OVERCOMING COMPETITIVE DISADVANTAGE:

FUTURE COMMERCIAL VIABILITY OF MICROALGAE BASED BIODIESEL

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CHAPTER I

INTRODUCTION

1.1 Objective

The objective of this thesis is to answer the question, “How can microalgae based biodiesel become competitive on price with petroleum diesel without government subsidies or other forms of market intervention?” To do so we will develop a hypothetical biodiesel production firm. The result will be targets for level of investment and production cost necessary for a start up biodiesel producer to compete on price with petroleum diesel.

We assume no government policies favoring biodiesel start up or operation. We also assume continuation of all current government policies from which the petroleum industry may benefit.

Competitiveness for a biodiesel firm is herein defined as the ability to achieve a required rate of return on a start up biodiesel project by selling fuel (B100, as defined in Section 1.2) at a price equal to or less than the price of petroleum diesel. The purchaser of biodiesel fuel is the distributor, who is a wholesaler, blender, and/or distributor, hereafter referred to as “distributor.”

The competitor is any petroleum refiner, such as ExxonMobil or Valero. See Chapter VI for a more detailed description of the competing firm.

Various sources use “B20,” “B100,” and “biodiesel” interchangeably. In the context of this thesis, “biodiesel” means “B100.” Whether the B100 is used for blend stock to make B20 or other blended fuel or it is used as a direct replacement for petroleum diesel is irrelevant.

According to the U.S. Department of Energy’s Energy Information Administration (EIA), the sulfur contained in petroleum diesel provides lubricity for certain engine parts. Biodiesel has superior lubricity, making it valuable as an additive. (Radich) Marketing biodiesel as an additive to improve the performance of petroleum diesel creates the opportunity for commercial viability at a price greater than that of petroleum diesel. A biodiesel project would then be more likely to achieve the required rate of return. However, this thesis only addresses the commercial viability of biodiesel as a replacement fuel for petroleum diesel.

Biodiesel is distinct from renewable diesel. Although they are produced from the same feedstocks, renewable diesel is produced in petroleum refineries and is chemically identical to petroleum diesel. This thesis only addresses biodiesel. See Section 8.3 for a brief discussion of renewable diesel.

1.2 Biodiesel Properties

Biodiesel, as defined by the National Biodiesel Board (NBB), is “a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751” and is a direct substitute for petroleum diesel. (NBB, “Definitions”) It “is typically produced by a reaction of a vegetable oil or animal fat with an alcohol such as methanol or ethanol in the presence of a catalyst to yield mono-alkyl esters and glycerin, which is removed." (NBB, "Definitions") This process is called trans-esterification. (Weber and Van Dyne) ASTM D 6751 is the industry quality standard for 100% biodiesel, as specified by ASTM International—formerly known as the American Society for Testing and Materials. (ASTM) Biodiesel fuel is usually blended with petroleum diesel for consumers' use and is designated by the percentage of biodiesel in the blend. A blend of 20% biodiesel and 80% petroleum diesel is designated "B20." Fuel that is 100% biodiesel is "B100." (NBB, "Questions") Biodiesel is safe for use in any diesel engine with little or no modification. Some older vehicles may need modification.

Biodiesel outperforms petroleum diesel in several areas. (NBB, "Emissions") However, petroleum diesel has a distinct advantage over biodiesel in cold weather performance (Table 1.1). Biodiesel forms wax crystals at relatively high temperatures. The temperature at which this occurs depends on the feedstock used to produce the fuel. Fuel produced from high quality vegetable oils, such as soy, perform better in cold weather than does fuel produced from tallow or yellow grease. (Radich) Other feedstocks produce fuel with cold weather performance between these extremes. This shortcoming can be mitigated via use of additives.

Table 1.1: Low Temperature Properties

Fuel	Cloud Point		Pour Point	
	°C	*°F*	*°C*	*°F*
No. 2 Diesel	-23	-9	-27	-17
Soy Biodiesel	2	35	0	32
Yellow Grease Biodiesel	5	41	3	37
Tallow Biodiesel	14	57	18	64
2% Soy Biodiesel	-21	-5	-27	-17
2% Yellow Grease Biodiesel	-21	-5	-27	-17
2% Tallow Biodiesel	-20	-4	-27	-17

Source: NBB and Cold Flow Blending Consortium.

Product development has mitigated this disadvantage. Biofuel Systems Group Ltd., for example, markets a cold weather additive. They claim a pour point of -33° F (-36°C) for B100 fuel as opposed to the B2 fuel in Table 1.1. (Biofuel Systems) The National Biodiesel Board notes that many consumers are using biodiesel successfully in very cold climates. (NBB, “Let it Snow”)

A second disadvantage is lower energy content than petroleum diesel. Consumers using B20 (a common blend) should expect approximately 2.2% lower fuel economy. (Radich)

1.3 Economic Principles

Since government economic policies are often transitory, an entrepreneur considering a biodiesel production start up project should strive for competitiveness without the need for favorable government policies, such as subsidies or renewable portfolio standards. Current subsidies provide biodiesel producers with an indirect uplift of up to $1.00 per gallon via credit to blenders who blend biodiesel with petroleum diesel. (Internal Revenue Service, “Form 8864”) This allows producers to sell their B100 at a higher price to distributors who blend. The hypothetical firm developed in this thesis will not rely on any government intervention in the market.

