, soil erosion, fertilizer and pesticide use, water consumption, and GHG emissions, sustainable biofuels production can play a helpful role in reducing GHG emissions and dependence on fossil fuels.

Marshall (2007) calls for a comprehensive sustainable biofuels policy framework that combines environmental performance, land use decisions, life-cycle performance criteria, and internationally accepted criteria and certification programs to be put in place *prior* to further large-scale pursuit of biofuels production. Other suggested elements of sustainable production include a modest or appropriate scale, environmentally sound production practices, and locally appropriate and produced feedstocks that do not induce land use changes or reduce carbon stores in the soil and vegetation, such as agricultural and food residues and wastes (Fargione et al., 2008; Wong, 2008).

2.3.6 Economic Impacts

Biofuels production also impacts the local, regional, and national economy in terms of jobs, income, and multiplier effects. Most studies addressing the macroeconomic impacts of commercial-scale biodiesel production use input-output analysis to estimate direct and indirect multiplier effects for employment, income, and taxes generated by economic activity in a particular sector. Fortenberry and Deller (2008) have developed a set of local economic multipliers for biofuel plants using the popular IMPLAN (Impact Analysis for Planning) input-output software program.

Parcell and Westhoff's (2006) analysis of seven input-output studies of ethanol plants from 2000 to 2005 found a total economic effect of $28 million to $232 million per plant, depending on the plant's operating capacity. Employment associated with each plant was 3 to 15 jobs per million gallons of production, and the median labor income effect was approximately $0.50 per gallon of ethanol production. Parcell and Westhoff also suggest the following metrics for analyzing biofuel production facilities:

- Feedstock price (local)
- Feedstock usage increase (local)
- Net farm income (noninvestment)
- Government farm payment reduction (total farm sector)
- Biofuel production/use incentives (plant-specific)
- Biofuel plant jobs created
    - Total
    - Production workers
    - Salary
- Total jobs created (local)
- Taxes generated (local)
- Capitalization expenses (one-time)
- Economic output (local)
    - Plant
    - Total
- Economic multipliers for assessing total impact:
    - Total jobs
    - Total income
    - Total output

CHAPTER 3: TECHNICAL AND ECONOMIC FEASIBILITY OF ON-FARM BIODIESEL PRODUCTION IN VERMONT

This chapter explores whether small-scale biodiesel production is technically and economically feasible for Vermont farmers, and estimates costs and returns under two sets of market conditions.

3.1 Introduction

As higher input costs and volatile prices squeeze Vermont farmers' profit margins and threaten farm viability, there has been growing interest in on-farm production of biodiesel and oilseed meal from Vermont-grown oilseed crops. Farmers, entrepreneurs, and policymakers are intrigued by the potential to decrease Vermont's dependency on imported fuels and feed, reduce farms' production costs, realize local economic benefits from import substitution, and lower greenhouse gas emissions.

The technical and economic feasibility of farm-scale oilseed, oilseed meal, and biodiesel production in Vermont is largely unknown, however. Although a few farmers grow soybeans as a feed crop, production of other oilseed crops is relatively rare in Vermont, especially in quantities sufficient for biodiesel or livestock meal production. The equipment, capital, acreage, and expertise needed to successfully grow, harvest, and process these crops have not been identified, and the potential profitability of each of the possible on-farm enterprises is also unknown.

Previous economic feasibility studies of biodiesel production show that the primary determinants of profitability are (1) the cost of the feedstock, (2) the value of and access to markets for biodiesel, (3) the value of and access to markets for the co-products (glycerin and oilseed meal), (4) government support policies, and (5) utility costs. Previous farm-scale analyses have used the enterprise or partial budget methods to estimate and compare costs and returns, and most have shown that biodiesel production at this scale (2,650–10,600 gallons/year) is not economically feasible, with estimated production costs ranging from $4.66 to $5.87 per gallon (Carter, 2006; Kingwell & Plunkett, 2006; Whittington, 2006).

This analysis investigates the technical and economic feasibility of on-farm production of biodiesel and livestock feed from Vermont-grown oilseeds based on data from several Vermont farms experimenting with these enterprises. Specifically, this study seeks to (1) identify technical issues related to on-farm production of oilseed crops, oilseed meal, and biodiesel; (2) estimate costs and returns for oilseed crop, oil and meal, and biodiesel production at the farm scale; and (3) understand how sensitive the profitability of these enterprises is to fluctuations in market prices for key production inputs and outputs: oilseeds, fertilizer, oilseed meal, vegetable oil, and diesel fuel.

3.2 Data and Methods

This study relies on quantitative and qualitative data related to the three stages of biodiesel production from local feedstocks: crop production, harvest, and storage; oil and meal production by seed press; and biodiesel production. Technical feasibility is assessed using data primarily from two case study sites in Vermont, State Line Farm in Shaftsbury and Borderview Farm in Alburgh. (Appendix A contains detailed information on the technical aspects of production.)

Economic feasibility is analyzed using the enterprise budget method to estimate costs, revenues, expected profit (or loss), and break-even points, with separate budgets for crop production, oil and meal production, and biodiesel production. Although all of the budgets rely in part on data from the two case study sites, the budgets are designed to present as ‘typical’ a case as possible in order to assess feasibility. The study makes conservative assumptions while striving to create budgets that can be considered representative of potential conditions on active Vermont dairy farms, realizing that individual farm operations, costs, and circumstances vary widely. Input costs for each enterprise are estimated at market prices, not at their cost of production, although profit or loss is also calculated based on cost of production for purposes of comparison.

For the crop enterprise, crop yields, seeding and fertilizer rates, seed costs, and production techniques were obtained from field- and small-scale replicated trials of oilseed crops on Vermont farms in 2006 and 2007 conducted by Dr. Heather Darby and Dr. Vernon Grubinger of University of Vermont (UVM) Extension (Darby & Hills, 2007; Grubinger, 2007). Average custom machinery rates from Pennsylvania were used to estimate field preparation, planting, cultivating, fertilizer spreading, grain hauling, and grain storage costs; drying costs are Kentucky custom rates (Halich, 2007; Pike, 2008). Custom harvest rates are Vermont estimates (H. Darby, personal communication, March 4, 2009).

For the oil and meal enterprise, oil and oilseed meal yield data were collected for some but not all crop varieties from the two case study sites. In addition, selected meal samples were sent to laboratories for a nutrient content analysis. The value of farm-produced livestock meal was estimated by analyzing how a sunflower meal sample from

State Line Farm might replace commercial feed products in a dairy cow's feed ration using CPM-Dairy software, a program that formulates least-cost dairy cow feed rations based on linear and nonlinear programming (Cornell University, University of Pennsylvania, & William H. Miner Agricultural Research Institute, 2007). Equipment, electricity, and labor costs for seed pressing and meal pelletizing are based on data from Borderview Farm (R. Rainville, personal communication, October 16, 2008). Meal testing costs are based on a "Ration Balancer Plus" wet chemistry analysis from Dairy One Cooperative, Inc. (2009).

For the biodiesel enterprise, equipment costs are estimated primarily from industry sources, with estimated labor and filtering costs based on experience at State Line Farm. Industry estimates are used because State Line Farm's new, dedicated facility for oilseed processing and biodiesel production would be cost-prohibitive for most farms, and biodiesel production in the new facility had not yet begun during the study period. Biodiesel processing equipment is estimated at a size adequate to process the expected yield of vegetable oil efficiently.

Budgets for each enterprise are constructed under two scenarios: "normal prices" and "high prices." The two scenarios are designed to show what impact higher food, fuel, and fertilizer prices would have on the profitability of each enterprise. The normal-price scenario assumes 2007 average or actual production costs and output prices as expected or actual for the 2007 growing season. For example, in the normal-price scenario, the expected oilseed price is assumed to be the price from the previous, 2006-2007 marketing year; the biodiesel price is estimated at the 2007 average Vermont diesel fuel price.

The high-price scenario assumes input costs and output prices at 2008 peak levels. Thus, for example, fertilizer prices are estimated at April 2008 levels, oilseed prices at the average sunflower price for the 2007-2008 marketing year, and biodiesel prices at the July 2008 diesel fuel price for Vermont.

Sensitivity analyses of profitability to key input and output prices were conducted to gauge the sensitivity of profit or loss to changing market conditions. Profitability was analyzed at differing prices for diesel/biodiesel fuel (assumed to be the same since the farmer would be substituting one for the other), whole oilseeds or beans, fertilizer, and oilseed meal, ranging from 20% below to 20% higher than the scenarios' expected levels.

3.3 Results

3.3.1 Crop Production

Although crop production information for oilseeds such as canola, flax, mustard, and sunflowers is well established nationally and in other regions of the country, little data have been reported on which varieties, equipment, and agronomic practices work best in Vermont. Results from field trials indicate that oilseed crops can be grown successfully in Vermont, with yields at or exceeding national averages.

Harvesting. Although yields were affected by several factors—including the variety of cultivar, weather and soil conditions affecting germination and emergence, weed pressure (especially for canola and mustard), and bird damage to sunflowers—the major challenges to optimizing oilseed crop production in Vermont appear to be related to harvesting and storage. Growing oilseed crops in this climate is relatively easy compared to harvesting and storing those crops optimally to capture their full potential yield. Difficulties include scarcity of and familiarity with necessary equipment, optimally timing the harvest given Vermont's short growing season and fall weather, and access to a range of equipment that can provide flexibility in using the best technique for a given crop and season.

Concerning equipment, harvesting soybeans, canola, and sunflowers requires either a combine or a swather, and it has proven difficult to find affordable equipment of this type for small-scale oilseed production in Vermont. Both State Line and Borderview Farms are using older-model combines that have been modified (with a two-row corn head and a custom-made plywood attachment, respectively) for sunflower harvesting. Swathing is an especially important technique for harvesting canola, the seed pods of which can shatter during harvest if too dry. If the farmer can 'swath' the crop (meaning to cut and place it into a windrow) as the seeds begin to mature, the plants can continue drying on the ground and be picked up by a combine with their seed pods intact.

Obtaining the proper field moisture for harvest is also a challenge in Vermont. In general, oilseed crops should be as dry as possible at harvest for optimal handling and storage and prevention of mold and spoilage. Vermont's relatively short growing season, however, makes it difficult to leave crops in the field long enough to reach the proper moisture. In addition, dairy farmers may find that the optimal timing of forage harvesting, particularly corn silage, may conflict with or take precedence over oilseed harvesting.

Yields. Despite these challenges, yields of several varieties in the 2006 and 2007 trials were comparable to or better than national averages. At State Line Farm, two varieties of sunflowers achieved yields higher than 1 ton per acre, and 2007 canola yields at Borderview Farm were more than 1.5 times the national average of 0.85 tons (1700 lbs) per acre. The data suggest that Vermont farmers can attain national-average oilseed yields with improved access to equipment and additional experience with harvesting techniques. Yields from 2006 and 2007 Vermont oilseed field trials are shown in Table 4.

Table 4: Crop yields from 2006 and 2007 Vermont oilseed field trials

Crop	Variety*	Date: Plant	Date: Harvest	Moisture	Yield (lbs/acre)
2006 trials					
State Line Farm, Shaftsbury, VT					
Canola	Hyola 401	May 9	Aug 25	7.7%	1404
Canola	601	May 9	Aug 25	7.9%	1128
Canola	Oscar	May 9	Aug 25	8.3%	996
Canola	Hyola 420	May 9	Aug 25	8.0%	984
Canola	KAB	May 9	Aug 25	9.4%	756
Sunflower	IS 6521	May 10	Oct 6	8.0%	2200
Soybean	IA 24, IF 61	May 10	*Crop failure due to wet weather*		
Clearbrook Farm, Shaftsbury, VT					
Canola	Oscar	June 13	Sept. 15	9.0%	471
Canola	Oscar	June 13	Sept. 15	9.0%	620
Sunflower	Perdovia	June 13	*Crop failure due to herbicide carryover*		
Borderview Farm, Alburgh, VT					
Canola	601	May 19	Not reported	13.6%	1750
Canola	KAB	May 19	Not reported	12.0%	1608
Canola	Oscar	May 19	Not reported	11.5%	1363
Canola	601	May 29	Not reported	13.0%	1200
Canola	KAB	May 29	Not reported	14.0%	1337
Canola	Oscar	May 29	Not reported	12.4%	1000
2007 trials					
State Line Farm, Shaftsbury, VT					
Canola	601	May 9	Aug 14	15.2%	792
Mustard	Golden	May 9	Aug 14	11.1%	861
Sunflower	Hysun1521	May 9	Sept	7.0%	1643
Sunflower	Defender	May 9	Sept	8.0%	1854
Sunflower	IS6039	May 9	Sept	10.0%	1806
Sunflower	IS6111	May 9	Sept	6.0%	1247
Sunflower	IS6521	May 9	Sept	8.0%	1454
Sunflower	IS4049	May 9	Sept	8.0%	2397
TioGrain Farm, Shoreham, VT					
Sunflower	Seeds2000 Defender	May 9	*Crop failure due to low germination rate and bird damage*		
Sunflower	IS6039	May 9			
Sunflower	IS6111	May 9			
Sunflower	Croplan803	May 9			
Boivin Farm, West Addison, VT					
Canola	KAB 36	Late June	November	Not reported	500
Borderview Farm, Alburgh, VT					
Canola	Croplan 601	May 23	Sept 5	Not reported	3160
Canola	Oscar	May 23	Sept 5	Not reported	2600
Canola	Croplan Python	May 23	Sept 5	Not reported	3360
Sunflower	Hysun1521	May 23	October 17	12.0%	1439
Sunflower	Seeds2000 Blazer	May 23	October 17	13.0%	2146
Sunflower	Croplan 803	May 23	October 17	12.0%	1247
Sunflower	Croplan 322NS	May 23	October 17	13.0%	1527

*All seeds were non-transgenic, or non-genetically modified (GMO).
Source: (Darby & Hills, 2007)

Seed Cleaning and Drying. Once harvested, the oilseeds may need cleaning to remove chaff, weeds, and other impurities. Uncleaned seed stored with too much non-seed material can heat up, reducing the quality of the seed meal, and causing mold growth that can potentially reduce oil quality. Early experience at State Line and Borderview Farms has shown that the need to clean seeds prior to pressing seems to depend in part on the type of seed, the amount of weeds in the field, and the effectiveness of harvesting equipment and techniques in not picking up unwanted material along with the crop and in cleanly separating seed from other material. In general, the bigger the seed, and the higher it is off the ground when combined, the cleaner it is after harvest.

The need for seed cleaning also appears to depend on the size and sensitivity of the oilseed pressing equipment. Borderview Farm has a relatively large press that can accommodate a certain amount of "trash" mixed with the seed. State Line Farm, on the other hand, has a smaller press, which requires that the seed be very clean before pressing; unwanted material jams the press and stops its operation. As few in-state facilities for seed cleaning are currently available, State Line Farm purchased a seed cleaner (Eclipse model 324) that uses multiple screens to clean different seeds harvested under various conditions. State Line Farm has found that with one input stream and as many as six output streams, setting up a system to deliver and sort material to and from the cleaner can be complicated, requiring several bins and space to position them accordingly.

Finally, adequate facilities for drying and storage are essential to successful oilseed crop production. According to Borderview Farm, harvest moistures can range as high as 13% to 20%, whereas the optimal moisture content for storage and pressing is approximately 9%. Seeds that are stored too wet will mold. Farmers growing these crops in Vermont will therefore need to have facilities and equipment for drying or aerating the seeds after harvest. Borderview Farm, for example, uses aerators placed in bins or bags of seed that have reportedly dried 14 tons of seed from 14% to 9% moisture in three days (R. Rainville, personal communication, October 16, 2008).

3.3.2 Oil and Meal Production

Early experience with pressing oilseeds into vegetable oil and meal at the two case study sites has shown that on-farm oil and meal production is technically feasible. The quality and yield of oil and meal produced from Vermont-grown oilseeds appears to have strong potential to meet or exceed national averages and be competitive with commercial products, although additional experience with the equipment is necessary to refine techniques to maximize quality and consistency.

Equipment. Most Vermont farmers will need to purchase a new or used oilseed expeller press. The expeller method uses a motor-driven screw to push the seed material against a small outlet under significant pressure to extract the oil. Expelling is a continuous method and can reduce meal fat content to 6%–7%, capturing 50%–85% of the available oil. To press well, the seed must be clean and have a moisture content of 6% to 9%. If the seed is wet, it does not flow through the nozzle well, and if it is too dry, the press grinds the seed to dust.

Borderview Farm and State Line Farm have taken different approaches to their pressing equipment, each with advantages and disadvantages. Both presses have successfully pressed soybeans and canola, mustard, flax, and sunflower seeds.

State Line purchased a Swedish-made expeller press (Täbypressen model 70) that is capable of pressing one ton of seed per day, depending on the condition of the seed and how fast it is pressed. State Line's press has an automatic shutoff and can run automatically for long periods of time, requiring minimal oversight and allowing the farmer to go about other tasks. This press, however, has a relatively small nozzle and is therefore sensitive to jams, interruptions in the flow of seed, or overheating, requiring the seed to be very clean prior to pressing. Depending on feedstock and adjustment, the State Line Press can produce one to three gallons of oil per hour (equating to 23,000–35,000 gallons of oil per year if run 24 hours per day).

Borderview Farm purchased a larger and less-expensive press from China, along with a pellet mill. The Borderview press has a larger nozzle and is therefore more "forgiving," obviating the need for seed-cleaning (in fact, the meal pellets reportedly hold together better if there is a little chaff in the seed) (R. Rainville, personal communication, October 16, 2008). Seeds pressed at Borderview are yielding 30% to 40% oil by weight, in line with standards for commercial operations. The Borderview press does require an operator to be present, and therefore may have higher labor/variable costs of operation. At a reported rate of 400 lbs per hour for sunflower seed and assuming a six-hour day of pressing, the press will process 1.2 tons of seed per day, roughly equivalent to State Line's press.

Meal from both presses requires pelletizing. Borderview's pellet mill expresses the pellets at 180°F, which reportedly makes the meal less likely to mold. The mill pelletizes 1000–1200 lbs of meal per hour, and has successfully pelletized sunflower seed, canola seed, soybeans, grass, manure, and wood.

Oilseed pressing operations also require dedicated space, either in a new or existing barn, shed, or shop; existing buildings may require some retrofit to minimize dust and spills and maximize efficiency.

Yields. Oil and meal yields from 50-lb subsamples of seed grown and pressed at State Line Farm are shown in Table 5. Sunflowers grown in 2006 and three of the varieties grown in 2007 had oil yields above the national average of 70 gallons per acre. The variety seeded at the highest rate (IS4049) produced both the highest yield and the highest percent oil content, yielding 119 gallons of oil per acre. Although canola oil yields are relatively low, Grubinger believes that with better growing and harvesting practices, canola seed yields of 1 ton per acre are achievable, and that 75 gallons of canola oil per acre could be expected for Vermont (2007).

Table 5: State Line Farm oil and meal yields

					Yield per acre	
Crop	**Variety**	**Moisture**	**Oil content**	**Seed (lbs)**	**Oil (gall)**	**Meal (lbs)**
2006						
Canola	Hyola 401	7.7%	Not reported	1404	26	1205
Canola	601	7.9%	Not reported	1128	19	985
Canola	Oscar	8.3%	Not reported	996	11	910
Canola	Hyola 420	8.0%	Not reported	984	18	846
Canola	KAB	9.4%	Not reported	756	Press malfunction	
Sunflower	IS 6521	8.0%	Not reported	2200	84	1563
2007						
Sunflower	Hysun1521	7.0%	29%	1643	64	Not reported
Sunflower	Defender	8.0%	27%	1854	66	Not reported
Sunflower	IS6039	10.0%	33%	1806	79	Not reported
Sunflower	IS6111	6.0%	29%	1247	48	Not reported
Sunflower	IS6521	8.0%	36%	1454	71	Not reported
Sunflower	IS4049	8.0%	37%	2397	119	Not reported

Source: (Darby & Hills, 2007; Grubinger, 2007)

Meal quality. Samples of soybean, canola, and sunflower meal pressed at State Line Farm were sent to the UVM Agricultural Testing Lab and the DairyOne lab in Ithaca, New York for a comprehensive analysis of their components. Table 6 shows the

State Line meal nutrient analyses as compared to typical nutrient values of commercial feeds. The crude protein levels of the State Line meals compare very favorably with commercial livestock meals. This is important because commercial oilseed meals are fed primarily as a protein source. The amount of fat in the State Line meal samples, however, is very high, at two to twelve times that of the commercial meals. Because too much unsaturated fat can cause digestion problems in ruminants, this level of fat may limit the amount of these meals that can be fed to dairy cows, and indicates that a significant amount of oil is being left in the meal and not extracted by the press (Hutjens, 2001).

Table 6: Nutrient analysis of State Line Farm oilseed meals (dry matter basis)

	Components (dry matter basis)									
	DM (%)	CP (%)	Fat (%)	NEL (Mcal/lb)	TDN (%)	ADF (%)	NDF (%)	Ca (%)	P (%)	Ash (%)
Soybean meals										
State Line Farm Oct 06 sample, UVM	87.0	54.4	13.0	1.05	97.8	10.0	12.0	0.37	0.96	5.7
State Line Farm Jan 07 sample, DairyOne	93.1	40.0	12.9	0.98	92.0	11.5	18.1	0.33	1.12	6.0
Commercial soybean meal, extruded 140ºC (Maiga, Marx, Crary, & Linn, 1997)	89.0	46.0	5.5	0.92	87.0	8.0	10.0	0.3	0.68	*not given*
Canola meals										
State Line Farm Oct 06 sample, UVM	90.5	39.0	23.6	1.12	105.3	25.3	36.3	0.72	1.24	5.9
State Line Farm Jan 07 sample, DairyOne	89.0	34.7	28.5	1.21	100.0	26.0	34.9	0.7	0.95	5.1
Commercial canola meal, extruded (Maiga et al., 1997)	92.0	38.0	3.0	0.79	72.0	18.0	36.0	0.3	1.0	*not given*
Sunflower meals										
State Line Farm Oct 06 sample, UVM	90.9	33.8	17.1	0.98	92.6	36.5	52.3	0.33	1.12	5.3
State Line Farm Jan 07 sample, DairyOne	95.8	23.2	24.0	1.05	87.0	30.3	50.9	0.37	0.96	5.3
Commercial sunflower meal, with hulls (Maiga et al., 1997)	90.0	34.0	2.1	0.63	57.0	33.0	40.0	0.23	1.03	*not given*

Abbreviations: ADF, acid detergent fiber; Ca, calcium; CP, crude protein; DM, dry matter; NDF, neutral detergent fiber; NEL, net energy for lactation; P, phosphorus; TDN, total digestible nutrients.
Sources: (Darby & Hills, 2007; Grubinger, 2007)

3.3.3 Biodiesel Production

Small-scale biodiesel production operations are relatively easy to establish and are used by many "home-brewers" nationwide. From a technical perspective, on-farm biodiesel production in Vermont is no different, requiring only adequate, heated space for the operations and the necessary equipment. If desired, farms could increase their fuel-making capacity by collecting waste vegetable oil from area restaurants and other sources to add to the new oil from their oilseed crops. The farm-produced biodiesel would most likely be used for farm use, but could also be sold directly to end-users for "off-road" use in farm, construction, or marine equipment; heating; or running diesel generators.