One could argue that intervention in the market is a legitimate role for the government in order to reduce the effect of negative externalities. An externality is the impingement of one economic agent’s decision upon another economic agent. It can have either a positive or negative effect. (Binger and Hoffman) If petroleum diesel imposes a negative externality on the public (pollution), and the use of biodiesel could reduce that externality (Radich), then one could argue a subsidy or some other intervention in the market by the government is appropriate. While that may be true, it is still a government policy. Therefore, it may be transitory. The entrepreneur should not rely on such policies when evaluating a biodiesel project. This is in spite of the fact that many European countries have had a wide variety of policies favoring petroleum diesel and biodiesel over gasoline, which have been applied consistently for many years. (Prock) The result of these policies is that diesel powered cars accounted for 53% of new cars sold in the European Union in 2007. (Diesel Technology Forum)

Product specification is a form of government intervention in the market, which may negatively affect the value of a proposed biodiesel project. The petroleum diesel industry recently experienced such an intervention, when the requirements of ultra-low-sulfur diesel (ULSD) were imposed. Estimates of the premium of ULSD over low-sulfur diesel vary widely, but EIA estimated it would add 6.5 to 7.2 cents per gallon. (EIA, “Transition”) The government’s product specification also required the industry to spend $8 billion in capital investments in new equipment. (American Petroleum Institute, "Recent") Although the NBB promotes quality standards for the biodiesel industry (NBB, "Fuel Quality"), and biodiesel generally has lower emissions than petroleum diesel (NBB, "Emissions"), the entrepreneur should be aware that biodiesel is subject to government product specification policies and the associated potential risk. Interestingly, the ULSD product specification may lead to an increase in demand for biodiesel as an additive for lubricity.

Other government policies affect the market indirectly. For example, tax revenues could be spent on research and development of improvements to processing, distribution, or feedstock production. Federal, state or local governments could also create programs to educate consumers on the virtues of biodiesel, which amounts to free advertising. Both of these allow biodiesel firms to reduce their costs, thereby increasing the likelihood the entrepreneur will achieve the required rate of return.

Since this thesis is not intended as a review of policy, we will not address whether the government should intervene in the market. Neither will we evaluate the efficacy of specific government policies.

CHAPTER II

COST OF FEEDSTOCK

2.1 Introduction

Biodiesel is currently not competitive on price with petroleum diesel. As discussed more fully in Section 4.2, the primary reason is the cost of feedstock. Soy oil and yellow grease are the most common feedstocks among U.S. producers. (Radich) However, soy oil costs more than the market value of the biodiesel fuel and accounts for 88% of the cost of production. (Haas, *et al*) This, of course, is not sustainable without government intervention in the market.

2.2 Limiting Factor

Perhaps the greatest limiting factor in biodiesel production is the source of feedstock. Biodiesel is produced primarily from oilseed crops. While it is true crops are renewable, as opposed to one-time use of a petroleum crude oil deposit, land suitable for crops is limited. Replacing substantially all of U.S. annual diesel consumption with biodiesel would require an enormous area of surface crops. In fact, if the entire U.S. production of soy oil in 2006—its most productive year[1]—was committed exclusively to biodiesel production, it would only replace 4% of petroleum diesel consumption for that year.[2]

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[1] Economic Research Service (ERS), “Oil Crops Yearbook” (OCY).

[2] Energy Information Administration (EIA), “Custom Table Builder” (CTB).

This alone should have been enough to predict a severe increase in the price of soy oil as the biodiesel industry grew. In 2006, total soybean cultivation was 74,602,000 acres. (ERS, “OCY”) In order to replace just 50% of petroleum consumption would require 29,260 million gallons. (EIA, “CTB”) Considering yield was 42.7 bushels per acre in 2006 (ERS, “OCY”), and 1.4 gallons of oil per bushel (Avery), it would require 20,900 million bushels harvested from 508,777,518 new acres of soybeans devoted exclusively to biodiesel feedstock production.