Equipment and facilities. The equipment required to make biodiesel includes several tanks linked by piping, pumps, and valves; an oil filtration or settling system; a fuel filtration system; and titration and testing equipment. Handling vegetable oil, methanol, and the catalysts required to make biodiesel (sodium hydroxide or potassium hydroxide) presents unique safety concerns. Explosion-proof pumps, review by a licensed electrician, and other components are necessary to minimize the safety risks associated with the materials, venting of gases, and recovery of ethanol/methanol. Careful space and site planning is required both to ensure adequate safety measures and to maximize throughput and efficiency.

Neither State Line nor Borderview Farms' new biodiesel production facilities were fully operational at the time of data collection for this study, although State Line Farm has been making biodiesel with smaller and older equipment for several years. State Line's new biodiesel facility has a batch capacity of 400 gallons, and is located in the same building as its oilseed processing facility (Figure 10).

Photo credit: Vermont Sustainable Jobs Fund

Figure 10: State Line Farm biodiesel processor

Quality. Any on-farm biodiesel facility will need to optimize production processes and product quality. Even when making "off-road" biodiesel that does not need to meet ASTM standards for on-road use, quality testing is important. High-quality fuel is free of excess methanol, potassium or sodium soaps, glycerin residue, and emulsifiers, indicating that the transesterification process was complete and efficient. Fuel that contains too many of these contaminants can cause engine damage.

Regulatory & tax implications. State Line Farm's initial experience has been that it can produce biodiesel for its own use or for sale to end-users in the off-road market under a minimum of tax and environmental regulation. If farm-produced biodiesel is used or sold for use in licensed vehicles traveling public roads, however, federal air quality regulations and taxation by the Environmental Protection Agency and Internal Revenue Service, respectively, may apply. This study examines only farm or off-road use.

3.3.4 Economic Feasibility Analysis

Oilseeds have at least six potential end-uses, depending on the type of seed and the amount of processing performed: (1) whole beans or seeds for livestock feed, (2) whole beans or seeds for human consumption, (3) meal for livestock feed, (4) food-grade oil, (5) fuel-grade oil, or (6) biodiesel. This thesis analyzes the economic feasibility of three of these enterprises: (1) production of whole seeds or beans from oilseed crops, (2) non–food-grade oil and livestock meal production, and (3) biodiesel production.

This analysis assumes that 50 acres of sunflowers are planted, with seed yields of 70 bushels or 1 ton per acre, oil yields of 44% by weight, meal yields of 56% by weight, and an oilseed expeller press that is 80% efficient compared to commercial extraction methods. Total crop yield is therefore estimated at 3500 bushels or 52.5 tons; oil yield at 5,200 gallons (or 36,400 lbs); meal yield at 29.4 tons; and biodiesel yield at 4,789 gallons.

Crop Production Enterprise. In the normal-price scenario, the expected oilseed price is assumed to be the price for sunflower seed for oil from the 2006-2007 marketing year, or $282 per ton (National Agricultural Statistics Service, 2006b); fertilizer prices are those from April 2007 (National Agricultural Statistics Service, 2008a), and machinery custom rates are from 2007 (Pike, 2007). In the high-price scenario, the expected oilseed price is $428 per ton, the price for sunflower seed for oil from the 2007-2008 marketing year (National Agricultural Statistics Service, 2007b); fertilizer prices are those from April 2008 (National Agricultural Statistics Service, 2008a); and machinery custom rates are from 2008 (Pike, 2008). All other production costs remain the same between the two scenarios and are based on 2007 data.

As shown in Figure 11, returns above total cost are negative for both scenarios. The high-price scenario is closer to breaking even, but the higher expected seed price still does not outweigh the higher input costs for that scenario.

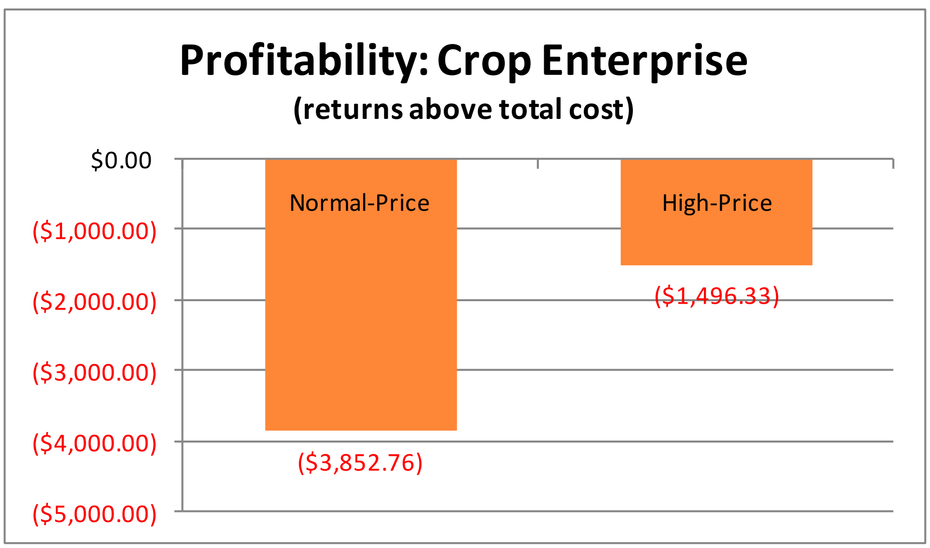


Figure 11: Returns above total cost, crop enterprise, based on 50 acres of sunflower

The complete enterprise budgets and breakeven analyses for the normal-price scenario are shown in Table 7 and Table 8 for the normal-price scenario and Table 10 and Table 11 for the high-price scenario.

Several aspects of the budgets are notable. On the cost side, fixed costs for both scenarios are approximately the same, at \$4,300–\$4,500 or 19% to 22% of total costs. In addition, returns above variable costs are positive for both scenarios. This indicates that production in the short-run may be desirable for some farms, especially if they anticipate reduced variable costs for their operation compared to these scenarios which would allow them to cover their total costs. Fertilizer costs in particular (which represent 36% to 43% of variable costs) may be reduced if existing soil fertility is good and multi-year crop rotations are considered. Finally, on the revenue side, adequate access to oilseed commodity markets is an important consideration for Vermont farmers considering whether to grow these crops for sale. The expected per ton crop value can only be realized if the farmer is able to bring the crop to market, and may be reduced by transportation costs.

Table 7: Normal-price scenario crop production enterprise budget (50ac sunflwr)

Item	Unit	Quantity	Price or Cost/Unit	Value or Cost	Value or Cost/Acre
Revenues					
Sunflower seeds for oil	Tons	52.5	$282.00	$14,805.00	$296.00
Variable Costs					
Soil test	Kit	2	$11.00	$22.00	$0.44
Planting prep-moldboard plow	Acre	50	$16.40	$820.00	$16.40
Planting prep-disk harrows	Acre	50	$12.30	$615.00	$12.30
Seed	Lbs	200	$4.00	$800.00	$16.00
Planting	Acre	50	$15.30	$765.00	$15.30
Lime (1 ton/acre every 3 yrs)	Ton	16.50	$40.00	$660.00	$13.20
Nitrogen (urea)	Lb	5000	$0.49	$2,461.96	$49.24
Phosphorus (super-phosphate)	Lb	3500	$0.45	$1,590.22	$31.80
Potassium (KCl)	Lb	5000	$0.23	$1,166.67	$23.33
Fertilizer spreading	Acre	50	$7.70	$385.00	$7.70
Cultivation/Herbicides	Acre	100	$12.50	$1,250.00	$25.00
Harvest	Acre	50	$35.00	$1,750.00	$35.00
Hauling seed from field	Bushel	3500	$0.18	$630.00	$12.60
Drying	Pt/bu	7	$0.03	$735.00	$14.70
Interest on operating expense	9-mo loan	$13,650.84	7.00%	$716.67	$14.33
Total variable costs				$14,367.51	$287.35
Fixed Costs					
Tractors & equipment	n/a	n/a	n/a	$0.00	$0.00
Grain storage (6 months)	Bu/month	3500	$0.05	$1,050.00	$21.00
Land/building rent	Acre	50	$50.00	$2,500.00	$50.00
Management (Ward, 2008)	% per $ rev	14805	5.00%	$740.25	$14.81
Total fixed costs				$4,290.25	$71.00
Total Costs				$18,657.76	$373.16
Return above variable costs				**$437.49**	**$8.75**
Return above total costs				**($3,852.76)**	**(77.06)**

Table 8: Normal-price scenario crop production break-even analysis (50ac sunflwr)

Breakeven price at projected yield	per bushel	per ton	Breakeven yield at projected price	bushels /acre	tons/ acre
at expected yield	$5.33	$355.39	at projected price	88.22	1.32
at 90% of expected yield	$5.92	$394.87	at 90% of expected price	98.02	1.47
at 75% of expected yield	$7.11	$473.85	at 75% of expected price	117.62	1.76
at 50% of expected yield	$10.66	$710.77	at 50% of expected price	176.43	2.65
at 120% of expected yield	$4.44	$296.15	at 120% of expected price	73.51	1.10
at 150% of expected yield	$3.55	$236.92	at 150% of expected price	58.81	0.88

Table 9: Normal-price scenario crop production sensitivity analysis (50ac sunflwr)

Return above total costs as seed price and yield vary

	-20% $225.60	**-10%** $253.80	**Price/Ton** **$282.00**	**+ 10%** $310.20	**+ 20%** $338.40
-20% (56 bu/acre)	($9,182.56)	($7,998.16)	($6,813.76)	($5,629.36)	($4,444.96)
-10% (63 bu/acre)	($7,998.16)	($6,665.71)	($5,333.26)	($4,000.81)	($2,668.36)
Yield (70 bu/acre)	($6,813.76)	($5,333.26)	**($3,852.76)**	($2,372.26)	($891.76)
+ 10% (77 bu/acre)	($5,629.36)	($4,000.81)	($2,372.26)	($743.71)	$884.84
+ 20% (84 bu/acre)	($4,444.96)	($2,668.36)	($891.76)	$884.84	$2,661.44

Table 10: High-price scenario crop production enterprise budget (50ac sunflwr)

Item	Unit	Quantity	Price or Cost/Unit	Value or Cost	Value or Cost/Acre
Revenues					
Sunflower seeds for oil	Tons	52.5	$428	$22,470	$449
Variable Costs					
Soil test	Kit	2	$11.00	$22.00	$0.44
Planting prep-moldboard plow	Acre	50	$18.00	$900.00	$18.00
Planting prep-disk harrows	Acre	50	$13.90	$695.00	$13.90
Seed	Lbs	200	$4.00	$800.00	$16.00
Planting	Acre	50	$16.70	$835.00	$16.70
Lime (1 ton/acre every 3 yrs)	Ton	16.50	$40.00	$660.00	$13.20
Nitrogen (urea)	Lb	5000	$0.60	$3,000.00	$60.00
Phosphorus (super-phosphate)	Lb	3500	$0.87	$3,043.48	$60.87
Potassium (KCl)	Lb	5000	$0.47	$2,337.50	$46.75
Fertilizer spreading	Acre	50	$9.15	$457.50	$9.15
Cultivation/Herbicides	Acre	100	$14.40	$1,440.00	$28.80
Harvest	Acre	50	$45.00	$2,250.00	$45.00
Hauling seed from field	Bushel	3500	$0.19	$665.00	$13.30
Drying	Pt/bu	7	$0.05	$1,225.00	$24.50
Interest on operating expense	9-mo loan	$18,330.48	7.00%	$962.35	$19.25
Total variable costs				$19,292.83	$385.86
Fixed Costs					
Tractors & equipment	n/a	n/a	n/a	$0.00	$0.00
Grain storage	Bu/month	3500	$0.05	$1,050.00	$21.00
Land/building rent	Acre	50	$50.00	$2,500.00	$50.00
Management (Ward, 2008)	% per $ rev	0	5.00%	$1,123.50	$22.47
Total fixed costs				$4,673.50	$93.47
Total Costs				$23,966.33	$479.33
Return above variable costs				**$3,177.17**	**$63.54**
Return above total costs				**($1,496.33)**	**($29.93)**

Table 11: High-price scenario crop production break-even analysis (50ac sunflwr)

Break-even price at projected yield	per bushel	per ton	Breakeven yield at projected price	bushels/ acre	tons/ acre
at expected yield	$6.85	$456.50	at projected price	74.66	1.12
at 90% of expected yield	$7.61	$507.22	at 90% of expected price	82.96	1.24
at 75% of expected yield	$9.13	$608.67	at 75% of expected price	99.55	1.49
at 50% of expected yield	$13.70	$913.00	at 50% of expected price	149.32	2.24
at 120% of expected yield	$5.71	$380.42	at 120% of expected price	62.22	0.93
at 150% of expected yield	$4.57	$304.33	at 150% of expected price	49.77	0.75

Table 12: High-price scenario crop production sensitivity analysis (50ac sunflwr)

Return above total costs as seed price and yield vary

	-20% $342.40	**-10%** $385.20	**Price/Ton** **$428**	**+10%** $470.80	**+20%** $513.60
-20% (56 bu/acre)	($9,585.53)	($7,787.93)	($5,990.33)	($4,192.73)	($2,395.13)
-10% (63 bu/acre)	($7,787.93)	($5,765.63)	($3,743.33)	($1,721.03)	$301.27
Yield (70 bu/acre)	($5,990.33)	($3,743.33)	**($1,496.33)**	$750.67	$2,997.67
+ 10% (77 bu/acre)	($4,192.73)	($1,721.03)	$750.67	$3,222.37	$5,694.07
+ 20% (84 bu/acre)	($2,395.13)	$301.27	$2,997.67	$5,694.07	$8,390.47

Sensitivity of profitability to changes in both yield and expected seed price per ton is shown in Figure 12 and Table 9 for the normal-price scenario, and Figure 13 and Table 12 under high-price conditions. Under normal-price conditions, both higher yields and a higher seed price would be necessary for the enterprise to be profitable. In both scenarios, good yields are an important factor in profitability; in the high-price scenario, for example, even with a 20% higher seed price, returns are still predicted to be negative if yield falls by 20%.

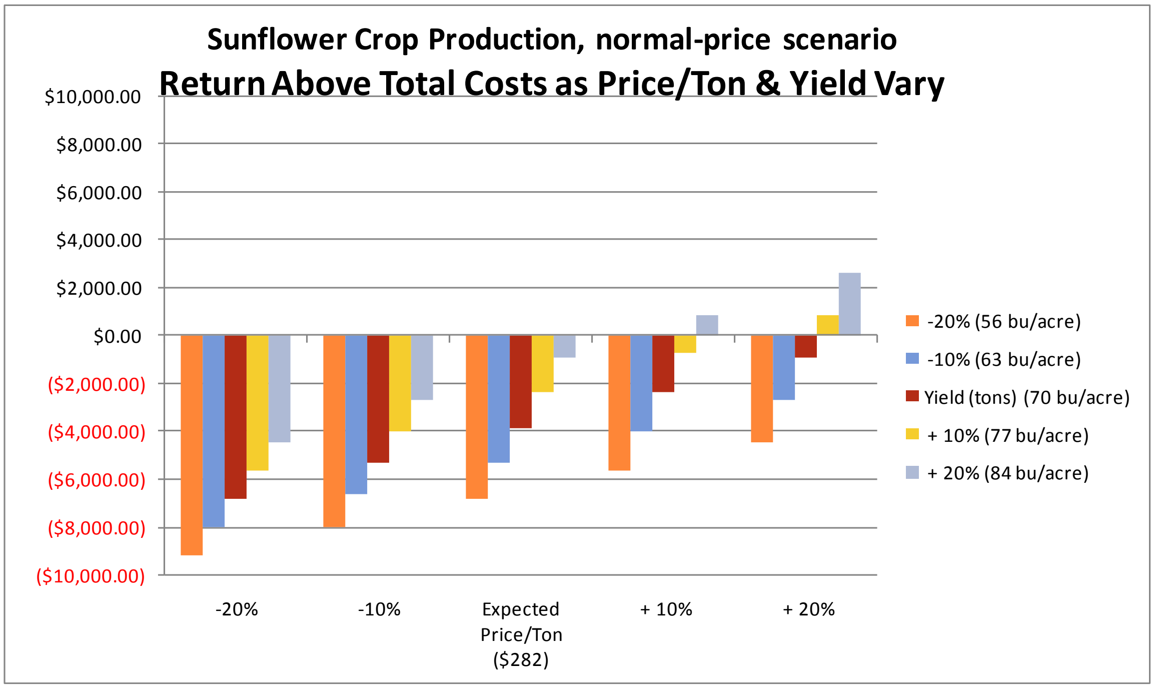


Figure 12: Sensitivity of crop production profitability to seed price and yield, normal-price scenario

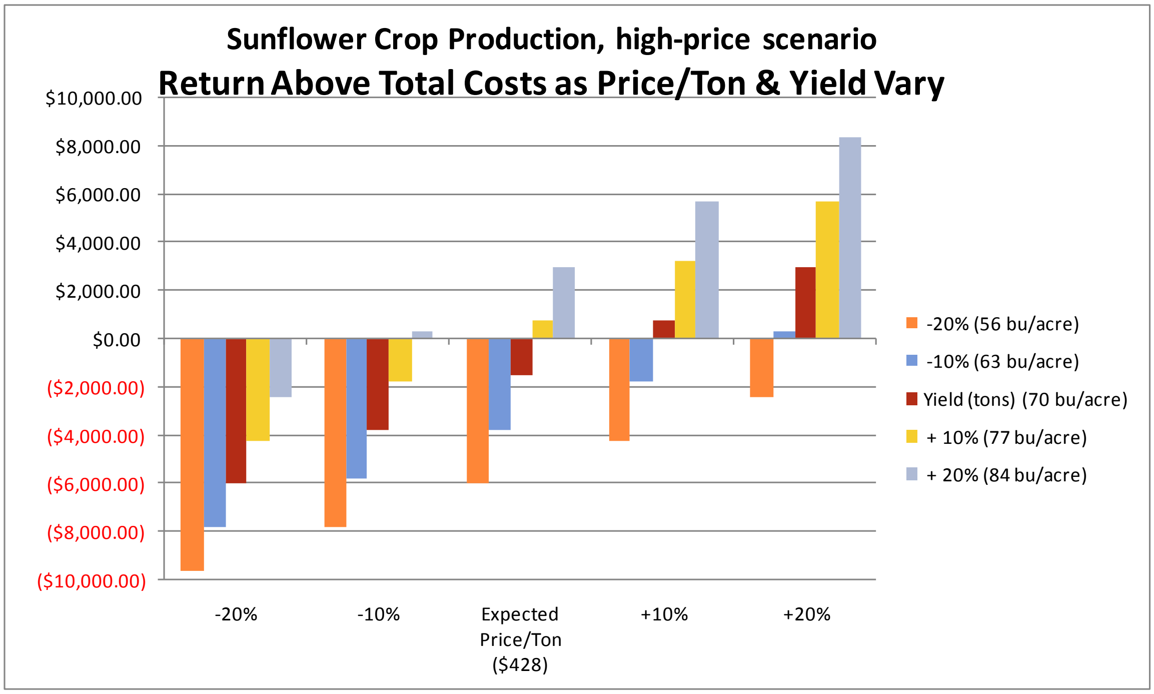


Figure 13: Sensitivity of crop production profitability to seed price and yield, high-price scenario

Oil & Meal Production Enterprise. The value of the oilseed meal as a livestock feed for dairy cows is a crucial component of the economic feasibility analysis of this enterprise in Vermont. The meal must consistently deliver high-quality nutrition components in order to be relied on by the producing farm or its customers as a replacement for commercial feeds in a balanced ration.

In order to estimate the potential value of farm-pressed oilseed meal, CPM-Dairy software was used to determine how much, if any, protein in a high-producing (24,000 lbs/year) dairy cow ration could be replaced with farm-pressed meal. First, a baseline ration containing several protein sources was established: 48% soybean meal at $278 per ton, soybean hulls at $200 per ton, SoyPass® (Borregaard LignoTech) meal at $330 per ton, AminoPlus® (Ag Processing, Inc®) soybean meal at $313 per ton, and corn gluten meal at $447 per ton.

Next, the nutrient values of the soybean, canola, and sunflower meals pressed at State Line Farm and analyzed by DairyOne in January 2007 were input into the program. The State Line meals were assigned varying per-ton values, to see how much of the meal would be incorporated into the daily ration at different price points. For each meal, the ration was calculated at zero cost, $200 per ton, $228 per ton ($50 less than the current price of 48% soybean meal), $278 per ton (price of 48% soybean meal), and $313 ($35 above the price of 48% soybean meal). Forage and corn gluten meal were capped at maximum levels, and 48% soybean meal was set at a minimum level of 1.5 pounds per day. As shown in Figure 14, farm-pressed meal has significant potential to replace commercial meals in the feed ration of a high-producing dairy cow.

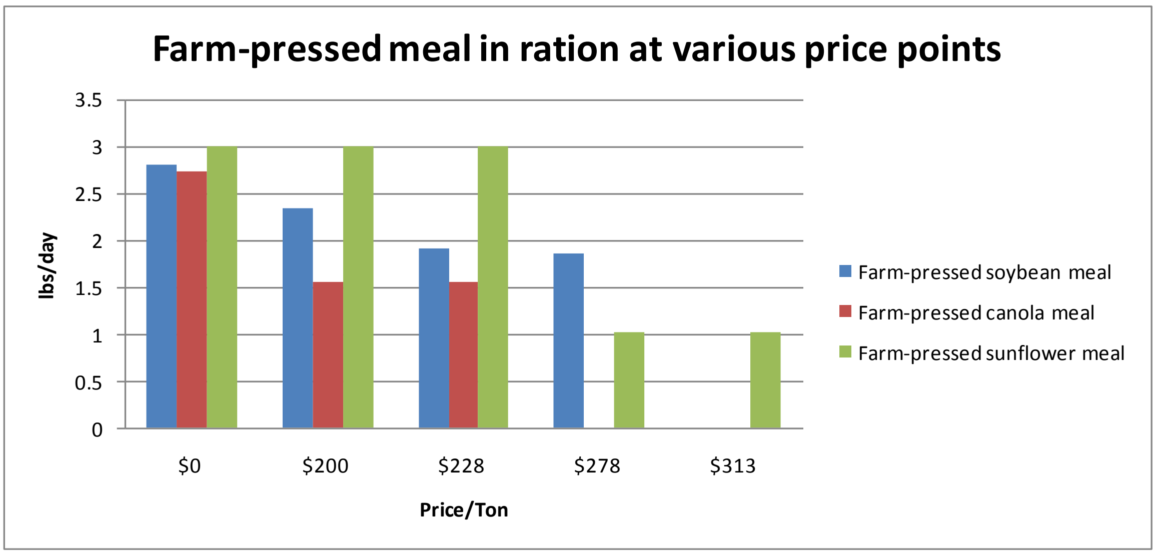


Figure 14: Inclusion of farm-pressed meals in dairy cow feed ration

Figure 14 shows that as the price for the farm-pressed meal was increased, the amount fed decreased. The rate of decrease differed for each meal, however, with sunflower faring the best, followed by soybean and then canola meal. To limit the total fat in the diet, a maximum amount of sunflower meal that could be included was set at 3 pounds. The software included the full 3 pounds of sunflower meal in the ration up to a cost of $228 per ton. When the price was set at $258 per ton, the amount fed dropped to approximately 1.5 pounds, but about 1 pound of State Line sunflower meal was included even when its price was set at or above the price of 48% soybean meal. In the scenarios that follow, $228 per ton is used as the expected price or value of the sunflower meal.

Another important consideration in this analysis is the feed cost per day. As shown in Figure 15, the base ration (without any farm-pressed meals) has a cost of $4.30 per day. None of the other rations that include farm-pressed meals exceed this cost, and many of them fall below this level when the price of the farm-pressed meal is discounted below that of commercial meals. Each pound of local soybean meal, for example, saves 11 cents per cow per day if it is free, but only 3 cents per cow per day if it costs $200 per ton, and there is no savings if it is priced at $278 per ton. Similarly, each pound of local canola meal saves 10 cents per cow per day if free, but savings diminish quickly when the meal assigned a price—at $200 per ton, for example, the per-pound savings per cow per day drop to only 2 cents. Local sunflower meal again fares best, with each pound of meal saving 14 cents per cow per day when free, 4 cents per cow per day at $220 per ton, and 2 cents per day up to $278 per ton.

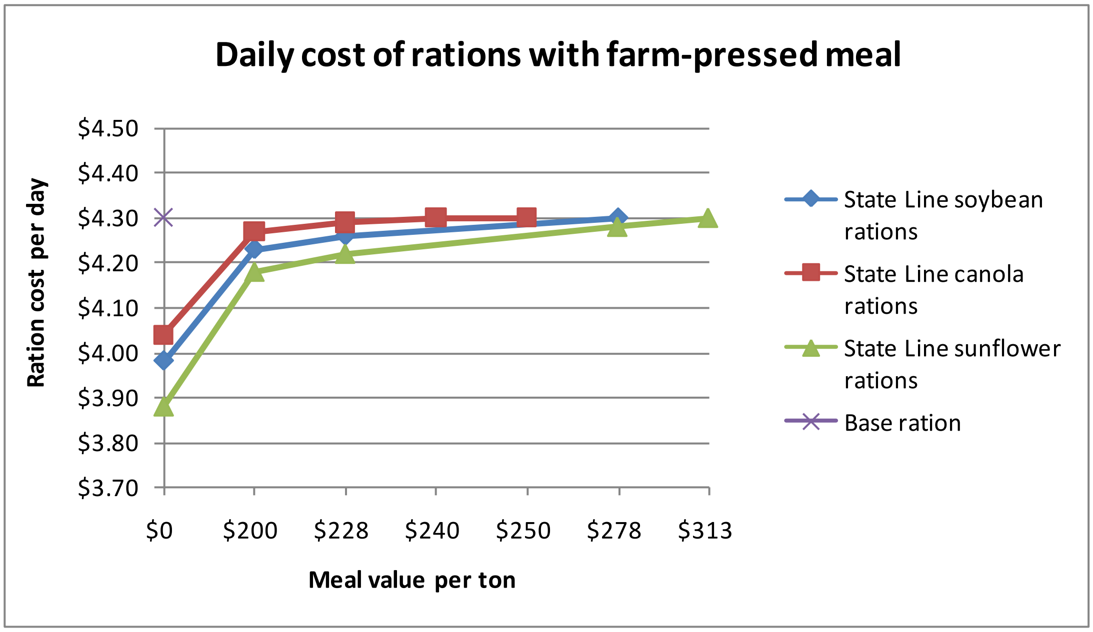


Figure 15: Daily cost per cow of feed rations with farm-pressed meal

In the normal-price scenario, the expected oil price is assumed to be the 2007 average price for soybean oil (the benchmark price for vegetable oils), or $0.35 per lb (USDA Market News Service, 2007); meal value is estimated at $228 per ton (based on CPM-Dairy analysis); and the assumed seed input cost is $282 per ton (the 2006-2007 marketing year price for sunflower seed for oil).

In the high-price scenario, the expected price is the 2008 average price for soybean oil, or $0.62 per lb (Agricultural Marketing Service, 2008); meal value is estimated at 60% above the CPM-Dairy value (approximating the 60% increase in soybean meal price between 2007 and 2008) (Agricultural Marketing Service, 2008); and the oilseed input cost is $428 per ton, the price for sunflower seed for oil from the 2007-2008 marketing year. All other production costs remain the same between the two scenarios and are based on data from Borderview Farm (R. Rainville, personal communication, October 16, 2008). Capital costs related to oil and meal production are shown in Table 13.

Table 13: Capital costs for oil & meal production

Item	Cost	Salvage	Yrs of Life	Depreciation (SL)	Interest Rate	Interest
60-ton grain bin & concrete pad	$11,800	$0.00	7	$1,685.71	7.00%	$826.00
Seed press, 3-phase motor, shipping/tax	$4,127	$0.00	7	$589.57	7.00%	$288.89
Pellet mill, 3-phase motor, shipping/tax	$1,777	$0.00	7	$253.86	7.00%	$124.39
Meal storage	$1,000	$0.00	7	$142.86	7.00%	$70.00
Oil storage	$1,000	$0.00	7	$142.86	7.00%	$70.00
Power conversion to 3-phase	$1,200	$0.00	7	$171.43	7.00%	$84.00
Total	**$20,904**	**$0.00**		**$2,986.29**		**$1,463. 28**

Source: (R. Rainville, personal communication, October 16, 2008)

As shown in Figure 16, returns above total cost are negative for both scenarios. The high-price scenario loses less money, but the higher expected oil and meal prices are not enough to outweigh the higher input costs.

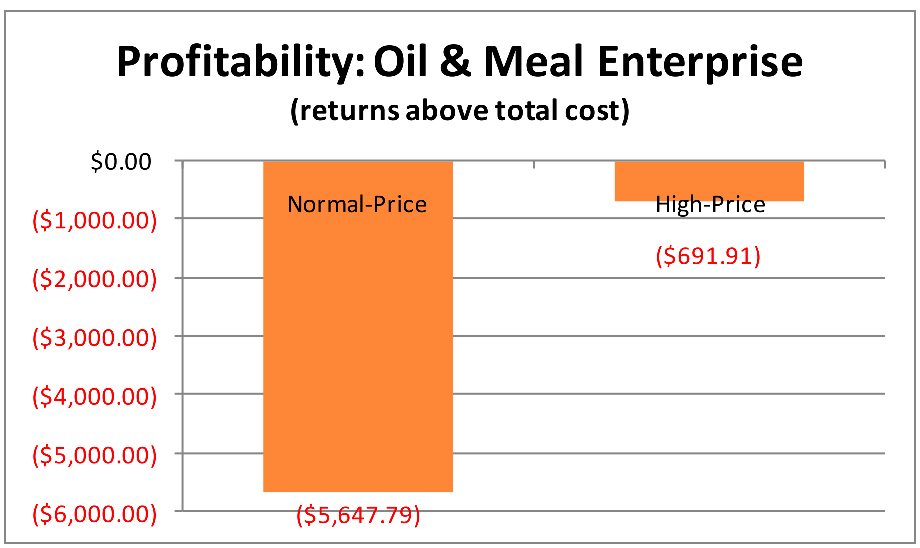


Figure 16: Returns above total cost, oil & meal enterprise

The complete oil and meal enterprise budgets and breakeven analyses for the normal-price scenario are shown in Table 14 and Table 15 for the normal-price scenario and Table 17 and Table 18 for the high-price scenario. The most significant input cost is the value of the oilseed itself, which represents 75%–81% of variable costs and 59%–66% of total costs. As with crop production, the oil and meal enterprise comes much closer to profitability under high-price conditions. In the normal-price scenario, for example, the potential "value-add," or difference between the oilseed input cost and expected oil and meal revenue, is only $4600, whereas for the high-price scenario it is $10,800. In addition, returns above variable costs are negative for the normal-price scenario but positive for the high-price scenario.

It is also notable that if the oilseed production cost is used (instead of market price), returns above total costs are more negative under normal-price conditions but less negative under high-price conditions. In other words, in the normal-price scenario it costs more to grow the crop for the oil and meal enterprise than it would to purchase oilseeds for pressing. Under these high-price conditions, however, growing one's own oilseed would be cheaper than purchasing it at market prices.

Table 14: Normal-price scenario meal & oil enterprise budget

Item	Unit	Quantity	Price/ Unit	Value or Cost	Value or Cost/Acre	Value or Cost/lb Oil	Value or Cost/ton Meal
Revenues							
Oil	lbs	36,400	$0.35	$12,740.00	$254.80	$0.35	n/a
Meal value	Tons	29.4	$228.00	$6,703.20	$134.06	n/a	$228.00
Total revenues				$19,443.20	$388.86		
Variable Costs							
Oilseed	Tons	52.5	$282.00	$14,805.00	$296.10	$0.41	$503.57
Electricity-cleaner	Hour	0	0	$0.00	-	-	$0.00
Electricity-press	Hour	262.5	$0.70	$183.75	$3.68	$0.01	$6.25
Electricity-pellet mill	Hour	53.5	$0.75	$40.09	$0.80	$0.00	$1.36
Labor – cleaner	Hour	0	$10.00	$0.00	-	-	$0.00
Labor - press	Hour	262.5	$10.00	$2,625.00	$52.50	$0.07	$89.29
Labor - pellet mill	Hour	53.45	$10.00	$534.55	$10.69	$0.01	$18.18
Meal drying	Tons	29.40	$1.50	$44.10	$0.88	$0.00	$1.50
Meal testing	Test	3	$50.00	$150.00	$3.00	$0.00	$5.10
Interest on operating expense	$/yr	$18,382.49	7.00%	$1,286.77	25.53	$0.04	$43.41
Total variable costs				$19,669.26	$393.39	$0.54	$669.02
Fixed Costs							
Depreciation	$	1	$2,986.29	$2,986.29	$59.73	$0.08	$101.57
Interest	$	1	$1,463.28	$1,463.28	$29.27	$0.04	$49.77
Taxes & insurance	$	1	$0.00	$0.00	-	-	$0.00
Management (Ward, 2008)	%/$ rev	0	5.00%	$972.16	$19.44	$0.03	$33.07
Total fixed costs				$5,421.73	$108.43	$0.15	$184.41
Total costs				$25,090.99	$501.82	$0.69	$853.43
Returns above variable costs				**($226.06)**	**($4.52)**	**($0.06)**	**($0.01)**
Returns above total costs				**($5,647.79)**	**($112.96)**	**($1.61)**	**($0.16)**
Returns above variable costs, assuming production cost for oilseed				**($2,881.97)**	**($57.64)**	**($0.08)**	**($98.03)**
Returns above total costs, assuming production cost for oilseed				**($8,303.70)**	**($166.07)**	**($0.23)**	**($282.44)**

Table 15: Normal-price scenario meal & oil break-even analysis

Break-even price at projected yield	per lb oil	per ton meal	Break-even yield at projected price	lbs oil/bu seed	lbs meal/bu seed
at expected yield	$0.69	$853.43	at projected price	20	63
at 90% of expected yield	$0.77	$948.26	at 90% of expected price	23	70
at 75% of expected yield	$0.92	$1,137.91	at 75% of expected price	27	84
at 50% of expected yield	$1.38	$1,706.87	at 50% of expected price	41	126
at 120% of expected yield	$0.57	$711.20	at 120% of expected price	17	52
at 150% of expected yield	$0.46	$568.96	at 150% of expected price	14	42

Table 16: Normal-price scenario meal & oil sensitivity analysis

Return above total costs as oil and meal prices vary

	-20%	-10%	Oil Price/lb ($0.35)	plus 10%	plus 20%
-20%	($9,536.43)	($8,080.43)	($6,988.43)	($5,532.43)	($4,440.43)
-10%	($8,866.11)	($7,410.11)	($6,318.11)	($4,862.11)	($3,770.11)
Meal Price/ton	($8,195.79)	($6,739.79)	**($5,647.79)**	($4,191.79)	($3,099.79)
plus 10%	($7,525.47)	($6,069.47)	($4,977.47)	($3,521.47)	($2,429.47)
plus 20%	($6,855.15)	($5,399.15)	($4,307.15)	($2,851.15)	($1,759.15)

Return above total costs as oilseed input cost varies

	Profit
0 cost	$9,157.21
-50%	$1,754.71
-40%	$274.21
-30%	($1,206.29)
-20%	($2,686.79)
-10%	($4,167.29)
Oilseed Cost/ton ($282)	($5,647.79)
plus 10%	($7,128.29)
plus 20%	($8,608.79)

Table 17: High-price scenario meal & oil enterprise budget

Item	Unit	Quantity	Price/Unit	Value or Cost	Value or Cost/Acre	Value or Cost/lb Oil	Value or Cost/ton Meal
Revenues							
Oil	Lbs	36,400	$0.62	$22,568.00	$451.36	$0.62	n/a
Meal value	tons	29.4	$364.80	$10,725.12	$214.50	n/a	$364.80
Total revenues				**$33,293.12**	**$665.86**		
Variable Costs							
Oilseed	Tons	52.5	$428.00	$22,470.00	$449.40	$0.62	$764.29
Electricity - cleaner	Hour	0	0	$0.00	-	-	$0.00
Electricity - press	Hour	262.5	$0.70	$183.75	$3.68	$0.01	$6.25
Electricity - pellet mill	Hour	$53.45	$0.75	$40.09	$0.80	$0.00	$1.36
Labor – cleaner	Hour	0	$10.00	$0.00	-	-	$0.00
Labor – press	Hour	262.5	$10.00	$2,625.00	$52.50	$0.07	$89.29
Labor - pellet mill	Hour	$53.45	$10.00	$534.55	$10.69	$0.01	$18.18
Meal drying	Tons	29.40	$1.50	$44.10	$0.88	$0.00	$1.50
Meal testing	Test	3	50.00	$150.00	$3.00	$0.00	$5.10
Interest on operating expenses	$/yr	$26,047.49	7.00%	$1,823.32	$36.47	$0.05	$62.02
Total variable costs				$27,870.81	$557.42	$0.77	$947.99
Fixed Costs							
Depreciation	$	1	$2,986.29	$2,986.29	$59.73	$0.08	$101.57
Interest	$	1	$1,463.28	$1,463.28	$29.27	$0.04	$49.77
Taxes & insurance	$	1	$0.00	$0.00	-	-	$0.00
Management (Ward, 2008)	% per $ rev	0	5.00%	$1,664.66	$33.29	$0.05	$56.62
Total fixed costs				$6,114.22	$122.28	$0.17	$207.97
Total costs				$33,824.53	$676.49	$0.93	$1,150.49
Returns Above Variable Costs				**$5,422.31**	**$108.45**	**$1.55**	**$0.15**
Returns Above Total Costs				**($691.91)**	**($13.84)**	**($0.20)**	**($0.02)**
Returns above variable costs, assuming production cost for oilseed				**$5,659.38**	**$113.19**	**$0.16**	**$192.50**
Returns above total costs, assuming production cost for oilseed				**($454.84)**	**($9.10)**	**($0.01)**	**($15.47)**

Table 18: High-price scenario meal & oil break-even analysis

Breakeven price at projected yield	per lb oil	per ton meal	Breakeven yield at projected price	lbs oil/bu seed	lbs meal/bu seed
at expected yield	$0.93	$1,155.95	at projected price	16	53
at 90% of expected yield	$1.04	$1,284.39	at 90% of expected price	17	59
at 75% of expected yield	$1.24	$1,541.27	at 75% of expected price	21	71
at 50% of expected yield	$1.87	$2,311.91	at 50% of expected price	31	106
at 120% of expected yield	$0.78	$963.29	at 120% of expected price	13	44
at 150% of expected yield	$0.62	$770.64	at 150% of expected price	10	35

Table 19: High-price scenario meal & oil sensitivity analysis

Return above total costs as oil and meal prices vary

	-20%	-10%	Oil Price/lb ($0.62)	plus 10%	plus 20%
	$0.50	$0.56	$0.62	$0.68	$0.74
-20%	($7,204.94)	($5,020.94)	($2,836.94)	($652.94)	$1,531.06
-10%	($6,132.42)	($3,948.42)	($1,764.42)	$419.58	$2,603.58
Meal Price/ton	($5,059.91)	($2,875.91)	**($691.91)**	$1,492.09	$3,676.09
plus 10%	($3,987.40)	($1,803.40)	$380.60	$2,564.60	$4,748.60
plus 20%	($2,914.89)	($730.89)	$1,453.11	$3,637.11	$5,821.11

Return above total costs as oilseed cost varies

	Profit
0 cost	$21,778.09
-50%	$10,543.09
-40%	$8,296.09
-30%	$6,049.09
-20%	$3,802.09
-10%	$1,555.09
Oilseed Cost/ton ($428)	($691.91)
plus 10%	($2,938.91)
plus 20%	($5,185.91)

Sensitivity of the profitability of the oil and meal enterprise to changes in the expected oil and meal prices is shown in Figure 17 and Table 16 for the normal-price scenario and in Figure 18 and Table 19 for the high-price scenario. Under normal-price conditions, the enterprise fails to reach profitability with oil and meal price increases of 20%; under high-price conditions, the enterprise could be profitable with 10% to 20% higher oil or meal prices.

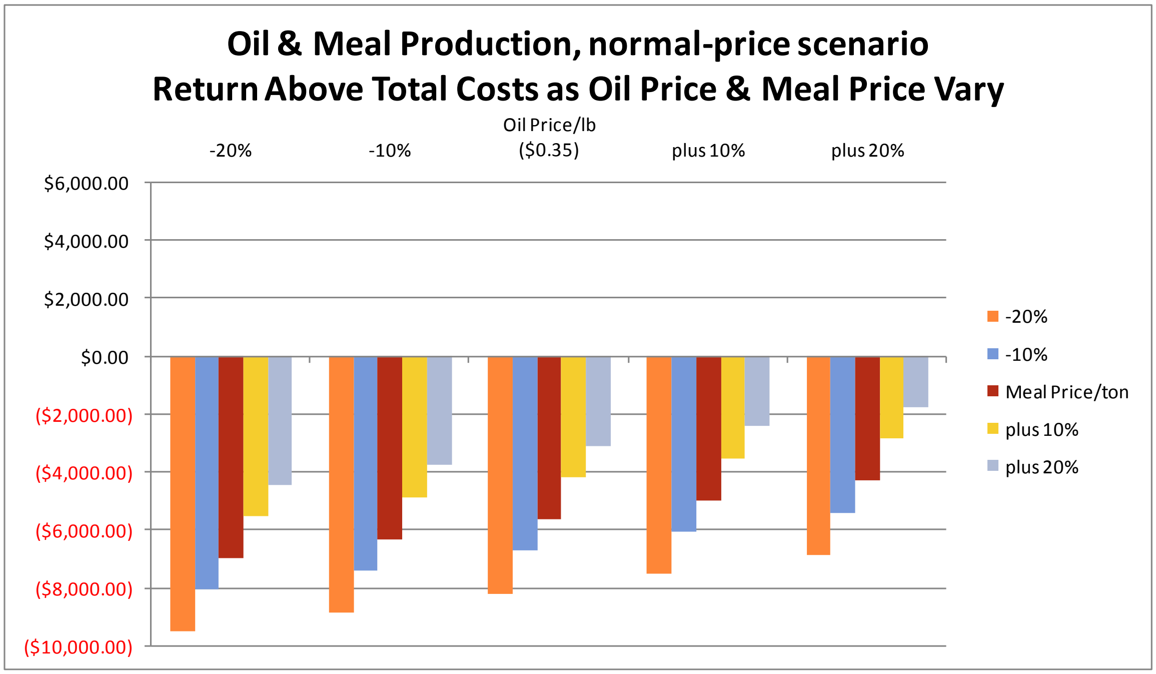


Figure 17: Sensitivity of oil & meal production profitability to oil and meal prices, normal-price scenario

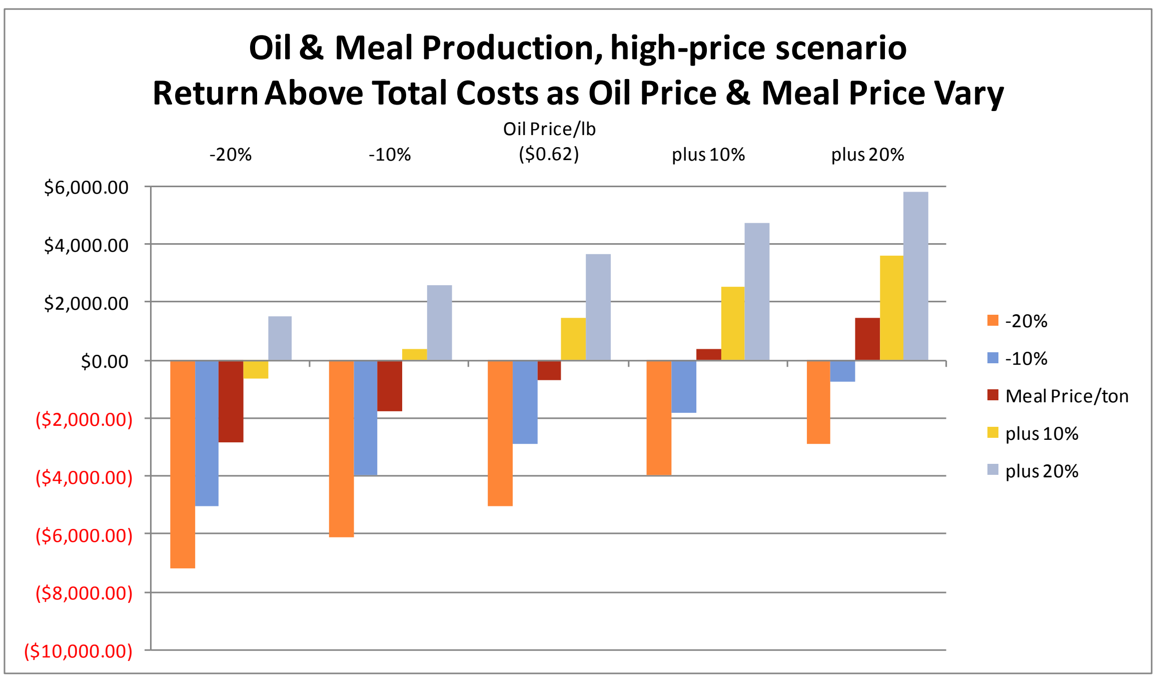


Figure 18: Sensitivity of oil & meal production profitability to oil and meal prices, high-price scenario

Biodiesel Production Enterprise. In the normal-price scenario, the expected biodiesel price is assumed to be the 2007 average price for diesel fuel in Vermont, or $3.02 per gallon (Vermont Department of Public Service, 2007). Estimated input costs are $0.35 per lb for vegetable oil (the 2007 average price for soybean oil) (USDA Market News Service, 2007), and spring 2007 prices for methanol and potassium hydroxide of $3.44 per gallon and $1.60 per lb, respectively (S. Gordon, personal communication, April 9, 2007). In the high-price scenario, the expected biodiesel price is $5.00, the 2008 peak price for diesel fuel in Vermont (Vermont Department of Public Service, 2008). Input costs are estimated at $0.62 per lb for vegetable oil (the 2008 average price for soybean oil) (Agricultural Marketing Service, 2008), and peak 2008 prices for methanol and potassium hydroxide of $7.27 per gallon and $2.20 per lb, respectively (Allen Engineering & Chemical, personal communication, January 20, 2009). All other production costs remain the same between the two scenarios and are based on data from industry sources and State Line Farm (J. Williamson, personal communication, February 7, 2009). Capital costs related to biodiesel production are shown in Table 20.