That would just keep pace with current levels of consumption. Even modest long term growth presents even greater difficulty. The number of new acres is probably even greater, because expanded farming activities will require the use of less productive land than is already in use. (Leetmaa, *et al* and Brady)

2.3 Supply and Demand

The high cost of quality feedstock (soy oil) is a result of basic supply and demand. When biodiesel first appeared on the market in very small quantities, it had little effect on total demand for soy oil. As the industry grew, demand began to outstrip supply, which forced biodiesel producers to compete with the food industry and others for the supply. This led to unprecedented price levels. (See Appendix A.) New biodiesel producers began looking for alternatives to soy oil, such as liquefied chicken fat. However, the same market forces have affected alternatives, as well. In an analysis conducted in 2004, the EIA concluded the availability of adequate feedstock would “continue to limit its commercial application.” (Radich)

One approach to overcoming this limitation is to increase the yield per acre of oilseed crops. The ERS expects total soy yields to increase only 9% by 2014. (Ash and Dohlman) That progress is slight compared to total diesel consumption. Only 20% of current soybean production is dedicated to biodiesel. (ERS, “Agricultural Outlook” and EIA, “Table 10.3”) Recalling the above statement that dedicating *all* current output of soybeans to biodiesel would only replace 4 percent of total petroleum diesel consumption, yield per acre must increase by far more than 9% without substantial increases in acreage dedicated to soybean cultivation. It is unrealistic to expect that degree of success in the short run or perhaps even in the long run.

A new biodiesel producer, as described in Chapter IV, may be able overcome the competitive disadvantage of the cost of feedstock by using oil from microalgae.

CHAPTER III

ECONOMY OF SCALE

3.1 Introduction

Competing against an industry as mature as petroleum is a daunting task for a new company. Petroleum diesel benefits from many decades of development. It is not practical to invest enough money to make the biodiesel industry equal in scale to petroleum diesel in the short run. Economy of scale is the second area in which biodiesel suffers competitive disadvantage.

3.2 Access to Capital

In addition to the scale of the petroleum industry as a whole, the scale of individual firms is also very large. The biggest of these have access to levels of capital that would be difficult for a start up biodiesel producer to match. For example, a report prepared by Ernst and Young, LLP for the American Petroleum Institute (API) shows that from 1996 to 2007 BP, Chevron, ConocoPhillips, Exxon Mobil, and Royal Dutch Shell alone allocated $712 billion to new investment. (Ernst and Young)

The high price of crude oil in 2006 – 2008 (EIA, “CTB”) encouraged record levels of investment by petroleum companies. (Ernst and Young) This investment will increase supply, which will bring prices back down. In fact, a variety of factors have already returned prices to approximately the level prior to the run up. (EIA, "CTB")

The petroleum industry may not be able to make full use of its competitive advantage. The same Ernst and Young report explains that even though U.S. oil companies have access to very high levels of capital, significant constraints exist for investing that capital. Their reasoning is most discoveries are outside the U.S. and are subject to restrictions and licensing by the host nation. In addition, new projects typically involve "increasingly larger investments, with multi-year planning and multi-year construction before production can occur." They also face new geo-political, regulatory and environmental risks, in addition to the general economic, operational, and financial risks associated with such projects. (Ernst and Young)

3.3 Biodiesel Potential

Competitors' access to capital may seem insurmountable, but biodiesel has potential. In May of 1998, the U.S. Department of Agriculture (USDA) and U.S. Department of Energy (DOE) jointly published the results of a 3½ -year study comparing a comprehensive life cycle inventory for both petroleum diesel and biodiesel, as well as for blends of biodiesel with petroleum diesel. (USDA and DOE) The results favored biodiesel substantially. "Biodiesel yields 3.2 units of fuel product energy for every unit of fossil energy consumed in its life cycle…[P]etroleum diesel's life cycle yields only 0.83." A 2007 update to the study adjusted the figure to 3.5 units for biodiesel. (Pearson) Although this report is based on biodiesel produced from oilseed crops, it indicates some potential in the hypothetical firm developed in Chapter IV, which uses oil from microalgae as feedstock.

A new biodiesel producer, as described in Chapter IV, may be able overcome the competitive disadvantage of economy of scale by reducing or even eliminating some sources of price risk through vertical integration.

CHAPTER IV

THE HYPOTHETICAL BIODIESEL FIRM

4.1 Introduction

What can the entrepreneur do to overcome the obstacles of the cost of feedstock and economy of scale?

The hypothetical firm employs biodiesel processing equipment identical to that of existing firms. Therefore, processing costs (the cost to convert feedstock to fuel) is identical to that for existing biodiesel firms. Equipment, fixed costs, and variable costs associated with storage are also identical. The distinguishing feature of the hypothetical firm is the ability to produce its own feedstock.