Table 20: Capital costs for biodiesel production

Item	Cost	Salvage	Years of Life	Depreciation (SL)	Interest Rate	Interest
Biodiesel processor kit (400-gallon capacity)	$10,000	$0.00	7	$1,428.57	7.00%	$700.00
Glycerol storage	$250	$0.00	7	$35.71	7.00%	$17.50
Biodiesel storage*	$0	$0.00	7	$0.00	7.00%	$0.00
Kit customization	$500	$0.00	7	$71.43	7.00%	$35.00
Storage/fire locker	$5,000	$0.00	7	$714.29	7.00%	$350.00
Filter housing	$600	$0.00	7	$85.71	7.00%	$42.00
Pumps	$400	$0.00	7	$57.14	7.00%	$28.00
Building retrofit	$4,000	$0.00			7.00%	$280.00
Secondary containment [SPCC-compliant]	$0	$0.00	7	$0.00	7.00%	$0.00
	$20,750			**$2,392.86**		**$1,452.50**

*Assumes the use of free, used 55-gallon drums for biodiesel storage.
Source: (N. White, personal communication, January 29, 2009)

As shown in Figure 19, returns above total cost are negative for both scenarios. In this case, the high-price scenario loses more money than the normal-price scenario, mainly due to the high input costs of the vegetable oil. At $0.62 per lb, this line item alone nearly equals expected revenues (or value in avoided costs) from biodiesel at $5.00 per gallon. (Or in other words, the potential value-add is only $1380 for the high-price scenario and $1724 for the normal-price scenario).

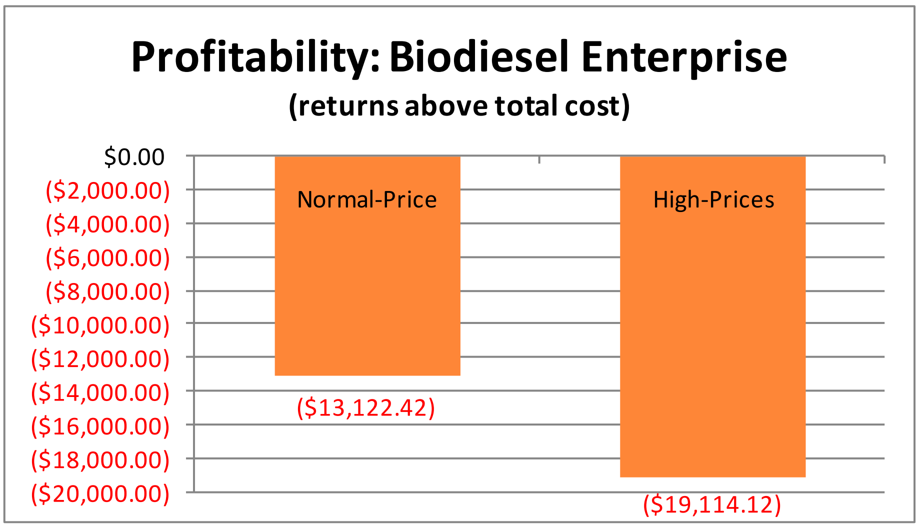


Figure 19: Returns above total cost, biodiesel enterprise

The complete biodiesel production enterprise budgets and breakeven analyses for the normal-price scenario are shown in Table 21 and Table 22 for the normal-price scenario and Table 24 and Table 25 for the high-price scenario. If the oil production cost is used (instead of market price), returns above total costs are more negative under both normal-price and high-price conditions. In other words, it costs slightly more to grow and press the oilseed for the biodiesel enterprise than it would to purchase oil.

Table 21: Normal-price scenario biodiesel enterprise budget

Item	Unit	Quantity	Value or Cost/Unit	Value or Cost	Value or Cost /Gal Biodiesel
Revenues					
Biodiesel	gallon	4,789	$3.02	$14,464.21	$3.02
Variable costs					
Oil produced on-farm	lbs	36,400	$0.35	$12,740.00	$2.66
Methanol	55-gall drum	24	$189.00	$4,467.27	$0.93
Catalyst (KOH)	50-lb bag	6	$80.00	$486.04	$0.10
Lab fees and testing services	test	1	$50.00	$50.00	$0.01
Lab chemicals	yearly supply	1	$15.00	$15.00	$0.00
Filters (raw oil)	Ea	0	$5.00	$0.00	$0.00
Glycerol disposal		0	$0.00	$0.00	$0.00
Energy/electricity	KwH/ga biod	4789	$0.02	$114.76	$0.02
Labor	Hr	13	$15.00	$195.00	$0.04
Total variable costs				$18,068.06	$3.77
Fixed costs					
Depreciation on equipment	$	1	$2,392.86	$2,392.86	$0.50
Interest on equipment cost	$	1	$1,452.50	$1,452.50	$0.30
Insurance (liability)	Premium/mo	12	$350.00	$4,200.00	$0.88
Permitting fees	$	0	$0.00	$0.00	$0.00
Electrician; biodiesel consultant fees	Each	1	$750	$750.00	$0.16
Management (Ward, 2008)	% per $ rev	$14,464.21	5%	$723.21	$0.15
Total fixed costs				$9,518.57	$1.99
Total Costs				$27,586.63	$5.76
Returns Above Variable Costs				**($3,603.85)**	**($0.75)**
Returns Above Total Costs				**($13,122.42)**	**($2.74)**
Returns above variable costs, assuming production cost of oil				**($11,907.55)**	**($2.49)**
Returns above total costs, assuming prod cost of oil				**($21,426.12)**	**($4.47)**

Table 22: Normal-price scenario biodiesel break-even analysis

Breakeven price at projected yield	Price per gallon	Breakeven yield at projected price	Gallons biodiesel
at expected yield	$5.76	at projected price	9,135
at 90% of expected yield	$6.40	at 90% of expected price	10,150
at 75% of expected yield	$7.68	at 75% of expected price	12,180
at 50% of expected yield	$11.52	at 50% of expected price	18,269
at 120% of expected yield	$4.80	at 120% of expected price	7,612
at 150% of expected yield	$3.84	at 150% of expected price	6,090

Table 23: Normal-price scenario biodiesel sensitivity analysis

	Zero Cost	-10%	Oil Cost/lb ($0.35)	plus 10%	plus 20%
-20%	($3,256.11)	($14,904.11)	($15,996.11)	($17,452.11)	($18,544.11)
-10%	($1,819.26)	($13,467.26)	($14,559.26)	($16,015.26)	($17,107.26)
Diesel Price/Gal ($3.02)	($382.42)	($12,030.42)	($13,122.42)	($14,578.42)	($15,670.42)
plus 10%	$1,054.42	($10,593.58)	($11,685.58)	($13,141.58)	($14,233.58)
plus 20%	$2,491.26	($9,156.74)	($10,248.74)	($11,704.74)	($12,796.74)
plus 30%	$3,976.00	($7,672.00)	($8,764.00)	($10,220.00)	($11,312.00)
plus 50%	$6,849.68	($4,798.32)	($5,890.32)	($7,346.32)	($8,438.32)
plus 60%	$8,286.53	($3,361.47)	($4,453.47)	($5,909.47)	($7,001.47)
plus 70%	$9,723.37	($1,924.63)	($3,016.63)	($4,472.63)	($5,564.63)

Return above total costs as diesel price varies

	Profit (Loss)
-20%	($15,996.11)
-10%	($14,559.26)
Diesel Price/Gal ($3.02)	($13,122.42)
plus 10%	($11,685.58)
plus 20%	($10,248.74)
plus 30%	($8,764.00)
plus 50%	($5,890.32)
plus 60%	($4,453.47)
plus 70%	($3,016.63)

Table 24: High-price scenario biodiesel enterprise budget

Item	Unit	Quantity	Value or Cost/Unit	Value or Cost	Value or Cost /Gal Biodiesel
Revenues					
Biodiesel	gallon	4,789	$5.00	$23,947.37	$5.00
Variable costs					
Oil produced on-farm	lbs	36,400	$0.62	$22,568.00	$4.71
Methanol	55-gall drum	24	$400.00	$9,454.55	$1.97
Catalyst (KOH)	50-lb bag	6	$110.00	$668.30	$0.14
Lab fees and testing services	test	1	$50.00	$50.00	$0.01
Lab chemicals	yearly supply	1	$15.00	$15.00	$0.00
Filters (raw oil)	Ea	0	$5.00	$0.00	$0.00
Glycerol disposal		0	$0.00	$0.00	$0.00
Energy/electricity	KwH/ga biod	4,789	$0.02	$114.76	$0.02
Labor	Hr	13	$15.00	$195.00	$0.04
Total variable costs				**$33,068.76**	**$6.90**
Fixed costs					
Depreciation on equipment	$	1	$2,392.86	$2,392.86	$0.50
Interest on equipment cost	$	1	$1,452.50	$1,452.50	$0.30
Insurance (liability)	Premium/mo	12	$350.00	$4,200.00	$0.88
Permitting fees	$	0	$0.00	$0.00	$0.00
Electrician; biodiesel consultant fees	Each	1	$750	$750.00	$0.16
Management (Ward, 2008)	% per $ rev	$23,947.37	5%	$1,197.37	$0.25
Total fixed costs				**$9,992.73**	**$2.09**
Total Costs				**$43,061.49**	**8.99**
Returns Above Variable Costs				**($9,121.39)**	**($1.90)**
Returns Above Total Costs				**($19,114.12)**	**($3.99)**
Returns above variable costs, assuming production cost of oil				**($9,576.23)**	**($2.00)**
Returns above total costs, assuming prod cost of oil				**($19,568.96)**	**($4.09)**

Table 25: High-price scenario biodiesel break-even analysis

Breakeven price at projected yield	Price per gallon	Breakeven yield at projected price	Gallons biodiesel
at expected yield	$8.99	at projected price	8,612
at 90% of expected yield	$9.99	at 90% of expected price	9,569
at 75% of expected yield	$11.99	at 75% of expected price	11,483
at 50% of expected yield	$17.98	at 50% of expected price	17,225
at 120% of expected yield	$7.49	at 120% of expected price	7,177
at 150% of expected yield	$5.99	at 150% of expected price	5,742

Table 26: High-price scenario biodiesel sensitivity analysis

	Zero Cost	-10%	Oil Cost/lb ($0.62)	plus 10%	plus 20%
-20%	($1,335.59)	($21,719.59)	($23,903.59)	($26,087.59)	($28,271.59)
-10%	$1,059.14	($19,324.86)	($21,508.86)	($23,692.86)	($25,876.86)
Diesel Price/Gal ($5.00)	$3,453.88	($16,930.12)	**($19,114.12)**	($21,298.12)	($23,482.12)
plus 10%	$5,848.62	($14,535.38)	($16,719.38)	($18,903.38)	($21,087.38)
plus 20%	$8,243.35	($12,140.65)	($14,324.65)	($16,508.65)	($18,692.65)
plus 30%	$10,638.09	($9,745.91)	($11,929.91)	($14,113.91)	($16,297.91)
plus 50%	$15,427.56	($4,956.44)	($7,140.44)	($9,324.44)	($11,508.44)
plus 60%	$17,822.30	($2,561.70)	($4,745.70)	($6,929.70)	($9,113.70)
plus 70%	$20,217.04	($166.96)	($2,350.96)	($4,534.96)	($6,718.96)

Return above total costs as diesel price varies

	Profit (Loss)
-20%	($23,903.59)
-10%	($21,508.86)
Diesel Price/Gal ($3.02)	($19,114.12)
plus 10%	($16,719.38)
plus 20%	($14,324.65)
plus 30%	($11,929.91)
plus 50%	($7,140.44)
plus 60%	($4,745.70)
plus 70%	($2,350.96)

Sensitivity of the profitability of the biodiesel enterprise to changes in the expected oil and biodiesel prices is shown in Figure 20 and Table 23 for the normal-price scenario and in Figure 21 and Table 26 for the high-price scenario. The importance of the oil cost is plain; in both scenarios, the enterprise is profitable only if the oil cost is zero, even with diesel prices increased by 70%.

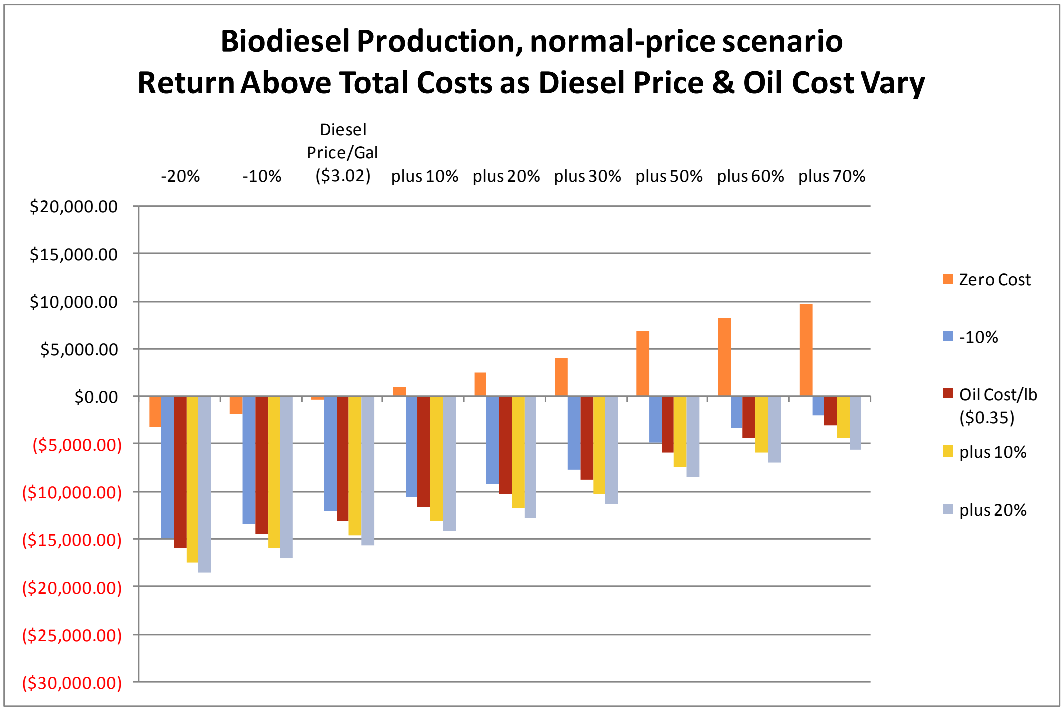


Figure 20: Sensitivity of biodiesel production profitability to oil and biodiesel prices, normal-price scenario

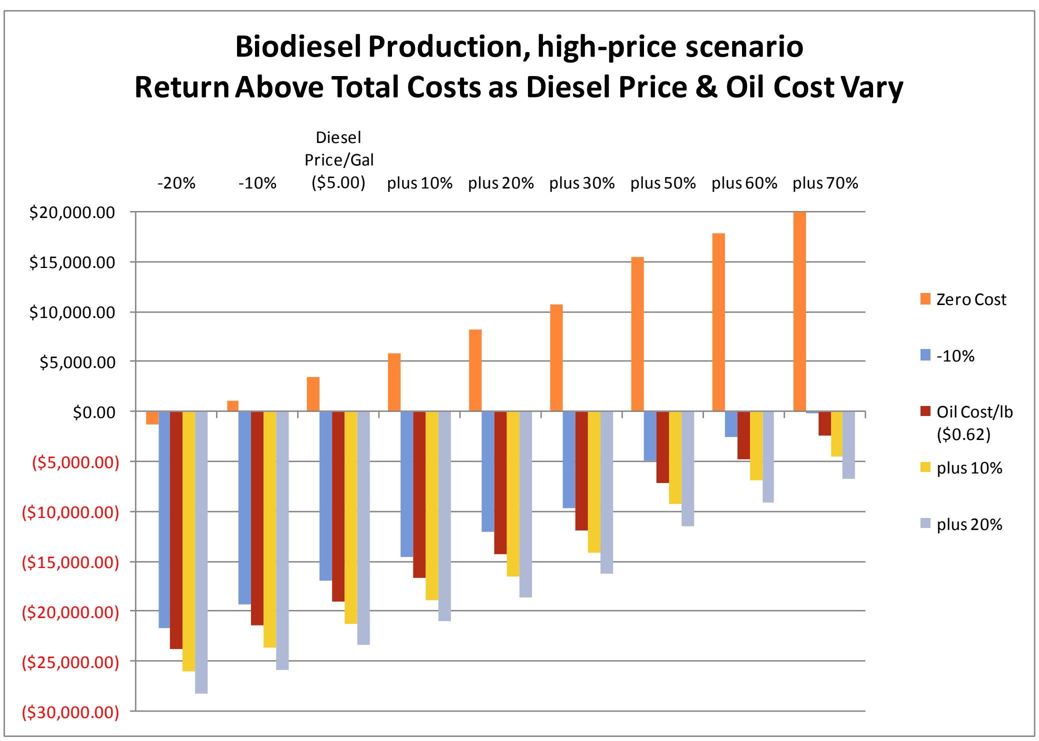


Figure 21: Sensitivity of biodiesel production profitability to oil and biodiesel prices, high-price scenario

3.4 Conclusions

3.4.1 Conclusions

Crop production. Data from field trials to date show that oilseed crops in Vermont have strong potential to attain yields at or above national averages. Yields have been affected by weather, pests, weeds, and harvest-related challenges. Although not all challenges can be eliminated, improved access to harvesting equipment and more experience with harvesting techniques will be especially important for Vermont oilseed farmers to consistently achieve potential yields and bring the crop in at the moisture and quality levels required for storage and processing.

Oilseed crop production may be economically viable in Vermont given strong oilseed prices, limited input costs, and access to oilseed commodity markets. This analysis focused on sunflowers (largely because of the higher meal value, as noted above), but given that costs of production among canola, soybeans, and sunflowers are similar, with adequate yields canola and soybean production could also be profitable under higher-price conditions.

Oil and meal production. Oilseed pressing is also technically feasible on Vermont farms, given procurement of additional equipment and adequate space to set it up. Farm-scale expeller presses appear to produce meal and oil of adequate quality for use or sale. Additional experience in drying seeds to the correct moisture and fine-tuning the press will help improve fat content in the meal and the efficiency of the press.

From an economic perspective, however, oilseed pressing may not be feasible for many Vermont farms. The cost of the oilseed charged to the enterprise is 59%–66% of the total cost of production, depending on the scenario. Under normal-price conditions, profitability is negative even when the oilseed cost is set equal to its cost of production. Under higher-price conditions, the enterprise loses less money, but is profitable only when it is charged the production cost of the oilseed, not its market value. With an additional $10,000 to $12,000 in variable and fixed costs beyond the oilseed cost expected regardless of market conditions, farmers with other existing enterprises may not wish to invest the labor and capital to establish a pressing operation just to process their own crops. Under high-price conditions, however, given that returns to variable costs are positive, an oil and meal enterprise may be profitable at greater volumes that enable the farmer or entrepreneur to realize economies of scale on the capital investment in oilseed pressing equipment.

Furthermore, using farm-pressed meal in a dairy cow's ration reduces daily feed costs only if the meal is priced at a discount. These savings would produce a net gain for the farm only if milk production (and therefore revenues) does not suffer as a result of the change in the cows' diet. If the switch to farm-pressed feed were to cause a drop in milk production and farm revenue, the farmer would be no better or even worse off.

For these reasons, the importance of establishing consistency and quality of farm-produced meals cannot be overstated. If the local meal is not of guaranteed quality and consistency, it represents a major risk to the farmer in terms of its potential to reduce milk production and decrease revenues. Without quality assurance, farmers' only incentive to buy locally produced meal would be if it is available at a significant discount, reducing revenue potential for the oilseed grower/meal producer. If the meal's quality can be assured and it can be priced more competitively, the CPM-Dairy analysis shows that as the price of farm-pressed meal approaches that of commercial meals, the feed cost per day approaches that of the base ration, and the savings to the farmer of using local meal is reduced. In other words, when the price differential is removed, the two meals are competing solely on quality. Quality must therefore be assured to make locally produced meal competitive with commercially produced feed meals.

In sum, beyond simple cost savings, a farmer's decision to include the meal in a feed ration will also depend on several other logistical factors, such as the amount of meal processed, the consistency and reliability of supply, the need for feed analyses for each batch to ensure quality and consistency, and the effort needed to mix the meal. These factors will vary from farm to farm.

Biodiesel production. As with oil and meal production, on-farm biodiesel production in Vermont is technically feasible, requiring only adequate, heated space for the operations and the necessary equipment. Equipment costs and space/retrofit issues involved with biodiesel production are of similar scale as those required for oil and meal production, requiring significant investments of time, space, and capital to establish as a new farm enterprise.

The economic returns of an enterprise to process oil from crops grown at this scale, however, appear to be negative, and like oilseed pressing, may not be feasible for many Vermont farms. Again, the cost of the oil charged to the enterprise is a major factor, representing 46% to 52% of the total cost of production, depending on the scenario. Under normal-price conditions, profitability is even more negative when the oilseed cost is set equal to its cost of production; in other words, it is cheaper under these conditions to purchase new vegetable oil than to raise the crops and press it oneself. Under higher-price conditions, profitability is less negative when the enterprise is assessed at the production cost of the oilseed due to the off-setting higher value of the oilseed meal co-product. With an additional $15,000 to $20,000 in variable and fixed costs beyond the oilseed cost expected regardless of market conditions, it does not appear feasible for farmers with other existing enterprises to invest the labor and capital to establish a biodiesel operation to process oil derived only from their own crops. Given the negative returns above variable costs for both scenarios, this enterprise as configured would not appear to benefit from economies of scale.

3.4.2 Implications for Vermont Farmers and Small-Scale Entrepreneurs

This study has mixed implications for oilseed crop production by Vermont farmers. Vermont farmers can expect positive returns from oilseed crop production only given adequate yields, storage facilities, favorable market prices, and access to markets. As more farmers experiment with oilseed crops, the development of local expertise and information-sharing among the farm and Extension community should help new growers. Farmers may also be able to share harvesting equipment, provided that participating farms are close enough together to make it practical to transport equipment between farms. Custom harvesting could represent a new business opportunity in coming years as more farms add oilseeds to their crop rotations. Farmers, processors, and other business owners involved in oilseed crop production should continue to build networks for developing and sharing local expertise in processing, distribution, and sales.

Regarding oilseed pressing and biodiesel production enterprises, results of this study imply that these enterprises are not profitable in the context of a ‘typical’ Vermont dairy farm to which these enterprises would be ancillary operations. The oil and meal enterprise may, however, benefit from economies of scale, and prove feasible as primary lines of business for entrepreneurs who provide centralized or consolidated seed-pressing services to other farmer/growers. State Line Farm is pursuing this business model under the name “State Line Biofuels.”

3.4.3 Areas Recommended for Further Study

Several aspects and unanswered questions of this analysis would benefit from additional study. First, Vermont oilseed growers would benefit from additional crop trials to expand experience and improve production methods that optimize yields and economic returns. Second, further refinement of farm-scale oilseed pressing techniques is needed to ensure consistent production of high-quality oilseed meals that will allow producers to be able to sell this meal to other farmers or a feed dealer at a competitive price. Systematic processes for testing, refining, and recording results of on-farm meal production should be established, and additional, regular testing of the farm-pressed meal—as well as an in situ amino acid test to establish the protein characteristics of the meal—is recommended to establish quality and consistency.

Third, other business models for oilseed pressing and biodiesel production bear further investigation. Examples include mobile oilseed or biodiesel processing facilities; larger, dedicated facilities such as State Line Biofuels that are engaged in oilseed and biodiesel processing as a primary line of business; or small cooperatives for oilseed processing and biodiesel production by which several farmers share investment in larger-scale oilseed-processing or biodiesel-making facilities. Dividing capital and operating costs among five to ten neighboring farms could lower barriers to entry of these markets, but the economic feasibility of such a model has not been studied in-depth.

Fourth, further research should be conducted on the net liquid fuel or energy savings to the farmer of local biodiesel production. Crop production, seed processing, and biodiesel production all require energy. Further study is required to understand the extent to which on-farm oilseed and biodiesel production processes can use renewable, farm-produced energy, yielding a net energy savings to the farmer. Similarly, a lifecycle analysis of the net farm greenhouse gas emissions from local oilseeds in rotation with existing crops and biodiesel production should be conducted to determine if carbon and other emissions are indeed reduced.

Finally, there are many other potential markets for oilseed co-products besides livestock meal and biodiesel. Further study could focus on the viability of oilseed production for food-grade oil sales, lease of filtered, unrefined vegetable oil to restaurants (with the used oil then returned for biodiesel production), use of oilseed meal as a crop fertilizer, use of oilseed meal as a fuel (in pellet stoves, for example), and potential uses and markets for the glycerin byproduct of biodiesel production.

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CHAPTER 4: FEASIBILITY OF COMMERCIAL-SCALE BIODIESEL PRODUCTION IN VERMONT: RESULTS OF AN ECONOMIC AND ENVIRONMENTAL SIMULATION MODEL

This chapter investigates the economic feasibility of commercial-scale biodiesel production from Vermont-grown feedstocks. A simulation model is used to estimate the expected costs, returns, and greater economic and environmental impacts of 500,000-gallon and 2.5 million-gallon commercial biodiesel plants in Vermont under six market scenarios.

4.1 Introduction

High energy costs in 2008 prompted widespread concern in Vermont, a rural state highly dependent on personal vehicles and petroleum-based fuels, including diesel fuel, for transportation and a cold, northern state where home heating is a major expense. The spike in energy prices and growing concern about global climate change have prompted many in Vermont to call for alternative energy sources that are more local, renewable, and sustainable.

A commercial-scale biodiesel plant that uses vegetable oil from oilseed crops grown in Vermont could provide an alternative, renewable, locally produced fuel source to replace some of the diesel fuel and no. 2 heating oil used in the state. In-state biodiesel and oilseed meal production from locally grown feedstocks could have several potential benefits for Vermonters and Vermont farmers, including less dependency on fossil and imported fuels, less farmer dependency on livestock feed imported from the Midwest or Canada, potential reductions in dairy farm production costs, job creation and other economic benefits through import substitution, and reductions in greenhouse gas emissions.

There has been substantial interest in biodiesel production at the state level, with feasibility studies having been conducted for Georgia (Shumaker et al., 2003), Iowa (Hayes, 1995), New York (Urbanchuk & LECG LLC, 2004), North Dakota (VanWechel et al., 2002), Oregon (Jaeger et al., 2007), Vermont (Mulder, 2004), and Wisconsin (Fortenberry, 2005). These analyses use a combination of market assessment, capital and enterprise budgets, and input-output modeling to assess microeconomic feasibility of the plant and its macroeconomic effects.

All of these state-level studies found that commercial-scale biodiesel production was technically feasible, but all except Oregon's also found that it was not yet economically viable, citing high operations expenses, high production costs relative to the price of conventional diesel (primarily due to the high price of feedstocks), and the high level of risk, which discourages necessary investment. All studies further agreed that without government incentives to create demand, large-scale biodiesel production would be risky and unprofitable. The Oregon study found that biodiesel production from canola seed could be commercially viable under current market conditions and existing government subsidies, including an indirect "blender's credit" of $1.00 per gallon. It also concludes, however, that biodiesel production would offer the state a relatively small measure of energy independence, and would require 100 times more canola than is currently grown in the state.

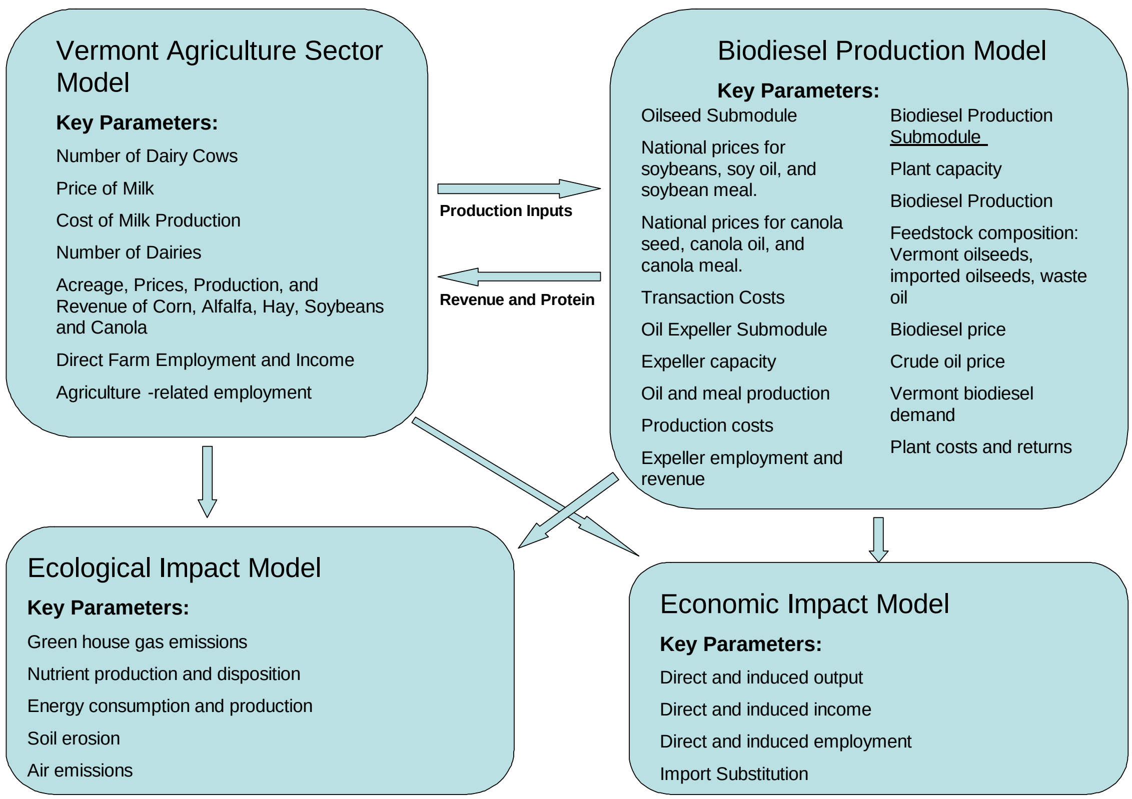
Mulder's study on Vermont (2004) used a dynamic and stochastic model that also estimates the ecological effects of biodiesel production. Mulder found that although a privately owned facility was projected to lose money, a cooperatively owned plant supported by producer tax incentives and strong local demand for the feed and biodiesel could be profitable and produce direct and induced local economic benefits, reduce greenhouse gas emissions, and yield a net positive energy return. Mulder recommends public policy incentives that require some portion of the biodiesel feedstock to be grown in Vermont in order to maximize potential economic and environmental benefits.

This analysis investigates the economic feasibility of commercial-scale production of biodiesel from Vermont-grown oilseeds based on a simulation model that evaluates six production scenarios. Specifically, this study seeks to estimate costs and returns, macroeconomic impacts, and environmental impacts of commercial-scale biodiesel production for facilities with annual production capacities of 500,000 gallons and 2.5 million gallons per year. Six scenarios that combine variations in fuel prices, oilseed prices, state capacity credits, and local oilseed crop production are modeled to analyze the sensitivity of profitability, macroeconomic impacts, and environmental effects to variations in these key input factors.

4.2 Data and Methods

This analysis uses a dynamic ecological-economic simulation model for commercial biodiesel production developed by Dr. Kenneth Mulder at the University of Vermont in 2003 (Mulder, 2004; White, 2007; Mulder et al., 2007). The model was specifically designed to estimate the microeconomic feasibility of a commercial biodiesel plant in Vermont and to predict its macroeconomic and ecological effects. As shown in Figure 22, the model has four main components: (1) an econometric model of the

Vermont agricultural economy that includes oilseed crop production by Vermont farmers; (2) a biodiesel production model that includes an econometric model of national oilseed markets and crushing of oilseeds for oil and meal co-products; (3) an ecological impact module that calculates changes in greenhouse gas emissions and net energy return on energy invested; and (4) a macroeconomic impact model that uses a regional input-output model (IMPLAN) to estimate multipliers for direct, indirect, and induced employment, income, production, and tax revenues (Minnesota IMPLAN Group, 2000).



Source: (Mulder, 2004)

Figure 22: Major components of the biodiesel production simulation model

Figure 23 is a simplified schematic of the model's major variables and their relationships in estimating costs and benefits of biodiesel production. The model contains several dynamic (stochastic) variables that are allowed to vary randomly within a defined range to better simulate real-world market fluctuations and price volatility. Many of these "driver" variables in the model, such as national commodity prices and crop yields, are drawn from normal distributions based on historical data.

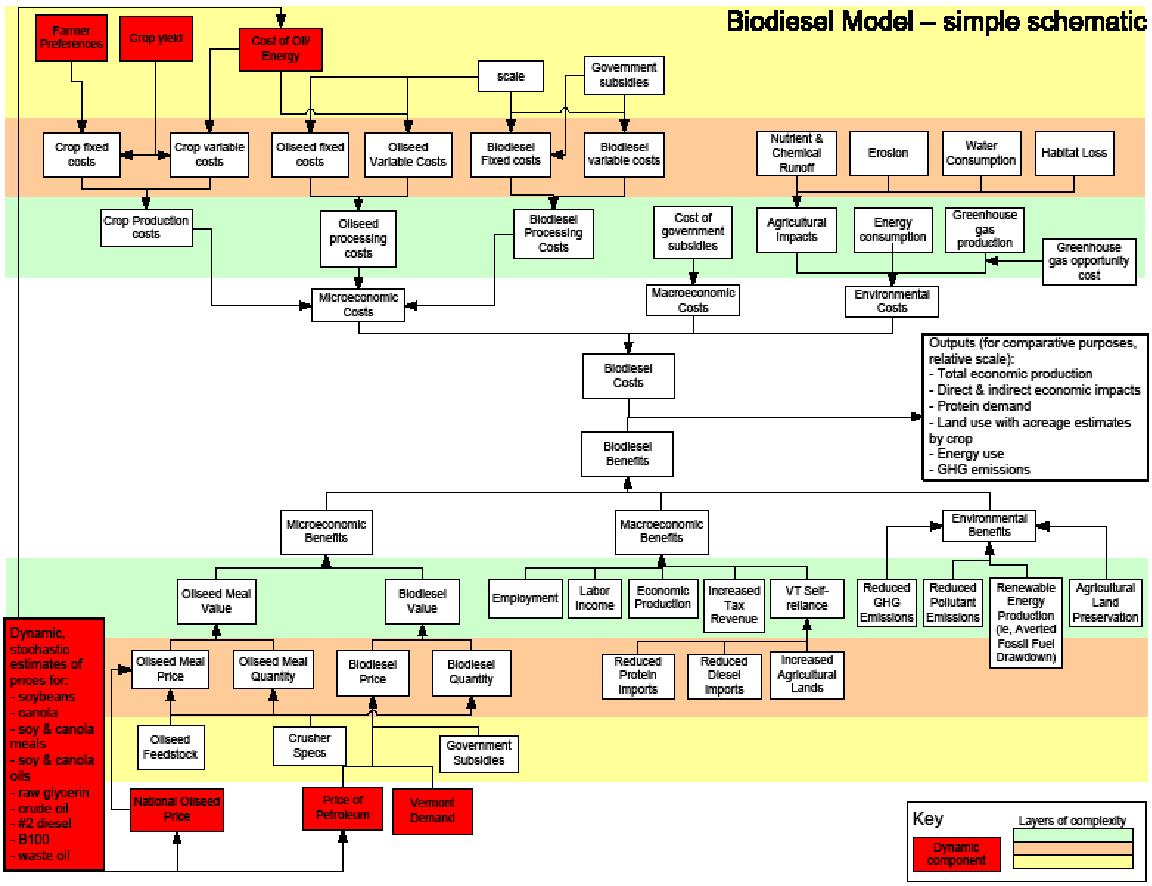


Figure 23: Major variables in the biodiesel production simulation model

4.2.1 Updates to the Model

As part of this analysis, the model was extended and recalibrated to reflect 2007 conditions, and new scenarios and assumptions were modeled. First, the model was updated to use only a private ownership structure in order to more accurately capture the transaction costs that would be incurred regardless of the ownership structure. (The original model contained an option for a cooperative ownership structure that assumed transaction costs would be internalized by the farmer-owners.)

Second, the predictions of the original model were verified to be consistent with actual, observed data for 2002–2006. Third, the model was updated to start in 2006 instead of 2002. This involved revising several key equations, as well as inputting observed data for 2004–2006 for key variables, including average crude oil price (domestic first purchase price) (Energy Information Administration, 2007b), soybean price (National Agricultural Statistics Service, 2006a), and the gross domestic product (GDP) price deflator (Bureau of Economic Analysis, 2007). Further research was also done on capital costs for biodiesel plants of less than five million gallons in annual capacity.

Finally, the parameters of several key input variables were modified from the original analysis to test feasibility under more-current market conditions, including higher crude oil and oilseed prices. The highest crude oil price modeled in the 2003 work was $35 per barrel (in year-2000 dollars), for example, and oilseed prices were not predicted to rise as a result of increased demand for biofuels. Therefore, the following five input variables were modified:

1) **Crude oil price.** The model was updated to include three settings for crude oil prices that were designed to better reflect the potential for higher prices in the petroleum market, and to test feasibility under conditions ranging from those predicted by oil depletion ("peak oil") scenarios to those based on the continued availability of petroleum supplies. The three settings are a 'low-price' trend based on EIA projections, or $45 per barrel in 2017 (Energy Information Administration, 2007a); a 'medium-price' case in which prices rise to $75 per barrel in 2017; and a 'high-price' case in which prices rise to

$125 per barrel in 2017. (When the model was being updated, the record prices of 2008 were still more than a year away.)

2) **Oilseed prices.** Two possible settings for oilseed prices were also constructed in order to model the possibility of higher commodity food prices as a result of increased biofuels production, increased energy prices, and growing global meat consumption. The model therefore includes a "baseline" setting for oilseed prices derived from historical oilseed price data (1974-2006) and a higher-price scenario under which soybean and canola oil prices are 25% higher than the baseline trend.

3) **Plant capacity.** The updated model also contains an option to simulate and compare two sizes of biodiesel production plants: 500,000 gallons per year and 2.5 million gallons per year. The 2004 model analyzed only a 2.5 million-gallon plant, which allows for more economies of scale. The smaller plant size was included to test the feasibility of a smaller-scale plant that is more in line with Vermont's oilseed production capacity. Biodiesel facilities with smaller capacities in the range of 500,000 gallons are relatively rare compared to larger facilities. Cost data, therefore, were limited with a relatively large spread, and as a consequence the model may overestimate capital costs for the smaller plant.

4) **Farmer willingness to plant oilseeds.** As part of his original study, Mulder surveyed Vermont dairy farmers about the likelihood that they would plant soybeans or canola under differing market conditions. The results of the survey were used to estimate an acreage response curve for soybean and

canola production in the state. The model uses this response curve to consider three levels of farmer response—best, average, and worst case—with the best and worst cases based on the upper and lower bounds of a 90% confidence interval for the response curve.

5) **State support for biofuels.** To understand the potential impact of state-level subsidies for biodiesel production in Vermont, the model allows for the optional inclusion of a $0.25/gallon new capacity credit.

4.2.2 Scenarios Modeled

Six scenarios were developed for simulation modeling by combining different values of the five key input variables above. The scenarios were constructed based on three levels of resource availability, each with two levels of Vermont support, action, and involvement. The scenarios are summarized in Table 27.

1) **"Resource Predictability."** Under this scenario, the world experiences relative price stability and historical trends in energy and food prices continue. Concerns about reductions in fossil fuel supplies and usage as a result of peak oil and global climate change turn out to be unfounded. Productivity increases in agriculture and fossil fuel extraction ensure that supply keeps up with demand. Prices follow historical trends with few spikes or crashes. Oil prices hold steady around $45 a barrel in 2017. Oilseed prices continue to slowly decline in real terms.

   a) <u>Less VT action</u>: A private firm constructs a 500,000-gallon biodiesel plant in Vermont. In general, Vermont farmers do not respond to supply the plant with oilseeds, transferring minimal acreage from hay and forage crops to oilseed crops. The state does not subsidize biodiesel production.

   b) More VT action: A private firm constructs a 2,500,000-gallon biodiesel plant in Vermont. Vermont farmers transfer modest acreage from hay and forage crops to oilseed crops. The state gives the firm a new-capacity credit of $0.25 per gallon of annual production capacity.

2) **"Resource Constrained."** Under this scenario, constrained energy resources effect meaningful but gradual shifts in the global fuel and food economy. Oil prices reach $75 a barrel by 2017. Increasing petroleum prices and rising demand for protein, food, and biofuels raise the price of oilseeds by 25%.
   a) Less VT action: A private firm constructs a 500,000-gallon biodiesel plant in Vermont. Vermont farmers transfer modest acreage from hay and forage crops to oilseed crops. The state does not subsidize biodiesel production.
   b) More VT action: A private firm constructs a 2,500,000-gallon biodiesel plant in Vermont. Vermont farmers transfer substantial acreage from hay and forage crops to oilseed crops. The state gives the firm a new-capacity credit of $0.25 per gallon of annual production capacity.

3) **"Resource Emergency."** In this scenario, scarce energy resources create significant changes in global energy and food markets. Oil prices reach $125 a barrel by 2017. Petroleum scarcity and rising demand for protein, food, and biofuels raise the price of oilseeds by 25%.

a) <u>Less VT action</u>: A private firm constructs a 500,000-gallon biodiesel plant in Vermont. Vermont farmers transfer modest acreage from hay and forage crops to oilseed crops. The state does not subsidize biodiesel production.

b) <u>More VT action</u>: A private firm constructs a 2,500,000-gallon biodiesel plant in Vermont. Vermont farmers transfer substantial acreage from hay and forage crops to oilseed crops. The state gives the firm a new-capacity credit of $0.25 per gallon of annual production capacity.