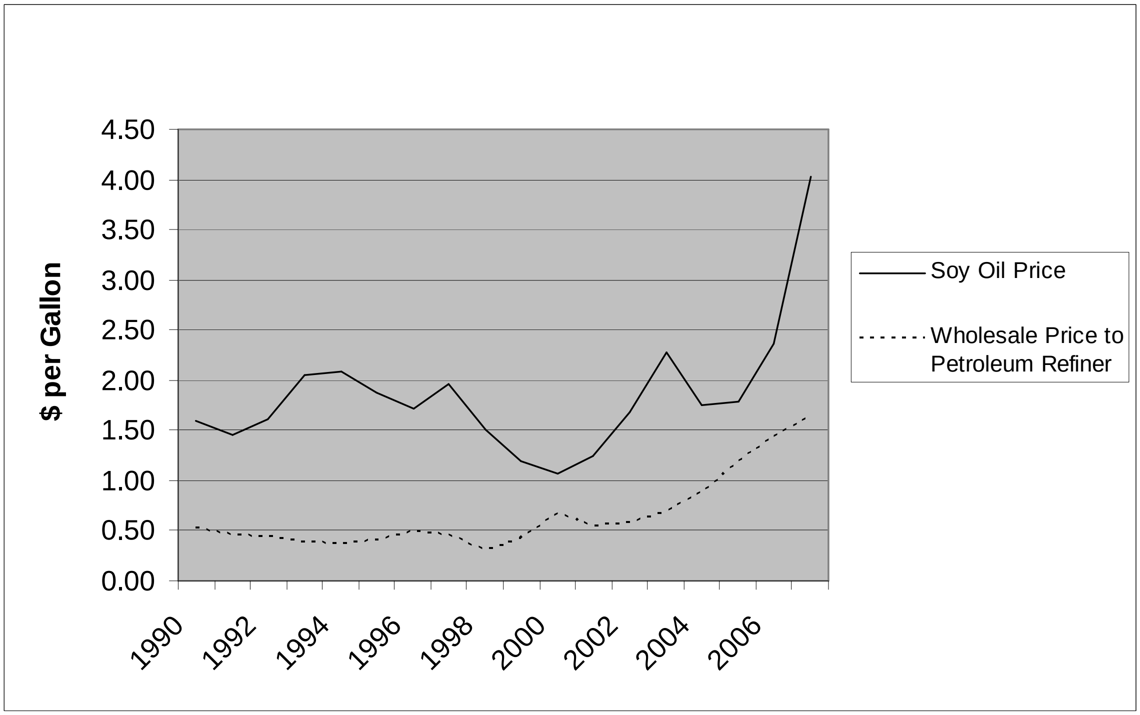
4.2 Alternative Feedstock

The U.S. Department of Agriculture conducted a study, which analyzed the effect of the cost of feedstock on overall production costs. (Haas, *et al*) The result was that each \$0.01/lb increase in the cost of oil (feedstock) caused a \$0.075/gal increase in processing costs. This result should have been expected, since the soy oil used for feedstock weighs approximately 7.6 lbs/gal (ERS, “Analysis” indicates 7.35, and ERS, “Weights” 7.7), and each gallon of feedstock produces approximately one gallon of fuel on average. (Van Dyne and Blase) The more useful finding of the study is that the cost of feedstock, as a percentage of production costs, is so high, that costs exceed the market value of the fuel. They conclude the deficit is so great, it is essential to develop a low cost feedstock in order to improve the economic viability of biodiesel. (Haas, *et al*) Although prices have risen and fallen dramatically since publication of this study, current price levels are similar to those evaluated by Haas, *et al*. (CBOT and EIA, “STEO Feb 09”)

It is simply not economical to use soy oil to make biodiesel fuel. On March 18, 2009, soy oil settled at 30.92 cents per pound for May09—near month—futures on the Chicago Board of Trade (See Appendix B), which equates to $2.35 per gallon. Using the production and transportation costs in Table 6.2 in Section 6.5, total cost is $2.995 per gallon. In order for soy based biodiesel to compete without government intervention in the market, the refiner wholesale price of diesel would have to be at least that high. Therefore, the retail price at the pump for petroleum diesel, including taxes, would likely need to be $4.00 per gallon or more indefinitely before soy based production would be a good investment.

Figure 4.1 shows historical prices for soy oil and the wholesale price to petroleum refiners, which is the benchmark for competitiveness in Chapter VI. Soy price data was not available for 2008.

Figure 4.1: Soy Oil and Petroleum Diesel Prices



Sources: U.S. Department of Agriculture (ERS, "OCY") and U.S. Department of Energy (EIA, "CTB")

What is the alternative to oilseed crops?

4.3 Microalgae

The U.S. Department of Energy funded the Aquatic Species Program (ASP) from 1978 to 1996. Sheehan, *et al*, report on the efforts to develop algae as a fuel source from 1980 to 1996. Their opinion of microalgae as a potential energy source follows.

> "The ASP regularly revisited the question of available resources for producing biodiesel from microalgae. This is not a trivial effort. Such resource assessments require a combined evaluation of appropriate

> climate, land and resource availability. These analyses indicate that significant potential land, water and CO_2 resources exist to support this technology. Algal biodiesel could easily supply several 'quads' of biodiesel—substantially more than existing oilseed crops could provide. Microalgae systems use far less water than traditional oilseed crops. Land is hardly a limitation. Two hundred thousand hectares (less than 0.1% of climatically suitable land areas in the U.S.) could produce one quad of fuel. Thus, though the technology faces many R&D hurdles before it can be practicable, it is clear that resource limitations are not an argument against the technology."

At the time they were very skeptical about the economics of any method of production other than open ponds.

> "The cost analyses for large-scale microalgae production evolved from rather superficial analyses in the 1970s to the much more detailed and sophisticated studies conducted during the 1980s. A major conclusion from these analyses is that there is little prospect for any alternatives to the open pond designs, given the low cost requirements associated with fuel production. The factors that most influence cost are biological, and not engineering-related. These analyses point to the need for highly productive organisms capable of near-theoretical levels of conversion of sunlight to biomass. Even with aggressive assumptions about biological productivity, we project costs for biodiesel which are two times higher than current petroleum diesel fuel costs."

Of course, they were unaware of what would happen with petroleum prices in the ensuing 12 years. Microalgae may now be a viable alternative.

Several companies are developing methods to grow various species of microalgae. Microalgae, such as *spirulina*, are laden with oil similar in quality, for biodiesel purposes, to soy oil. Microalgae have been farmed using racetrack ponds for many years.[3] PetroSun, Inc. is already producing microalgae for biodiesel feedstock using racetrack ponds. They claim 30 times the yield per acre of soy has been achieved in independent studies. If soybeans produce 60 gallons of oil per acre per year, a modest 10,000,000-gallon-per-year biodiesel plant would require 5,556 acres of ponds. The racetrack pond method encounters several limitations for commercial scale production, the most significant of which is contamination. (Sheehan, *et al*)

Microalgae offer a co-product, which effectively reduces the cost of oil production. The cake which remains following the oil extraction process is used for cattle feed and in a variety of human dietary supplements by companies like Nutrex Hawaii. Should the industry succeed in developing microalgae as feedstock, the supply of the co-product would dramatically increase. Therefore, long range planning should assume nominal value for the co-product. Such market trends already occurred in the earliest years of the biodiesel industry. Trans-esterification, regardless which feedstock is used, also yields a co-product: glycerin (a.k.a. glycerol). Glycerin is used in the manufacture of cosmetics, food, and pharmaceuticals. (Voegele) As biodiesel production increased, so did the supply of glycerin, and its market value diminished accordingly. Even at the modest levels of current biodiesel production (as compared to the petroleum industry), the volume of crude glycerin produced by the biodiesel industry exceeds that produced by all

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[3] See <www.nutrex-hawaii.com/> for an example of one company doing so.

other sources. (Voegele) This agrees with the EIA's assessment, that 300 to 600 million gallons per year of biodiesel would produce enough glycerin to oversupply the market and depress glycerin prices. (EIA, "Impacts") The same could occur with the microalgae press cake. If microalgae based biodiesel was able to replace 50% of petroleum diesel consumption, it would supply the market with approximately 157,602,409 metric tons of press cake per year. This is based on 60,829,000,000 gallons of total petroleum diesel demand in 2008 (EIA, "CTB"), 50% oil content (Sheehan, *et* al), and a 40% oil extraction rate.

By comparison, corn accounts for the bulk of feed grain for U.S. cattle production (ERS, "Agricultural Outlook") and totaled 134,909,091 metric tons dedicated to cattle feed in 2008. (ERS, "Weights") While the estimated volume of microalgae press cake exceeds this figure, corn consumed as cattle feed has been declining in recent years. (ERS, "Agricultural Outlook") The likely cause for this is demand for corn as feedstock for ethanol. Continuing and expanding government mandates for ethanol will increase the competition for corn. The resultant increase in the price of corn could mean that an abundant supply of microalgae press cake would not depress its market price as cattle producers look for alternative sources of feed. Without question, though, the first few commercial scale projects will be able to exploit the value of the press cake, while supplies remain modest.

4.4 Current Projects

The most promising research and development surrounds any of several versions of an apparatus called a "photobioreactor." This is a closed system in which microalgae are exposed to light and fed nutrients in combinations which maximize oil content and rate of growth. As discussed below, estimates of yield far exceed that of the best oilseed crops.

To date, the greatest obstacle facing developers of photobioreactors is scale up. While laboratory and demonstration scale photobioreactors have shown promising results, it is uncertain whether that success can be extrapolated to commercial scale systems.

4.4.1 A2BE

A few developers claim commercialization is imminent. One such company is A2BE. They propose a very large (geographically) microalgae production facility. (Sears) They claim to have achieved the goal of producing a low cost, high quality feedstock. Their data show the following.

- Carbon dioxide consumption: 110 MT per acre per year.
- Oil production: 54 kg per MT of carbon dioxide consumed.
- Microalgae production costs: $40 per MT of carbon dioxide consumed.

This leads to 54 kg oil/MT CO_2 * 110 MT CO_2/acre-year = 5,940 kg oil/acre-year or 1,719 gallons of oil per acre per year.

Also, ($40/MT CO_2 * 110 MT CO_2/acre-year) ÷ 1,719 gal/acre-year = $2.56/gal production cost.

This does not include the $10 of cost attributed to “CBW” (carbon bearing waste), which is associated with processing the co-products.