Table 27: Scenarios modeled

	1 - "Resource Predictability"		**2 - "Resource Constrained"**		**3 - "Resource Emergency"**	
	a-Less VT action	**b-More VT action**	**a-Less VT action**	**b-More VT action**	**a-Less VT action**	**b-More VT action**
Crude oil price	Low	Low	Medium	Medium	High	High
Oilseed prices	Baseline	Baseline	25% higher	25% higher	25% higher	25% higher
Plant capacity (gall/year)	500,000	2,500,000	500,000	2,500,000	500,000	2,500,000
Farmer willingness to grow oilseeds	Worst case	Avg. case	Avg. case	Best case	Avg. case	Best case
State support for biofuels	None	$0.25/gall capacity credit	None	$0.25/gall capacity credit	None	$0.25/gall capacity credit

4.2.3 Scenario Simulation

Because the simulation model contains several stochastic variables, the model should be run multiple times for each scenario in order to generate a range of results that reflects the inherent variation and internal dynamics of the model. Accordingly, the model was run 100 times per scenario, with each run yielding predictions for 15 years (from 2007 to 2021). Variables relating to crude oil price, oilseed prices, plant capacity, farmer willingness to grow oilseeds, and state support for biofuels were varied according to the scenario; all other variables were held constant. The average 2006 price (deflated to year-2000 dollars) was used as the starting point for all scenarios. For each year, the average value and standard deviation over all 100 runs was calculated for each variable of interest. All model calculations and output are in year-2000 dollars to account for inflation, including prices for all input variables in all scenarios.

4.3 Results

For each scenario, the simulation model produced 100 results for 135 variables in each of 15 years. Results reported here are limited to the average value (over the 100 runs) and standard deviations of key variables of interest for each scenario in year 5 (2011) only. The variables of interest were selected based on the study's primary research questions related to microeconomic impacts (estimated costs and returns), macroeconomic impacts, and environmental impacts. Descriptions of all model output variables are given in Appendix B. Year 5 of the model was chosen to illustrate expected results after the plant has been operating long enough to have an impact on Vermont's economy.

All dollar amounts are in year-2000 dollars, and error bars in each figure are set equal to one standard deviation. The scenarios are labeled along the horizontal axis, with the number indicating the level of resource availability, and the "less/more" indicating the level of Vermont supporting action (e.g., "1-less VT" indicates scenario 1, Resource Predictability, with less Vermont involvement). Full results, including yearly averages and standard deviations for all variables, are available from the UVM Libraries.

4.3.1 Microeconomic Feasibility

As shown in Figure 24, profitability of the biodiesel plant is highly dependent on the size of the plant, with the larger, 2.5 million-gallon plant consistently profitable, and the 500,000-gallon plant consistently losing money, although there is some chance that a smaller plant will be profitable, as shown by the error bars.

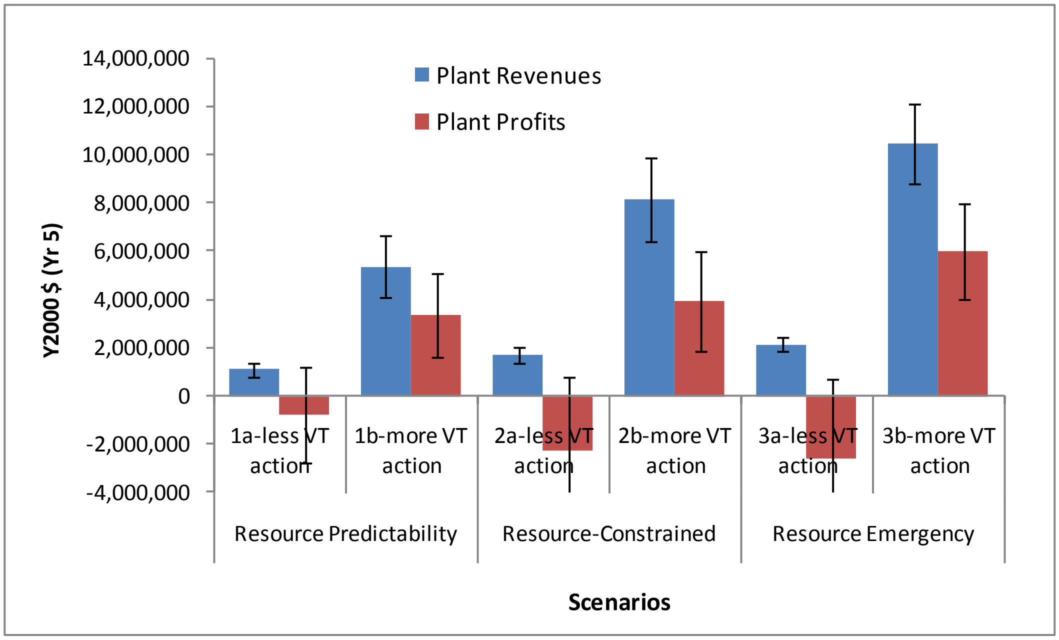


Figure 24: Projected biodiesel plant revenues & profits

The model treats regular diesel fuel and biodiesel as substitutes (the price of biodiesel increases proportionally as the price of crude oil rises). The model also contains links from the cost of crude oil to the cost of other production inputs, such as fertilizer and transportation. As crude oil prices increase from scenario 1 to scenario 3, both revenues and profitability for the larger plant increase, indicating that for the larger plant, increased input costs under the resource-emergency scenario, including the increased price of the oilseed feedstock, are more than offset by the increase in biodiesel prices.

For the smaller plant, by contrast, revenues increase as oil prices rise, but profitability becomes even more negative. It appears, therefore, that the scale of the smaller plant is insufficient to be profitable, even under more favorable oil/biodiesel price conditions.

4.3.2 Macroeconomic Impacts

Oilseed acres planted in Vermont. Figure 25 shows the importance of oilseed prices in the willingness of Vermont farmers to plant oilseed crops. Under scenario 1, even with an "average" willingness on the part of Vermont farmers to grow oilseeds, there is practically no oilseed production in the state. This is because, based on the results from Mulder's survey of farmers, the baseline projected oilseed prices are not high enough to induce Vermont farmers to plant oilseeds. Once oilseed prices rise above historical trends in scenarios 2 and 3, the model predicts that Vermont farmers are induced to produce nearly 35,000 acres of soy and canola.

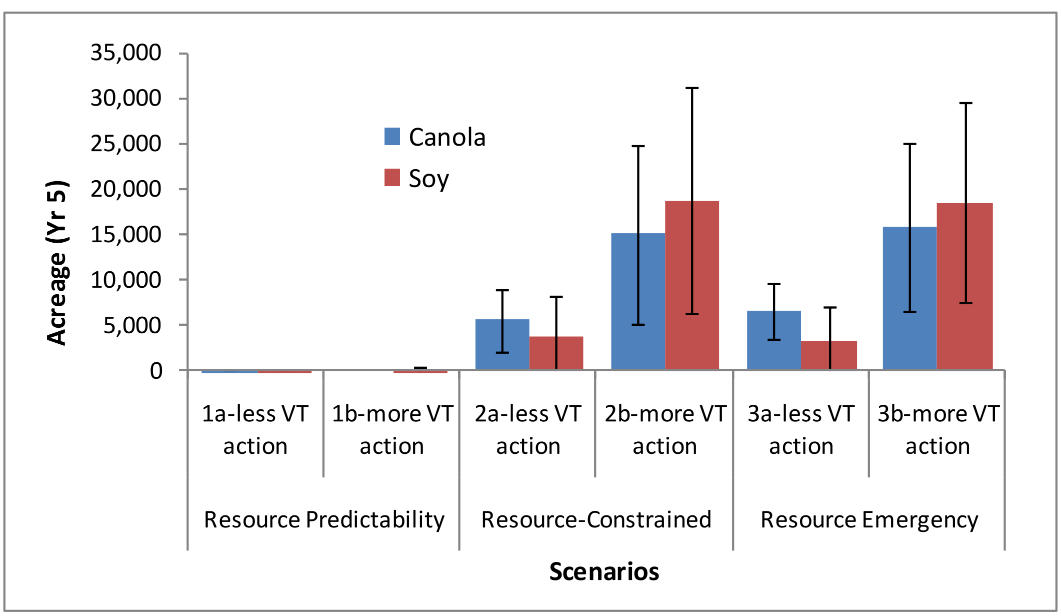


Figure 25: Projected oilseed acreage in Vermont

These projected new oilseed acres would be planted in addition to existing crops in Vermont. This is because in the model's agricultural econometric submodel, the corn, hay, alfalfa, and pasture acreages planted are driven primarily by the price of milk, the number of dairy cows (also driven by the price of milk), and the acreage planted in the previous year. As shown in Figure 26, milk prices are projected to rise along with energy prices, with the highest prices expected in scenarios 3a and 3b, and the lowest prices in scenarios 1a and 1b. It is this rise in energy and milk prices, not the rise in oilseed acreage, that drives total acreage in cultivation in this model.

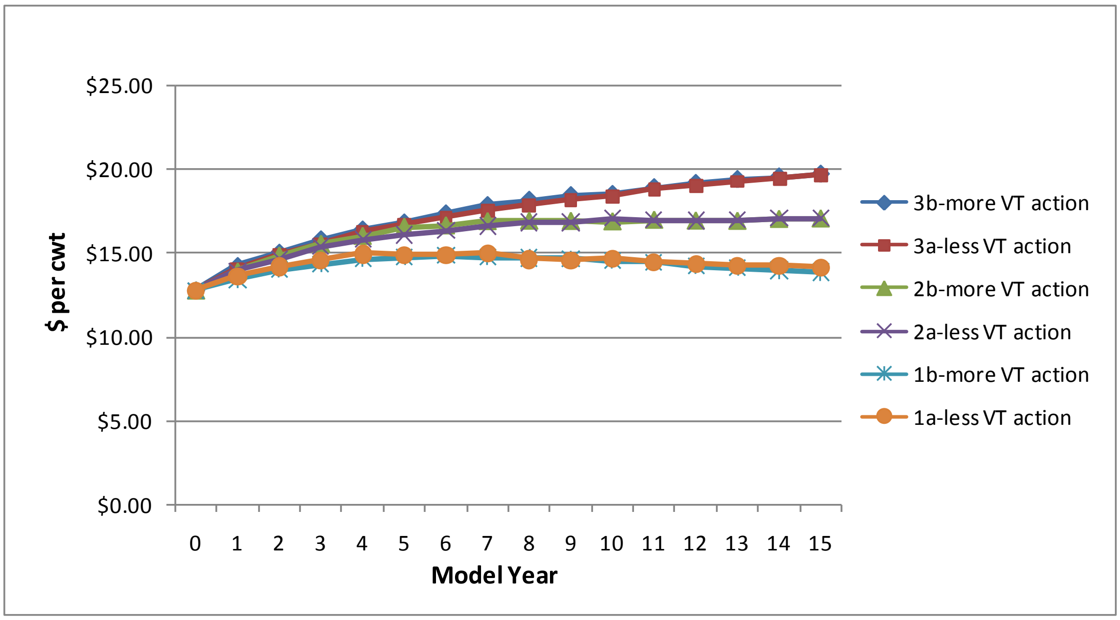


Figure 26: Projected milk price

The results also show that farmers' willingness to plant oilseeds is a significant factor. Three-to-four times as much acreage is planted in scenarios 2 and 3 when farmer willingness is increased from "average" to "best." These results indicate farmers must both be incented by higher oilseed prices and be willing to acquire new equipment, infrastructure, and expertise in order for oilseed and biodiesel production to affect the use of agricultural land in Vermont.

Job creation. Figure 27 shows the total employment impacts in Vermont of oilseed and biodiesel production. (Impacts include direct, indirect, and induced employment; biodiesel production includes operation of the oilseed crusher.) As expected, biodiesel employment is higher for the larger plant in all scenarios, but increases only modestly from scenario 1 to scenario 3, from approximately 25 to 50 jobs for the smaller plant and from 70 to 100 jobs for the larger plant.

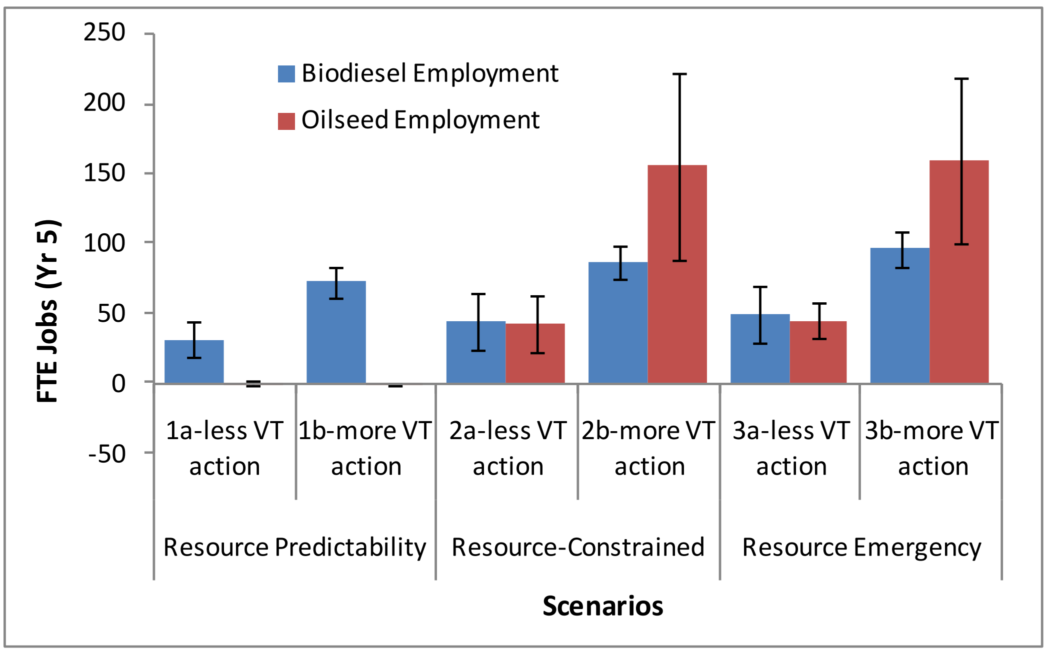


Figure 27: Projected total employment (direct, indirect, and induced) from biodiesel and oilseed production

Oilseed employment, by contrast, rises dramatically with Vermont farmers' willingness to plant more oilseeds. High levels of oilseed production in the state have the potential of tripling the employment impact because the total multiplier effect predicted by the model for oilseed production is three times that for biodiesel production.

Approximately 60% of these new jobs would come from growing the crops directly, and about 40% would be indirect and induced jobs in agricultural and community businesses.

Import substitution. As shown in Figure 28, the level of Vermont involvement strongly affects the expected degree of self-sufficiency the state would derive from biodiesel production. Import substitution measures the total value of out-of-state goods that would be replaced by Vermont products under a given scenario. Under scenarios assuming a greater level of involvement, the model predicts that the state could replace between $10 million and $15 million worth of imports. Such an increase in local production and purchasing would also provide additional economic and social benefits through a multiplier effect.

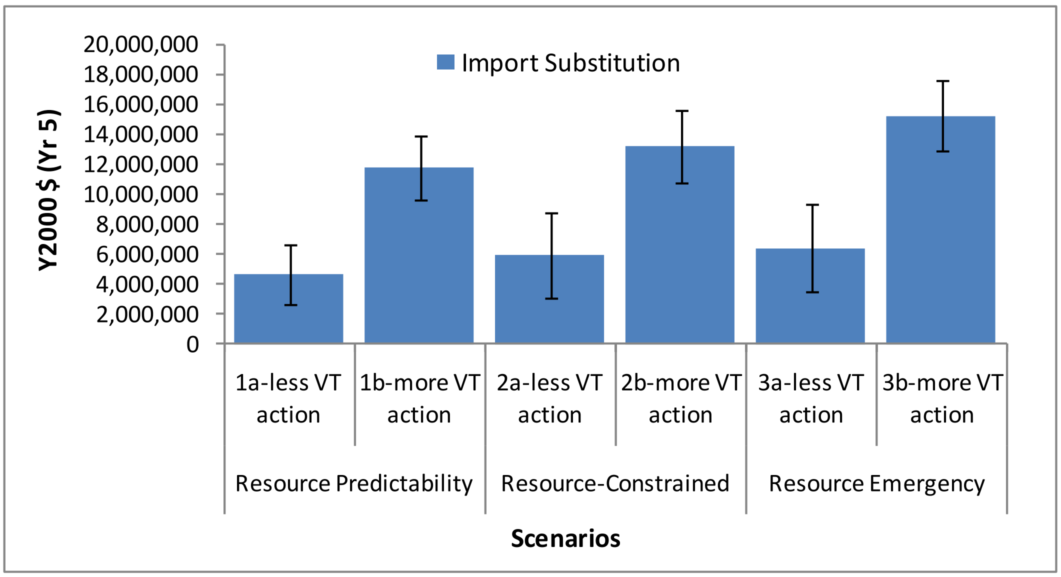


Figure 28: Projected value of imports replaced by in-state production

4.3.3 Environmental Impacts

Energy return on energy invested. Figure 29 shows the predicted energy return on energy investment (EROI) for biodiesel production in Vermont. EROI is calculated for the biodiesel facility's overall production, as well as for just the portion of production that is derived from Vermont-grown soybeans or canola. Since the price allocation method is used to distribute energy charges between co-products, there is variation in EROI between scenarios. The EROI of soybeans is consistently higher that the EROI of canola, largely due to the leguminous nature of soybeans and the obviated need for nitrogen fertilizers (even when considering nitrogen and other nutrients added by manure applications). The EROI of Vermont soybeans shows the best energy return across the board, although all measures are greater than one, implying that biodiesel production could yield a significant amount of net energy.

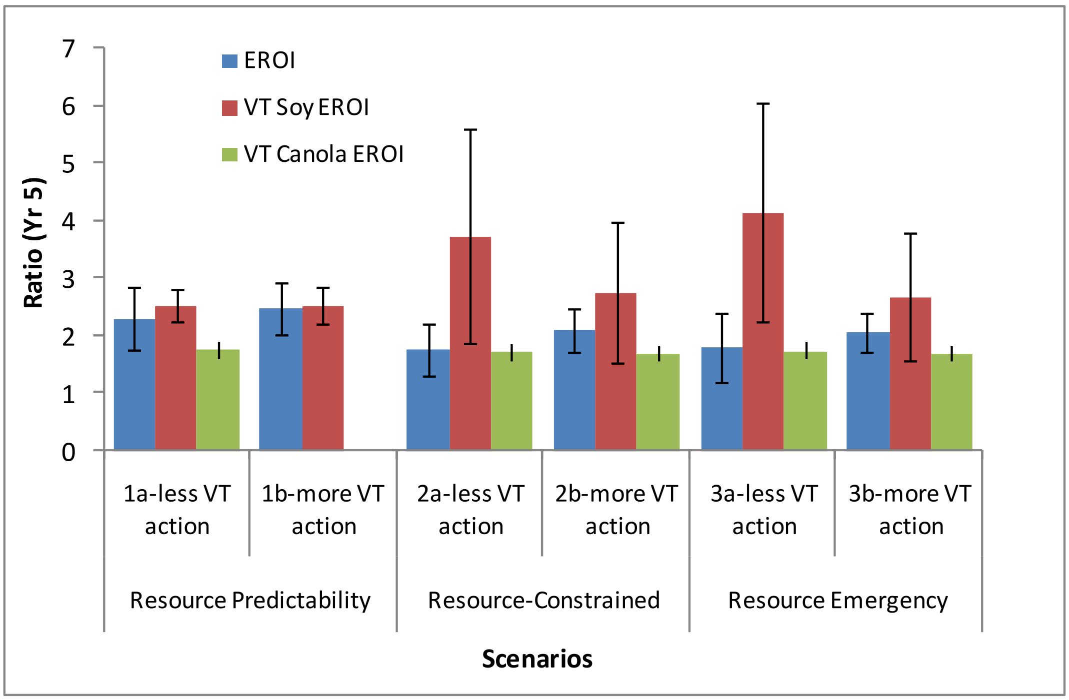


Figure 29: Projected energy return on energy investment

Energy return per acre. Figure 30 displays the net energy produced per unit of land. Although canola has a lower EROI than soybeans, because of its higher oil yield, canola is consistently projected to have a higher net energy yield per unit of land.

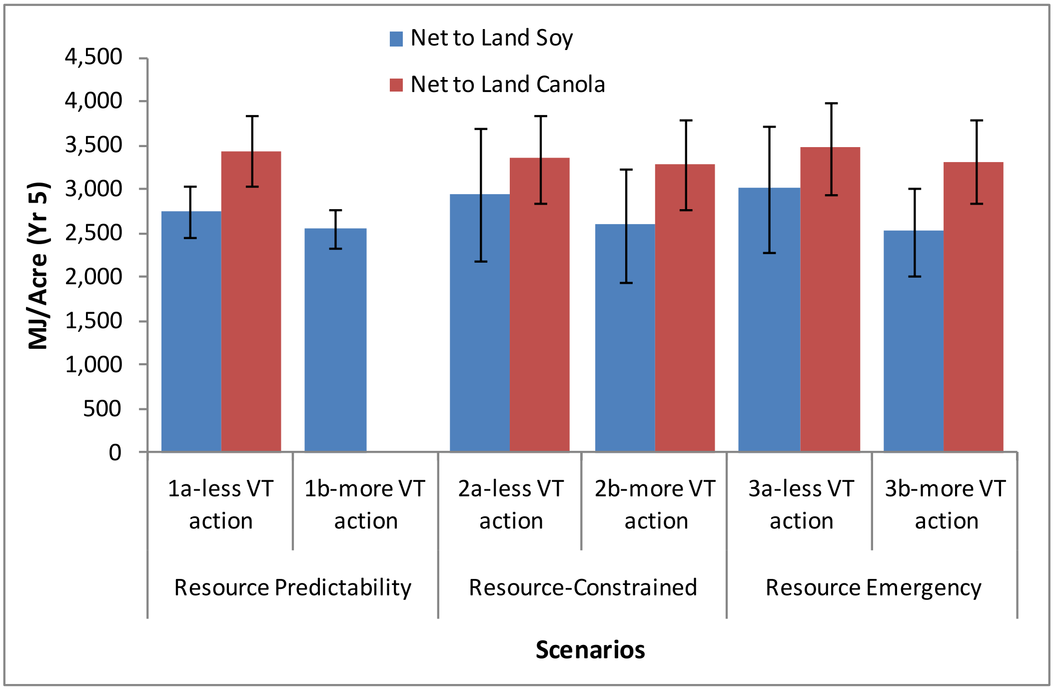


Figure 30: Projected net energy yield per unit of land

Greenhouse gas emissions. As seen in Figure 31, the model predicts that biodiesel production in Vermont has strong potential to reduce the state's carbon footprint. This is especially true for the larger plant; the model predicts that a 2.5-million gallon plant would reduce carbon loading by over 15,000 tons of CO_2 equivalent in year 5. This assumes, however, that land put into oilseed production would have been otherwise used for crop production in the model (includes hay, alfalfa, silage, and oilseeds). If a charge is assessed for the land's sequestration potential if it were allowed to revert to forest, then the model predicts an *increase* in greenhouse gas emissions. No such charge is assessed for land outside Vermont, which is why there is little difference in the two measures of greenhouse gas reduction for scenario 1, in which there is little in-state oilseed production.