Per gallon production cost of $2.56 is not substantially different than soy oil. (ERS, “OCY”) However, A2BE’s approach is to improve returns through multiple revenue streams. In fact, they only break even on the oil production. One of the additional revenue streams is processing carbon bearing waste via an anaerobic reactor to produce methane. They claim revenue of $25 per 76 cubic meters. (Sears) However, a review of the historical natural gas prices at the wellhead shows this figure is very optimistic. Using the EIA's historical prices (EIA, "Wellhead") and conversion calculator (EIA, "Calculator"), the $25 per 76 cubic meters figure equates to $9.31 per thousand cubic feet. This is a very optimistic figure, since it is greater than the EIA's wellhead price in all but 5 months in the last 5 years. (EIA, "Wellhead" and Bureau of Labor Statistics [BLS], "PPI for Commodities")

The $90 in revenue from protein also appears optimistic. The $90 applies to 135 kg of protein, which equates to $0.30 per pound for total production of 47,520 metric tons of protein. This compares to $0.07 per pound for corn (at the average of $3.90 per bushel estimated for 2007/2008). (ERS, "Agricultural Outlook")

In addition to the questionable revenue claims, A2BE's plan will encounter two primary difficulties: capital cost and land.

Their own website seems to admit that their plan cannot succeed without substantial government money up front. Plant construction could start in 2012, but assumes a "national effort" is launched.

A2BE's proposed facility requires 3,200 acres of land just for the photobioreactor. Given the 1,719 gallons per acre yield calculated above, the facility produces a total of 5,500,800 gallons per year, which equates to a relatively small biodiesel producer. (NBB, "Plants")

The U.S. on-highway sector consumed 39,801,744,000 gallons of diesel fuel in 2007. (EIA, "Sales") That is the largest of the consumption sectors, but still accounts for only

63% of total distillate fuel oil consumption. It would take 7,236 facilities like that proposed by A2BE to completely replace petroleum diesel with B100 in the on-highway sector (1,447 for B20). The EIA indicates there are a total of 616 coal fired power plants with a total of 1,493 generating units. (EIA, “Questions”) Additional EIA data shows 5,439 natural gas fired generating units. (EIA, “Existing”) However, it does not specify how many power plants they comprise.

The EIA reports total carbon dioxide emissions from all power plants in 2007 was 2,516,580,000 metric tons. (EIA, “Electric Power Annual 2007”) Using A2BE’s figures of 110 MT of carbon dioxide consumed per acre per year, the theoretical upper limit of microalgae production using A2BE’s proposed method is 22,878,000 acres or 7,149 facilities. It is unknown how many power plants may be suitable for the kind of facility proposed by A2BE. Completely replacing petroleum diesel with B100 or even B20 with this method appears difficult.

The purpose of this thesis, though, is to determine whether and how biodiesel can become competitive on price with petroleum diesel from the perspective of an individual entrepreneur considering an individual project. Therefore, even if an industry-wide scale up of A2BE’s proposal could not replace petroleum diesel in the on-highway sector, would an individual facility achieve the required rate of return? The EIA does not indicate how many of those power plants have 3,200+ acres of suitable land adjacent to them. Many natural gas fired plants are not feasible, because they are too small. It is also necessary to determine the load profile of each generator. Base load units are optimal sources, because they emit carbon dioxide at consistent levels on a continuous basis. First-on-last-off units are feasible, but marginal units and peaking units are not feasible due to unpredictable carbon dioxide emissions.

Start up cost is not explicitly stated. However, calculations based on the information provided indicate that total start up cost is at least $349,648,407. (Sears)

The combination of no profit for the oil, reliance on questionable co-product revenue streams, total start up cost, and A2BE's own admission that government assistance with capital is necessary makes this proposal unattractive to an entrepreneur.

4.4.2 GreenFuel Technologies Corporation

GreenFuel Technologies may be the company nearest deployment of a commercial scale system. They plan to produce 25,000 tons of biomass per year on 247 acres at their facility under development in Spain. It uses flue gasses from a cement plant and is a $92 million investment. (Mees) They also claim it will be eligible for subsidies from the Spanish government, but do not state whether that is necessary for commercial viability.

4.4.3 Others

PetroSun, Diversified Energy Corporation, Texas Clean Fuels, and Solix are also developing microalgae production systems. PetroSun claims commercialization, but is using the racetrack pond method. These companies make very limited data available, which is summarized in Table 4.1.

Table 4.1: Current Microalgae Production Projects

Company	Yield per Acre (*gal*)	Production Cost (*$/gal*)	Net Cost (*$/gal*)
A2BE	1,719	2.56	
PetroSun	1,800		
GreenFuel Technologies	5,500 or 13,158		
Diversified Energy Corporation	1,650 – 3,000		
Texas Clean Fuels	147,000		
Solix	6,181 – 28,947	3.32	1.57

Note: Net cost accounts for the value of co-products.

The figures in Table 4.1 are based on developers' claims and the following computations.

- A2BE: On their Slide 13 (Sears), it says production is 54 kg of oil per MT CO_2 consumed, which equates to $2.56 per gallon. Slide 7 states "Product Generation" is 60 tons per acre per year based on costs of $40/MT CO_2 and 110 MT CO_2/acre-year consumed. A2BE does not indicate if "product" refers to microalgae oil, dry biomass, or total including all co-products. However, 54 kg of oil per MT CO_2 consumed is approximately 60 MT. They also only specify "nutrients" as costs. All other costs are unknown.
- PetroSun: Based on 40 bushels per acre, 1.5 gallons of oil per bushel and 30 times the yield of soy oil. PetroSun doesn't actually claim 30 times. They cite "independent studies." An online article states PetroSun has achieved a yield of 4,000 gallons per acre based on total production of 4.4 million gallons of oil from 1,100 acres of ponds. (Clayton)
- GreenFuel Technologies: Based on 40% oil extraction rate (130 gallons per MT of dry biomass) and company claims of 25,000 MT of biomass per year at a 100-

hectare facility in Spain. (Mees) However, the company's general information states yields should average 5,500 gallons per acre. (GreenFuel) In yet another section on the same page, they state 52,000 MT of CO_2 per year consumed and 1 MT of biomass produced per 1.9 MT of CO_2 consumed. Assuming a 40% oil extraction rate (130 gallons per MT of biomass) results in 14,404 gallons per acre. It is difficult to evaluate this company's claims.

- Diversified Energy Corporation: Based on claims of 22 MT of biomass per acre and 20-30% oil content. The oil content figure is much lower than most other companies. The higher figure for yield is based on their goal of reaching 40 MT of biomass per acre. (Diversified)
- Texas Clean Fuels: Based on claim of 2,500,000 pounds per acre per year. While they admit it is a theoretical upper limit, just 10% of this figure puts them in the upper range of claims. They also claim this can be achieved using 450 MT of CO_2 per year. (Texas)
- Solix: They refer to the 6,181 gallons per acre per year as "the practical maximum," while the 28,947 gallons per acre per year is "the theoretical maximum." They also claim they will achieve 100,000 gallons per acre per year in the future. (Willson)

These systems are representative of systems under development. Other companies are pursuing similar objectives. None have achieved commercialization. It is understandable that they do not publish much of the proprietary supporting data. The claims also involve extrapolation from laboratory, prototype, and pilot scale systems. It is uncertain if the same results will be achieved after scale up to commercialization.

If a developer can achieve anywhere near the yields they claim, microalgae based biodiesel should be competitive on price with petroleum diesel. The National Renewable Energy Lab (NREL) believes that microalgae can achieve high enough yields, that land and other resource requirements are not an issue. (Sheehan, *et al*)

4.5 Vertical Integration

The life cycle inventory study cited in Chapter III indicates that a biodiesel firm could benefit from vertical integration by including the ability to produce its own feedstock. In general, existing biodiesel firms are not vertically integrated. (Van Gerpen) They purchase the feedstock, methanol, and catalyst used to produce biodiesel fuel. Then they sell the fuel to a distributor and market the glycerin co-product as a raw material for other industries. With the exception of a few large companies, such as Cargill and ADM, and a few smaller firms, such as Producer's Choice (Bevill), biodiesel producers are not involved with growing or harvesting the plants or extracting the oil. Vertically integrating the firm improves risk management and increases margins.

4.5.1 Risk Management

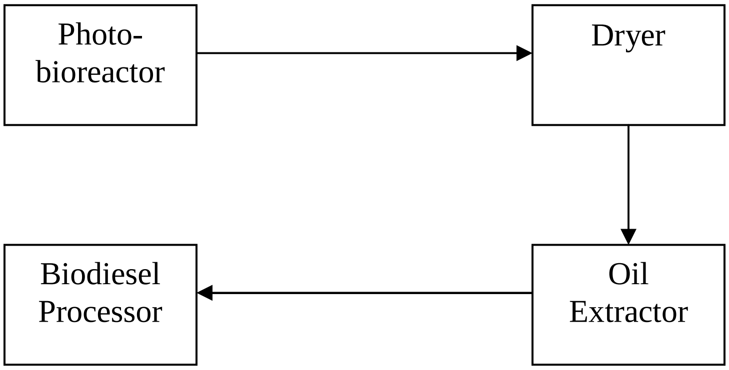
Producing the firm's own feedstock eliminates the risk of high prices associated with procuring it on the open market. It does have downside risk. If the market price for feedstock is below the firm's cost of production, the firm incurs an opportunity cost.

4.5.2 Increased Margins

Producing the firm’s own feedstock keeps costs relatively flat compared to procuring it on the open market. If the firm succeeds in producing its feedstock economically, it will achieve higher gross margins during times of increasing feedstock market prices.

Extracting the oil onsite dramatically reduces transportation costs from the farm to the biodiesel processor. (Bulk Transporter) Onsite pipelines, as opposed to trucks or rail cars, transport the harvested microalgae from the photobioreactor to the dryer, the extractor, and finally to the biodiesel processor.