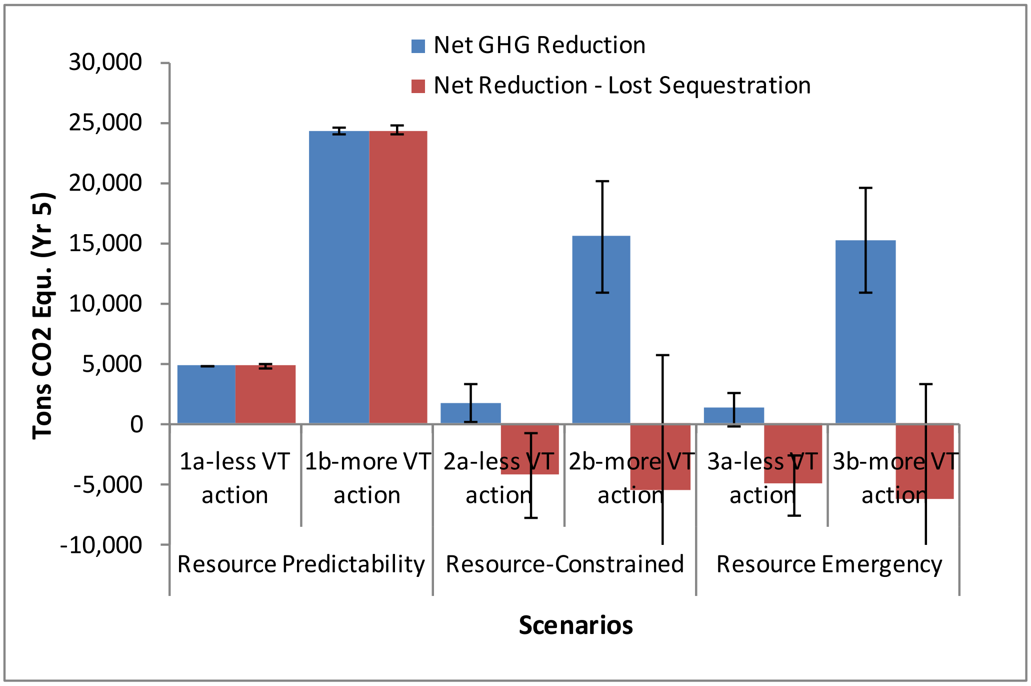


Figure 31: Projected reductions in greenhouse gas emissions

Biodiesel energy produced as a portion of total farm energy. To put the projected scale of biodiesel production in Vermont in some perspective, Figure 32 shows the ratio of net energy produced by the biodiesel facility to the energy cost (including fuel, electricity, and heating) of crop production for all crops grown in Vermont and included in the model (hay, alfalfa, silage, and oilseeds). The model predicts that 2.5 million gallons of biodiesel produced in-state would yield enough net energy to fuel only 8% to 10% of the crop production in Vermont. The ratio is at a maximum of just over 10% in scenario 1-less VT action, where there is a higher level of biodiesel production in the state but very little in-state oilseed production. Scenarios 2-more VT and 3-more VT have somewhat reduced values due to the energy costs of in-state oilseed production.

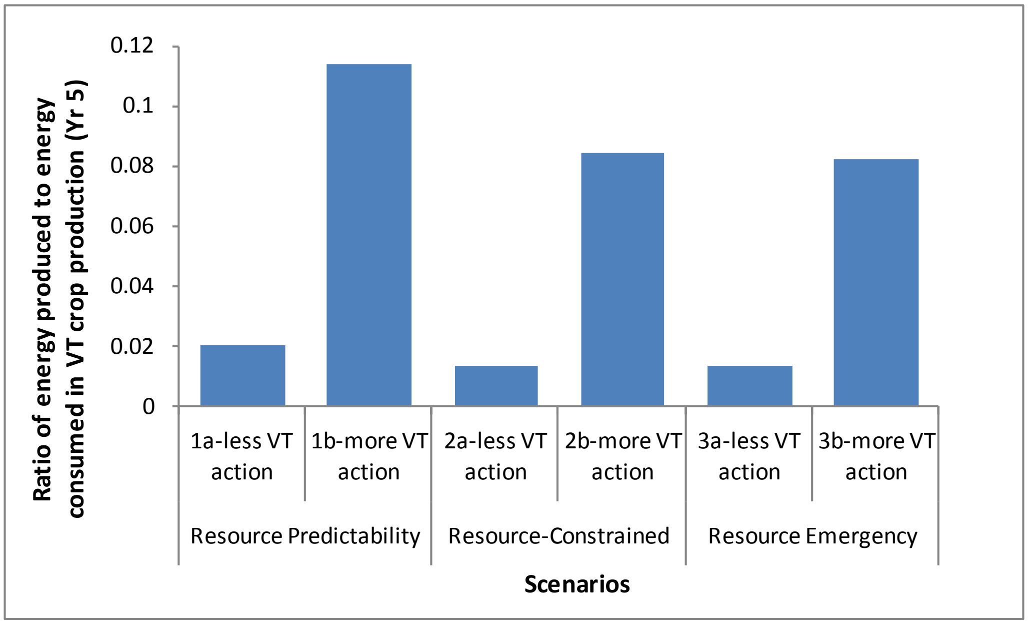


Figure 32: Ratio of net energy produced to total energy consumed by Vermont crop production

4.4 Conclusions

4.4.1 Conclusions

Several conclusions can be drawn based on the results of the simulation modeling.

Microeconomic feasibility. The economic feasibility of commercial-scale biodiesel production depends heavily on plant capacity. A 500,000-gallon plant has only a small chance of being profitable, whereas the model predicts that a 2.5 million-gallon plant will be profitable under every scenario. Plant revenues increase as the price of crude oil rises, as does profitability for the larger plant. Although a rise in the price of crude oil also causes the price of other inputs—particularly the oilseed feedstock—to rise, in the scenarios modeled, the fractional increases in input prices were more than offset by the higher value of the biodiesel product.

Macroeconomic impacts. Vermont farmers will produce oilseed crops only if induced to do so by higher-than-average oilseed prices. Higher prices and a high degree of farmer willingness to acquire new equipment, infrastructure, and expertise are needed for farmers to shift to new crops.

The greatest potential employment gains can be achieved only if Vermont farmers make a strong transition to oilseed crop production, and the biodiesel plant is able to obtain part of its oilseed feedstock from Vermont sources. Biodiesel production alone is predicted to produce 25 to 100 jobs, whereas high levels of oilseed production in the state have the potential of tripling the employment impact.

State involvement in the form of a new-capacity credit or other production incentive is needed to boost the level of import substitution Vermont can achieve from biodiesel production. At a cost of $625,000 (based on a $0.25/gallon new-capacity credit and a 2.5 million-gallon plant), the state could replace between $10 million and $15 million worth of imports.

Environmental impacts. Biodiesel production under every scenario produces a positive EROI. The EROI of soybeans is consistently higher that the EROI of canola, largely due to the leguminous nature of soybeans and the obviated need for nitrogen fertilizers. Canola, however, produces more net energy per unit of land, due to canola's higher oil yield.

Biodiesel production has a strong potential to reduce Vermont's carbon footprint, provided that Vermont's existing cultivated cropland can accommodate oilseed production. If land put into oilseeds would have otherwise reverted to forests, the model predicts an *increase* in greenhouse gas emissions. The greatest potential greenhouse gas reductions can be achieved with a larger plant; the model predicts that a 2.5-million gallon plant can reduce carbon loading by over 15,000 tons per year of CO_2 equivalent.

Even the highest level of Vermont oilseed production would only yield an amount of net energy equivalent to that needed to fuel about 10% of the total crop production in Vermont. Although the net energy return from biodiesel production is positive, in relative terms the energy produced is a small fraction of the energy cost of crop production for all crops grown in Vermont and included in the model (hay, alfalfa, silage, and oilseeds). This ratio decreases under scenarios in which more oilseeds are grown in Vermont, due to the added energy costs of in-state oilseed production.

4.4.2 Implications

These findings have several implications for policymakers or businesses contemplating the provision of incentives for or development of biodiesel production facilities in Vermont. First, it appears that the plant must have an annual production capacity greater than 500,000 gallons in order to take advantage of economies of scale for efficient and profitable production (this could change, however, in light of better or more recent data on capital costs for smaller-scale facilities). A larger plant also offers greater potential for the state to create jobs, increase import substitution, and decrease greenhouse gas emissions, all of which would also be facilitated by state tax credits or other incentives.

Second, the higher the price of crude oil, the more likely it seems that a biodiesel plant will be profitable; the most recent spike in energy prices in 2008, however, was accompanied by dramatic increases in food commodity prices far greater than those modeled in this analysis, which would increase the price of biodiesel feedstocks.

Perhaps the most difficult questions surround the implications of a shift in Vermont crop production to include oilseeds for biodiesel production. Table 28 compares the results predicted by the model for a biodiesel facility with and without feedstock grown in Vermont.

Table 28: Comparison of biodiesel plant impacts with and without VT-grown feedstocks

Variable	**2.5 million-gallon biodiesel facility plus $0.25/gallon new-capacity credit**	
	With Vermont-grown feedstock	**Without Vermont-grown feedstock**
Profitability	Profitable	Profitable
Employment	150 jobs	50-100 jobs
Import Substitution	$15,000 per year	$12,000 per year
EROI	1-2	>2
Greenhouse gas emissions	Increase by ~5,000 tons CO_2 equiv	Decrease by ~25,000 tons CO_2 equiv
Ratio of net energy produced to total VT crop production energy cost	0.8	0.11

If the state's primary objectives are economic (i.e., to increase import substitution, employment, and related economic multipliers), Vermont farmers should be encouraged to produced oilseeds for an in-state biodiesel facility. In the absence of higher commodity prices, the state could consider offering technical assistance and other support to incent such a production shift. If the state's objectives for biodiesel production are related primarily to environmental impacts, however, results from these simulations suggest that greater production of oilseed crops in Vermont should not be encouraged. Unless oilseed crops are substituted for existing row crops (primarily feed corn in Vermont) net greenhouse gas emissions are predicted to increase. EROI is also slightly higher when the plant's feedstock is produced out of state.

4.4.3 Areas Recommended for Further Study

Several aspects of this analysis would benefit from additional study. First, the unprecedented energy prices experienced in 2008 provide a new context for additional modeling at even higher crude oil prices—the crude oil price of $145 per barrel in July 2008 was $20 higher than the most ‘extreme’ case modeled in these scenarios. Similarly, the scenarios used in this analysis envisioned that oilseed prices would increase by 25% over 10 years, far short of the 83% increase experienced in just three years from 2005 to 2008. An update of Mulder’s acreage response survey of Vermont farmers may also be useful to discern any changes in the expected response of farmers to increased oilseed prices, now that they have had direct experience with the effects of such prices on their operations. Finally, as noted above, additional data on capital costs for biodiesel facilities with capacities in the range of 500,000 gallons should be considered in any future model simulations to reduce the likelihood that the model is not overestimating capital costs for smaller plants.

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CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the major findings of Chapters 3 and 4 and suggests directions for future research.

5.1 Summary of the Study

This study investigates the technical and economic feasibility of producing biodiesel and livestock feed from Vermont-grown oilseeds at both the individual-farm scale and at a small commercial scale. Technical feasibility at the farm scale is assessed by reviewing yield and quality data, challenges, and lessons learned from the experiences of two Vermont farms that are growing and harvesting oilseed crops, processing oilseeds into meal and oil, and producing biodiesel fuel from the vegetable oil. Sample enterprise budgets under two scenarios, ‘normal’ price conditions and ‘high’ price conditions, are used to assess the economic feasibility and profitability of the crop, oil and meal, and biodiesel enterprises.

A dynamic simulation model is used to estimate the microeconomic feasibility and environmental and macroeconomic impacts of a 500,000-gallon and 2.5 million-gallon commercial-scale biodiesel facility in Vermont. The analysis evaluates six production scenarios that combine variations in fuel prices, oilseed prices, state capacity credits, and local oilseed crop production to analyze the sensitivity of profitability, macroeconomic impacts, and environmental effects to variations in these key input factors. The key output variables reported on are plant revenues, plant profitability, Vermont oilseed acreage, employment, import substitution, energy return on energy investment (EROI), net energy per unit of land, reductions in greenhouse gas emissions, and the ratio of net energy produced to the total energy consumed in Vermont crop production.

5.2 Major Findings

5.2.1 Technical Feasibility

Results from this study indicate that biodiesel production from local oilseed crops is technically feasible in Vermont. Vermont oilseed crops can attain yields at or above national averages, although improved access to harvesting equipment and more experience with harvesting techniques will be important in consistently achieving potential yields and optimum moisture and quality levels.

Processing oilseeds into oil and meal is also technically feasible; additional equipment will be required on most Vermont farms, but it is relatively easy to acquire and operate. Farm-scale expeller presses appear to produce meal and oil of adequate quality for use or sale. Additional experience in drying seeds to the correct moisture and fine-tuning the press will help reduce fat content in the meal and improve the efficiency of the press.

On-farm biodiesel production in Vermont is also technically feasible, requiring only adequate, heated space for the operations and the necessary equipment. Small-scale biodiesel equipment is readily available from a number of manufacturers. These new enterprises require dedicated facility space as well as time to learn and operate, but the initial set-up work and technical knowledge required to process oilseeds and biodiesel safely and efficiently should not be prohibitive for Vermont farmers.

5.2.2 Economic Feasibility

In general, this study's results indicate that oilseed, oil and meal, and biodiesel production in Vermont may be economically feasible under certain conditions, but depend on at least two key factors in order for these enterprises to be profitable. The first factor is food and energy market conditions, in which both the key input and output price levels and the relationships to each other are important. None of the farm-scale enterprises were profitable as budgeted in this analysis, but the crop and oil/meal enterprises came close to breaking even under high-price conditions. Similarly, the commercial-scale plant was more profitable as crude oil prices rose. The more food commodity prices are correlated with energy prices, however, the more difficult it will be for biodiesel production from new vegetable oil to be profitable; the feedstock input price will rise along with expected revenues, eating up any profit margin.

The second important factor is scale. At the farm scale, the crop and oil/meal enterprises had positive returns above variable costs in all cases except oil and meal production under normal-price conditions. Positive returns in the short-run might therefore be achievable for some farms, especially if they anticipate different conditions unique to their operation that would allow for reduced costs compared to these scenarios, such as the ability to use existing equipment or facilities or improved soil fertility. Scale is also a factor at the farm scale with regard to access to markets for whole oilseed crops. Given Vermont's distance from national oilseed commodity market centers, Vermont farmers will need access to local and regional oilseed processors, which may in turn require a certain number of planted acres in order to contract with a farmer for production.

At the farm scale, the most promising enterprise appears to be oil and meal production. Under high-price conditions, this enterprise was close to breaking even, and achieved modest yet positive returns when the cost of the oilseed was set equal to the cost of its on-farm production. In addition, returns to variable costs were positive under high-price conditions, indicating the potential for the enterprise to be profitable at greater volumes that realize economies of scale on the capital investment in oilseed pressing equipment. Furthermore, under high-price conditions this analysis shows that it would be cheaper to grow the oilseed crop than to purchase seeds for pressing.

The profit potential of the oil and meal enterprise is increased by having two co-products, and the value of the oilseed meal is especially important to its economic viability in Vermont. The ability of any small-scale oilseed processor to consistently provide high-quality meals is therefore crucial. If the meal's quality or consistency with commercial meals is questionable, it must be sold at a discount, reducing revenue potential for the oilseed grower/meal producer and putting the dairy farmer's milk production and revenues at risk. When the price differential is removed, the local and commercial meals will be competing solely on quality. Quality must therefore be assured to make locally produced meal competitive with commercially produced feed meals.

At the commercial scale, the economic feasibility of biodiesel production depends heavily on plant capacity. A 500,000-gallon plant has only a small chance of being profitable, whereas a 2.5 million-gallon plant is predicted to be profitable under every scenario.

5.2.3 Macroeconomic and Environmental Impacts

Results of this study indicate that Vermont farmers will produce oilseed crops only if they are induced to do so by higher-than-average oilseed prices, and are highly willing to acquire new equipment, infrastructure, and expertise to shift to new crops. Similarly, the greatest potential employment gains of commercial-scale biodiesel production can be achieved only if Vermont farmers make a strong transition to oilseed crop production, and if the biodiesel plant is able to obtain part of its oilseed feedstock from Vermont sources. Biodiesel production alone is predicted to produce 25 to 100 jobs, whereas high levels of oilseed production in the state have the potential of tripling the employment impact.

State involvement in the form of a new-capacity credit or other production incentive is needed to boost the level of import substitution Vermont can achieve from biodiesel production. At a cost of $625,000 (based on a $0.25/gallon new-capacity credit and a 2.5 million-gallon plant), the state could replace between $10 million and $15 million worth of imports.

Biodiesel production under every scenario is predicted to produce a positive EROI, and has a strong potential to reduce Vermont's carbon footprint, provided that Vermont's cultivated cropland is expanded to accommodate oilseed production. If land put into oilseeds would have otherwise reverted to forests, the model predicts an *increase* in greenhouse gas emissions. The greatest potential greenhouse gas reductions can be achieved with a larger plant; the model predicts that a 2.5-million gallon plant can reduce carbon loading by over 15,000 tons per year of CO_2 equivalent.

5.3 Recommendations

5.3.1 For Farmers and Small-Scale Entrepreneurs

This study has mixed implications for oilseed crop production by Vermont farmers. Vermont farmers can expect positive returns from oilseed crop production only given adequate yields, storage facilities, favorable market prices, and access to markets. As more farmers experiment with oilseed crops, the development of local expertise and information-sharing among the farm and Extension community should help new growers. Farmers may also be able to share harvesting equipment, provided that participating farms are close enough together to make it practical to transport equipment between farms. Custom harvesting could represent a new business opportunity in coming years as more farms add oilseeds to their crop rotations. Farmers, processors, and other business owners involved in oilseed crop production should continue to build networks for developing and sharing local expertise in processing, distribution, and sales.

Regarding oilseed pressing and biodiesel production enterprises, results of this study imply that these enterprises are not profitable in the context of a 'typical' Vermont dairy farm to which these enterprises would be ancillary operations. The oil and meal enterprise may, however, benefit from economies of scale, and prove feasible as a primary line of business for entrepreneurs who provide centralized or consolidated seed-pressing services to other farmer/growers. Entrepreneurs interested in this business will need to further refine and test their seed-pressing techniques to ensure consistent production of high-quality oilseed meals that will allow sale of the meal to farmers or a feed dealer at a competitive price.

5.3.2 For Policymakers and Investors

These findings have several implications for policymakers or businesses contemplating the provision of incentives for or development of biodiesel production facilities in Vermont. First, it appears that a commercial biodiesel plant must have an annual production capacity greater than 500,000 gallons in order to take advantage of economies of scale for efficient and profitable production (this could change, however, in light of better or more recent data on capital costs for smaller-scale facilities). A larger plant also offers greater potential for the state to create jobs, increase import substitution, and decrease greenhouse gas emissions, all of which would also be facilitated by state tax credits or other incentives. Second, the higher the price of crude oil, the more likely it seems that a biodiesel plant will be profitable; the most recent spike in energy prices in 2008, however, was accompanied by dramatic increases in food commodity prices far greater than those modeled in this analysis, which would increase the price of biodiesel feedstocks.

Finally, the most significant question for Vermont in considering commercial-scale production is the extent to which Vermont crop production should shift to include oilseeds for biodiesel production. If the state's primary objectives are to promote economic development, import substitution, and job creation, Vermont farmers should be encouraged to produce oilseeds for an in-state biodiesel facility. If the state's objectives for biodiesel production are related primarily to environmental impacts, however, results from these simulations suggest that greater production of oilseed crops in Vermont should not be encouraged. Unless oilseed crops are substituted for existing row crops, the state's net greenhouse gas emissions may actually increase.

5.4 Limitations and Suggestions for Further Research

Several aspects and unanswered questions of this analysis would benefit from additional study. From a technical perspective, Vermont oilseed growers would benefit from additional crop trials to expand experience and improve production methods that optimize yields and economic returns. From an economic perspective, additional business models for oilseed pressing and biodiesel production bear further investigation, especially those that reduce capital investment costs, such as mobile oilseed or biodiesel processing facilities, mid-sized facilities that undertake oilseed or biodiesel processing as primary lines of business, and small cooperatives for oilseed processing and biodiesel production.

There are also many other potential markets for oilseed co-products besides livestock meal and biodiesel. Further study could focus on the viability of oilseed production for food-grade oil sales, lease of filtered, unrefined vegetable oil to restaurants, use of oilseed meal as a crop fertilizer, use of oilseed meal as a fuel (in pellet stoves, for example), and potential uses and markets for the glycerin byproduct of biodiesel production.

Although results from this study indicate that a commercial plant will be profitable even when feedstock prices increase along with crude oil, the magnitude of the oilseed price increase modeled was less than the actual increase in commodity prices that occurred in the summer of 2008. If similar energy-food price relationships continue in another period of rising oil prices, the simulation model should be adjusted accordingly. An update of Mulder's acreage response survey of Vermont farmers may also be useful to discern any changes in the expected response of farmers to increased oilseed prices since the original survey. Additional data on capital costs for biodiesel facilities with capacities in the range of 500,000 gallons should be considered in any future model simulations to reduce the likelihood that the model is not overestimating capital costs for smaller plants.

Finally, environmental impacts of these enterprises at the farm scale should also be better understood. Further research on the net liquid fuel or energy savings to the farmer of local biodiesel production is important to understand the extent to which using renewable, farm-produced energy in on-farm oilseed and biodiesel production processes yield a net energy savings to the farmer. Similarly, a lifecycle analysis of the net farm greenhouse gas emissions from local oilseed and biodiesel production should be conducted to determine if carbon and other emissions are indeed reduced.

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APPENDIX A: TECHNICAL INFORMATION FOR ON-FARM BIODIESEL PRODUCTION

A.1 Crop Production

A.1.1 Field Cultivation

Field trials at State Line Farm were planted in early May into a firm seedbed at a depth of 0.5 inches. Trial results indicate that a seeding rate of 6–12 lbs/acre provides optimum yields in canola; heavier seeding rates of 22 and 29 lbs/acre resulted in severe lodging and would create disease and harvest issues. Fertilizer was not used in the 2007 trials, and should be applied based on soil test results.

Experience at State Line Farm shows that weed pressure is one of the main challenges to growing (and harvesting) canola and mustard. Birds were also a major cause of sunflower seed loss in the 2007 growing season.

A.1.2 Harvesting

Field trial results indicate that harvesting is a major challenge in optimizing oilseed crop production in Vermont. Difficulties include scarcity of and familiarity with equipment, optimal timing, and having access to enough equipment to provide flexibility in using the best technique for a given crop and season.

Harvesting soybeans, canola, and sunflowers requires either a combine or a swather, but finding affordable equipment of this type for small-scale oilseed production in Vermont is challenging. New combines, which typically cost over $100,000, are prohibitively expensive for most Vermont farmers, and too large for many Vermont fields and facilities.

Used equipment may be a better option for farmers planning to grow oilseeds on a modest scale. State Line Farm owns a 1960s Massey Harris combine that was used to harvest all its oilseed crops; for sunflower harvesting, the combine was modified with a two-row corn head). The combine cost $1,000 and required significant time and $1,000 of parts to be in good operating condition.

Owning a combine, especially an older model, requires mechanical skills or access to someone who can maintain and repair it, and possibly a transport trailer. For these reasons, farmers may choose to hire a contractor for custom harvest rather than purchase their own equipment. In Vermont, access to a combine, whether contracted or purchased, is generally easier in the Champlain Valley region than in the rest of the state.

Field moisture is important in determining when to harvest oilseed crops, especially canola and sunflowers. The plants should be as dry as possible for optimal harvesting and eventual storage. If canola dries too long in the fields, however, the seed pods are likely to shatter during harvest, resulting in seed loss to the ground. Swathing is therefore a preferred technique for canola. Swathing lets the farmer cut the crop as the seeds begin to mature; the plants continue drying whole on the ground and can be picked up by a combine with the seed pod still intact.

Ideally, sunflowers should be left standing to dry in the field, but the length of the Vermont growing season sometimes makes this impracticable. Moisture in the heads can harbor white mold, and cause them to get mushy. Finally, for dairy farmers, optimal timing of forage harvesting may take precedence over oilseed harvesting. As a result, equipment may not be available when it is needed for oilseed crops.

A.1.3 Seed Cleaning, Drying, and Storage

To make high-quality oil, enhance seed storage, and protect the seed presses, it is necessary to clean the seed to remove chaff, weeds, and other impurities. At State Line Farm, some batches of uncleaned seed stored with chaff caused the seed to heat up, reducing quality of the seed meal, and potentially reducing oil quality if there is enough mold.

Few in-state facilities for seed cleaning are currently available. State Line Farm purchased an Eclipse model 324 seed cleaner with hundreds of available screen sizes and types for different seeds that can be used in different configurations. Different screens may be required for the same crop because different fields have different weed seeds that can contaminate seed lots.

The Clipper uses three screens at a time. The first screen lets the small grain pass through and uses bouncing or shaking to remove or "scalp" anything bigger than the desired seed. Then, a series of two sieving screens removes the weed seeds that are smaller than the crop seed. If there is a large variation in the crop seed size, the batch should be screened a second time to get the smaller crop seeds as well. In general, the bigger the seed, and the higher it is off the ground when combined, the easier it is to clean. The cleaner's operating speed depends on the seed type and the level of "trash" in the seed.

State Line Farm found that setting up a system to deliver and sort material to and from the cleaner can be complicated. The cleaner has one input stream and as many as six output streams. The farmer needs to have enough bins and adequate space to position them accordingly.

Finally, adequate facilities for drying and storage are essential to successful oilseed crop production. Seeds that are stored while too wet (above 13% moisture) will mold. In the Vermont climate, air-drying is often inadequate, and farmers may require a blower dryer or propane heat, which adds expense and creates a potential fire hazard.

A.2 Oil and Meal Production

Oilseeds have a relatively low value as a raw commodity, but processing the seed into oil and meal can add value to the crop. The meal has potential value as a livestock feed, and the oil can be used for human consumption, burned directly in waste oil furnaces, or combined with alcohol and a catalyst (lye) to make biodiesel.

After harvesting, cleaning, and drying, the oilseeds are "pressed" to extract the oil from the meal. The pressing equipment can range from a portable, bench-mounted device suitable for small-scale farm use to a much larger unit appropriate for an industrial processing facility, and there are sizes and combinations of extruders, expellers, and presses to meet any scale of operation.

A.2.1 Extraction methods

The method of oil extraction affects nutrient content and the meal's resulting value, both nutritionally and financially. The two methods most commonly used in the U.S and Canada are expelling and solvent extraction. The expeller method uses a motor-driven screw turning in a perforated cage. The screw pushes the material against a small outlet called the "choke." Significant pressure (hydraulic or manual) is exerted on the oilseed fed through the machine to extract the oil. Expelling is a continuous method and can reduce meal fat content to 6%–7%, capturing 50%–85% of the available oil. Expellers cost from $5,000 to $50,000, depending on the size.

Solvent extraction involves mixing oilseed cake with a solvent (hexane is most common) and distilling the solvent under vacuum to recover the oil. Hexane extraction is the most common process in industrial oil production because it is highly effective, capturing nearly 100% of the available oil. Hexane is a petroleum product and a known toxin, however, raising health concerns for some consumers and precluding its use in the manufacture of organic products. Solvent extraction also involves substantial capital cost and is only economical at a large scale.

A.2.2 Oilseed Press

State Line Farm purchased a Täbypressen (Tabby) model 70 seed press made in Sweden for $8,781. The U.S. distributor is located in Magic Mill, New Jersey. This press is in the middle range of sizes available, capable of pressing one ton of seed per day, depending on the condition of the seed and how fast it is pressed. The press has successfully pressed soybeans and canola, mustard, flax, and sunflower seeds, and can be adjusted to extract more or less of the total oil, affecting how much remains in the meal. Depending on feedstock and adjustment, it produces 1 to 3 gallons of oil per hour at State Line Farm (equating to 23,000–35,000 gallons of oil per year if run 24 hours per day). The press can run automatically for long periods of time. Seed must be thoroughly clean and dry before going into the press.

State Line Farm uses electricity to power the press, but could also use a diesel motor. The press has a 2.2-kW, 3 hp motor that runs at approximately 8 amps at 3 phase, using approximately 1500 watts. The unit has a heating collar on the nozzle which can improve meal quality by deactivating the trypsin inhibitors present in soybeans. There are electronic controls for variable speed of operation and counting of hours of operation, a voltmeter, and an automatic shutoff. The automatic shutoff is an important feature for unattended operation. In addition to preventing damage if the screw press gets jammed, the unit also shuts off if there is an interruption in the flow of grain, or if the nozzle becomes too hot. State Line Farm has installed a magnet over the stream of seed flowing into the mill to catch any metal in the seed that could jam the press.

To press well, the seed has to have a moisture content of approximately 6% to 9%. If the seed is wet it does not flow through the nozzle well and if it is too dry the press grinds the seed to dust. The grain handling has been designed to expel small batches of seed meal into polytarp totes, which facilitates handling and delivery.

A.2.3 Space Needs

State Line Farm constructed a dedicated facility for oilseed handling and processing in 2006. Previously they had been operating in the old dairy barn, which was not designed for this purpose, and not suitable to optimizing efficiency, health, and safety. Pressing oil is not compatible with a barn or equipment shop because of dust entering the process, inevitable oil spills, and the need for separating processing from foot and vehicle traffic patterns. Building from scratch allowed the facility to incorporate many desirable features to enhance energy efficiency, materials handling, and cleanliness.

The building at State Line Farm is 30’ x 50’ with a 16-foot interior clearance. The building has large garage doors to allow easy equipment movement, and a dock for ease of deliveries. There is a pitched cement slab floor with a grated drain that can hold 1,000 gallons in the event of a spill. The floor also has radiant heat pipes that will eventually be connected to a boiler. Windows with southern exposure provide passive solar heat. When dealing with vegetable oil in winter it is necessary to maintain a minimum temperature so the oil does not congeal.

State Line's facility is built into a small hillside in order to use gravity to feed raw seed into the building. When designing such a building, one needs to consider how the materials can flow through efficiently through all steps of the process, from input of seed to output of vegetable oil and/or biodiesel. At State Line Farm, seed drops from the the grain storage atop the hillside bank into a hopper in the upper level of the building, avoiding the use of an auger and reducing power consumption, potential damage to the seed, and noise of operation. Once the seed is pressed, the oil and meal flow by gravity into separate containers.

The town of Shaftsbury was consulted before construction started, and considered the building to be an agricultural building for permitting purposes. This may not have been the case if the facility was not built on a working farm that was producing crops that would be stored and processed in the building.

A.3 Biodiesel Production

State Line Farm has also developed small-scale biodiesel production capacity to reduce fuel costs by using the biodiesel on the farm; they could also increase farm revenue by selling the fuel.

A.3.1 Equipment and Facilities

From a technical perspective, small-scale biodiesel operations are relatively easy to establish, but they do require careful space and site planning to ensure adequate safety measures and maximum efficiency. Since methanol and the catalysts required to make biodiesel (i.e.sodium hydroxide or potassium hydroxide) are hazardous and flammable when combined, developing and following a best practices protocol is essential.

Every biodiesel production system contains several basic elements; in general, a processor consists of several tanks linked by piping, pumps, and valves. The “tank farm” typically includes a tank for producing and settling the biodiesel, a tank for mixing the methanol, and tanks for storing oil, glycerol, and finished biodiesel. Heating elements are sometimes included, and the system often includes electrical controls and switches. Other equipment expenses include a filtration system to remove impurities from the finished product, fireproof storage for methanol, and titration and testing equipment.

Processors designing a biodiesel facility must find the optimal balance among the cost factors of efficiency, safety, and throughput. Starter kits allow an entrepreneur to get up and running quickly, and can be added to in a modular fashion if more capacity is needed. To establish a system that can support reliable, growing production over a longer term, however, greater initial capital investment in larger, higher quality equipment will save money in the long run. The size of one’s system will also be limited in part by the size and characteristics of the space or facility available for biodiesel production. Larger tanks require high ceilings. Handling vegetable oil and methanol present unique concerns—wood walls, for example, can quickly become slippery. Having dedicated tanks for each purpose, which increases efficiency, requires adequate square footage.

APPENDIX B: MODEL OUTPUT VARIABLES

Key variables of interest are highlighted in yellow.

Variable Name	Description	Units
1. Crop Submodel		
VT Canola Yield	Per acre yield	Tons/acre
VT Canola Production	Total canola production of contracted canola growers	Tons
VT Soy Yield	Per acre yield	Tons/acre
VT Soy Production	Total soy production of contracted canola growers	Tons
Canola Acreage	Acreage planted to canola of contracted growers	Acres
Soy Acreage	Acreage planted to soy of contracted growers	Acres
Canola Revenue	Gross revenue of canola growers contracted with plant.	Y2000$
Soy Revenue	Gross revenue of soy growers contracted with plant.	Y2000$
Soy Net Revenue	Gross revenue minus cash costs	Y2000$
Canola Net Revenue	Gross revenue minus cash costs	Y2000$
Oilseed Revenue	Canola revenue plus soy revenue	Y2000$
Oilseed Value Added	Value added in production of soybeans and canola	Y2000$
Dairy Cows	Number of dairy cows in Vermont	Cows
Real Milk Price	Price of milk	Y2000$/cwt
Milk Production	Milk produced in Vermont	Lbs
Notes	*The model assumes that all oilseed from Vermont purchased for biodiesel was contracted prior to the season. How that contract price is set and how many acres are planted in response to that price are variables that should be inspected by all who want to use the data from this model.*	
2. Biodiesel Submodel		
2A. Oilseed Economics Submodel		
VT Contract Soy Price	Offered contract price by the plant. Currently taken as three year average of national price plus a VT premium.	Y2000$/ton
VT Contract Canola Price	See above.	Y2000$/ton
VT Canola Meal Price	Wholesale value of canola meal from plant.	Y2000$/ton
VT Soy Meal Price	Wholesale value of soybean meal from plant.	Y2000$/ton
National Canola Price	National price.	Y2000$/ton
National Soy Price	National price.	Y2000$/ton
VT Soy Oil Cost	Net cost to the plant of oil from contracted Vermont seed.	Y2000$/gal
VT Can Oil Cost	Net cost to the plant of oil from contracted Vermont seed.	Y2000$/gal
National Can Oil Cost	Net cost per gallon to the plant of oil from imported seed.	Y2000$/gal
National Soy Oil Cost	Net cost per gallon to the plant of oil from imported seed.	Y2000$/gal
National Canola Oil Price	National price.	Y2000$/gal
National Soy Oil Price	National price.	Y2000$/gal
Notes	*Prices for oilseed, oilseed meal, and oil in Vermont and nationally are very important to the costs and revenues of the plant.* *Vermont prices are generally assumed to be national prices plus a transaction cost with the exception of contracted oilseeds.*	
2.B. Crusher Submodel		
Tonnage crushed	Oilseed processed.	Tons
Crusher Oil Production	Oil produced.	Gal.
Soybeans Crushed	Soybeans processed.	Tons
Canola Crushed	Canola processed.	Tons
Soy Meal Production	Soy meal produced.	Tons

Variable Name	Description	Units
Canola Meal Production	Canola meal produced.	Tons
Crusher Protein Production	Protein in oilseed meal.	Tons
Soy Meal Revenue	Gross revenue from sale of soy meal.	Y2000$
Canola Meal Revenue	Gross revenue from sale of canola meal.	Y2000$
Total Crushing Costs	Total costs of operating crusher.	Y2000$
Canola Oil	Canola oil produced.	Gal.
Soy Oil	Soy oil produced.	Gal.
VT Canola Meal	Canola meal from VT canola.	Tons
VT Soy Meal	Soybean meal from VT soybeans.	Tons
2.C. Biodiesel Processor Submodel		
Crude Oil Price	Price of crude oil	Y2000$/bar
Nat Diesel Price	Wholesale price	Y2000$/gal
Biodiesel Price	Wholesale price	Y2000$/gal
Plant Capacity	Annual plant production	Gal/yr
VT Biodiesel Demand	Potential level of BD sales in VT in gallons	Gal/yr
Biodiesel Revenue	Plant revenue from BD sales	Y2000$
Glycerin Revenue	Plant revenue from glycerin sales	Y2000$
Excess Oil Revenue	Plant revenue from sales of excess vegetable oil	Y2000$
Subsidies	Total subsidies from state and fed	Y2000$
Plant Revenue	Total revenue not including subsidies	Y2000$
Raw Oil Demand	Oil requirements of plant	Gal
Waste Oil Supply	Available supply of waste oil (assumed used)	Gal
Waste Oil Price	Price of waste oil	Y2000$/gal
Vegetable Oil Demand	Required vegetable oil inputs for plant to produce at capacity	Gal
Feedstock Costs	Total costs to plant for oil and methanol	Y2000$
Plant Fixed Costs	Fixed costs assume to be 10% of capital investment	Y2000$
Operating Expenses	Plant annual operating costs.	Y2000$
Total Costs	Total costs per year	Y2000$
Plant Profits	Revenue – costs + subsidies	Y2000$
Notes	- All economic calculations are adjusted to Y2000 dollars.	
3. Land Use Submodel		
Total Current Acreage	Acreage in VT currently in cultivation (including hay) or pasture	Acres
Acreage In Cultivation	Acreage currently in cultivation (including hay)	Acres
Available Agricultural Soils	Undeveloped agricultural soils not currently in production. (Rough estimate of land that could be put into production.)	Acres
4. Economic Submodel		
4.A. Import Substitution Submodel		
Diesel Replaced	Value of diesel not imported to VT because of BD production.	Y2000$
Import Substitution Revenue	Total value of all goods not imported into VT because of replacement by goods associated with BD production (including the BD).	Y2000$
4.B. Indirect Economic Impact Submodel		
4.B.1. Revenue Submodel		
Total Revenue	Revenue of all ag-related enterprises (dairy, oilseed, and crops).	Y2000$
Crop Revenue	Revenue from crop production including oilseed.	Y2000$
Oilseed Revenue	Revenue from oilseed production.	Y2000$
4.B.2. State and Local Taxes Submodel		
Dairy Taxes	Impact upon state and local taxes of milk production.	Y2000$

Variable Name	Description	Units
Oilseed Taxes	See above.	Y2000$
Crusher Taxes	See above.	Y2000$
Biodiesel Taxes	See above.	Y2000$
Total Taxes	See above.	Y2000$
4.B.3. Direct Labor Income Submodel		
Crusher Labor Income	Wages paid to employees at the oilseed crusher.	Y2000$
Milk Labor Income	See above.	Y2000$
Oilseed Labor Income	See above.	Y2000$
Biodiesel Labor Income	See above.	Y2000$
Direct Labor Income	Sum of the above.	Y2000$
4.C. Total Economic Impact Submodel		
Total Jobs Produced	Direct, indirect and induced jobs produced by the entire system (dairy and biodiesel).	FTE jobs
Total Labor Income	Direct, indirect and induced labor income produced by the entire system (dairy and biodiesel).	Y2000$
Total Output	Direct, indirect and induced economic output of the entire system (dairy and biodiesel).	Y2000$
Total Value Added	Direct, indirect and induced value-added of the entire system (dairy and biodiesel).	Y2000$
Direct Employment	Direct jobs produced by the entire system (dairy and biodiesel).	FTE jobs
Direct Output	Direct economic output of the entire system (dairy and biodiesel).	Y2000$
Direct Value Added	Direct value-added of the entire system (dairy and biodiesel).	Y2000$
4.D. Protein Submodel		
Total Protein Demand	Protein demands of animals associated with the dairy industry.	Tons
In-State Protein Production	Protein produced as oilseed meal on VT acres	Tons
5. Biodiesel Impact Submodel		
Oilseed Labor Income	Total wage impact of oilseed production.	Y2000$
BD Taxes	Total tax impact of BD processor and oilseed crusher.	Y2000$
BD Value Added	Total impact upon state value-added of BD processor and oilseed crusher.	Y2000$
BD Labor Income	Total wage impact of BD processor and oilseed crusher.	Y2000$
BD Output	Total impact upon state economic production of BD processor and oilseed crusher.	Y2000$
BD Employment	Total job impact of BD processor and oilseed crusher.	FTE jobs
Oilseed Employment	Total employment impact of oilseed production.	FTE jobs
Notes	*"Total" means direct, indirect, and induced, per the input-output framework.*	
6. Environment Submodel		
6.A. Energy Submodel		
Canola Energy	Energy charge for canola production.	MJ
Soy Energy	Energy charge for soy production.	MJ
Milk Energy	Energy charge for dairy production.	MJ
Crusher Energy	Energy charge for oilseed processor.	MJ
Biodiesel Energy	Energy charge for biodiesel processing.	MJ
Crop Energy	Energy charge for crop production (a majority of which goes into milk production).	MJ
Total Energy	System wide energy use.	MJ
Energy Produced	Energy (BD) produced.	MJ
Notes	- Total energy is not derived from the sum of the above as there is overlap between the energy in crop production and the energy in milk production.	

Variable Name	Description	Units
6.B. Fertilizer Submodel		
Soy Fertilizer-N	Nitrogen applied to VT soybeans.	Lbs.
Soy Fertilizer-P	Phosphorus applied to VT soybeans.	Lbs.
Canola Fertilizer-P	Phosphorus applied to VT canola.	Lbs.
Canola Fertilizer-N	Nitrogen applied to VT canola.	Lbs.
Annual Fertilizer-N	System-wide nitrogen applied in VT.	Lbs.
Annual Fertilizer-P	System-wide phosphorus applied in VT.	Lbs.
6.C. Greenhouse Gas Submodel		
Total GHG Emissions	System-wide GHG charge	Tons CO2 equivalent
Vehicle Net Reduction	GHG emissions averted because of diesel replacement.	Tons CO2 equivalent
Sequestration Opportunity Cost	GHG that would be sequestered in VT if all land in current production were allowed to revert to forest.	Tons CO2 equivalent
Net GHG Emissions	Total GHG + Sequ. Opportunity cost – Vehicle Net Reduction	Tons CO2 equivalent
Canola GHG	GHG charge for canola production.	Tons CO2 equivalent
Soy GHG	GHG charge for soy production.	Tons CO2 equivalent
Crusher GHG	GHG charge for oilseed processing.	Tons CO2 equivalent
Biodiesel GHG	GHG charge for BD processing.	Tons CO2 equivalent
BD GHG 1	GHG charge to BD not counting sequestration charge (should be negative due to Vehicle Net Reduction).	Tons CO2 equivalent
BD Sequestration Cost	GHG that would be sequestered if land in oilseed production in VT were allowed to revert to forest.	Tons CO2 equivalent
BD GHG 2	GHG charge to biodiesel counting sequestration cost.	Tons CO2 equivalent
7. Biodiesel Energy Submodel		
Crusher Energy Charge	Life-cycle energy charge for crusher.	MJ
Oil Energy Charge	Life-cycle energy charge for oil inputs not including crusher energy.	MJ
Gross Energy Charge	Gross energy used in oilseed production, crusher and BD processor.	MJ
Total Energy Charge	Fraction of gross energy attributable to BD.	MJ
Net Energy Produced	Net energy value of BD production.	MJ
Net to Gross Ratio	Net energy to total energy charge ratio (see report for significance.)	
Energy Return	EROI of BD production.	
Notes	- *Formulas in this section are complex because of the need to allocate charges between co-products. Portion of oilseed production and processing energy is allocated to oilseed meal and portion of BD processing and oil charge is allocated to the glycerin.* - *Allocation is by price.*	
8. Vermont Biodiesel Energy Submodel		
8.A. Soybean Oil Source		
Total Energy Charge	Energy costs for the BD from VT soybeans	MJ
Energy Produced	Energy produced as BD from VT soy production	MJ
Net Energy Produced	Net energy produced from VT soy production	MJ
Energy Return	EROI of VT soy biodiesel	

Variable Name	Description	Units
Net to Gross Ratio	Net to Gross ratio of VT soy biodiesel	
Net to Land Ratio	Ratio of net energy produced from VT soybeans to the acreage planted	MJ/acre
8.B. Canola Oil Source		
Total Energy Charge	Energy costs for the BD from VT canola	MJ
Energy Produced	Energy produced as BD from VT canola	MJ
Net Energy Produced	Net energy produced from VT canola production	MJ
Energy Return	EROI of VT canola BD	
Net to Gross Ratio	Net to Gross ratio of VT canola biodiesel	
Net to Land Ratio	Ratio of net energy produced from VT canola to the acreage planted	MJ/acre