Figure 4.2: Vertically Integrated Site



High margins attract new market participants. Extraction facilities are the high margin component of the biodiesel system. (Laws) It makes sense for biodiesel producers to vertically integrate.

4.6 Economy of Scale

Biodiesel processing technology generally employs equipment that is minute compared to a petroleum refinery. They are often compact, skid mounted units that may be joined in modular fashion to increase capacity. A good example, which is about 20 feet long, is manufactured by Orbitek in Tulsa, OK.

Figure 4.3: Orbitek, Inc. BPU400

Source: Orbitek, Inc. web site (www.orbitekinc.com)

Existing biodiesel producers have capacities ranging from thousands of gallons per year to 100,000,000 gallons per year (2,381,000 barrels per year). (NBB, “Plants”) Even the largest biodiesel producers are dwarfed by petroleum refineries, which typically produce 5,000,000 gallons per *day*. (EIA, “Petroleum Refineries”) Although it is theoretically possible to link together enough of the modular processors to equal the output of a petroleum refinery, the problem associated with economy of scale lies with the source of feedstock, as discussed above.

So, how can a biodiesel producer mitigate this competitive disadvantage using existing processing technology? Facility planning must optimize production and distribution costs via site selection and configuration.

4.7 Site Selection

There are many factors to consider when determining where to locate a microalgae based biodiesel production facility. State and local regulatory policies weigh heavily on the decision. A review of the policies of all 50 states is beyond the scope of this thesis. We will consider the following.

- Availability of land.
- Source of carbon dioxide.
- Availability of water.
- Access to transportation systems.
- Industrial power rates.

4.7.1 Availability of Land

Even high yield photobioreactors will require substantial acreage. Assuming one can achieve a moderate yield (6,000 gallons per acre) of the estimates shown in Table 4.1, a facility with the capacity to produce 10,000,000 gallons of biodiesel fuel per year would need 1,667 acres of land just for the photobioreactor.

4.7.2 Source of Carbon Dioxide

Microalgae are aquatic plants. Like their terrestrial relatives, they use carbon dioxide for photosynthesis. A photobioreactor large enough to supply a 10,000,000-gallon-per-year biodiesel processor requires a very substantial source of carbon dioxide. The Aquatic Species Program concluded that adequate land and carbon dioxide resources were available. (Sheehan, *et al*) What is crucial, though, is the availability of resources in proximity to one another. For example, coal or gas fired power plants, large breweries, and even ethanol plants are potential sources of the necessary quantities of carbon dioxide, but sufficient land must also be available in the same location.

4.7.3 Availability of Water

Some of the water used to grow the microalgae is lost during the harvest and drying phases. Some of the photobioreactors under development retain and recycle more than others, claiming very low losses. If the facility is located near a power plant, an adequate source of water should be available. Coal and gas fired power plants need water for cooling. The same water source that serves the power plant may be used by the photobioreactor.

4.7.4 Access to Transportation Systems

The facility also needs access to adequate transportation systems for both shipping and receiving. Today biodiesel producers ship their product by truck, rail, and barge. Barge is the cheapest of the three at about 4 cents per gallon, but is also the least accessible. Transport via truck averages about 20 cents per gallon, and rail averages about 10. (Bulk Transporter) Shipping a 30,000-gallon tank car (Dow) from Tulsa to Denver with BNSF Railway Company costs $2,809, or 10.7 cents per gallon. (BNSF) CSX Corporation charges $2,831 from Memphis to Chicago. (CSX, "Price List") However, this does not include the cost of leasing the tank car, which is the common business practice. (CSX, "Description")

If the facility achieves adequate scale, it could use existing petroleum pipelines to transport biodiesel. Typical minimum batch sizes are 25,000 barrels. (Colonial, "Rules") Pipeline operators must first work out some issues associated with shipping the blended fuel. (Baker) Kinder Morgan recently shipped 20,000 barrels of B5 from Mississippi to South Carolina via pipeline. (Reuters) That required 1,000 barrels of B100, which represents a little less than two days' worth of production at a 10,000,000-gallon-per-year biodiesel facility. Shipping via pipeline could reduce transportation costs by as much as 90% compared to truck. (Bulk Transporter and Colonial, "Local") Assuming it costs the same to transport biodiesel via truck as it does to transport ethanol, the Competitive Enterprise Institute's analysis of ethanol transportation costs is useful. Their analysis concluded that transportation via truck adds 14 to 17 cents per gallon to the retail price of fuel as compared to transportation via pipeline. (Avery)

4.7.5 Industrial Power Rates

The equipment necessary for drying the harvested biomass and extracting the oil is also under development. Existing oilseed presses can extract the oil from microalgae, but they are not as efficient as they are with oilseed crops. Centrifugation is an elegant method for drying, but to date has not been cost effective due largely to very high power consumption. Consequently, it is difficult to quantify the power requirements for operating the equipment. It will be substantial, if only due to the expected size and number of pumps required to circulate the water in the photobioreactor. Facilities located in states with lower industrial power rates will be more competitive. See Appendix D for industrial power rates by state.

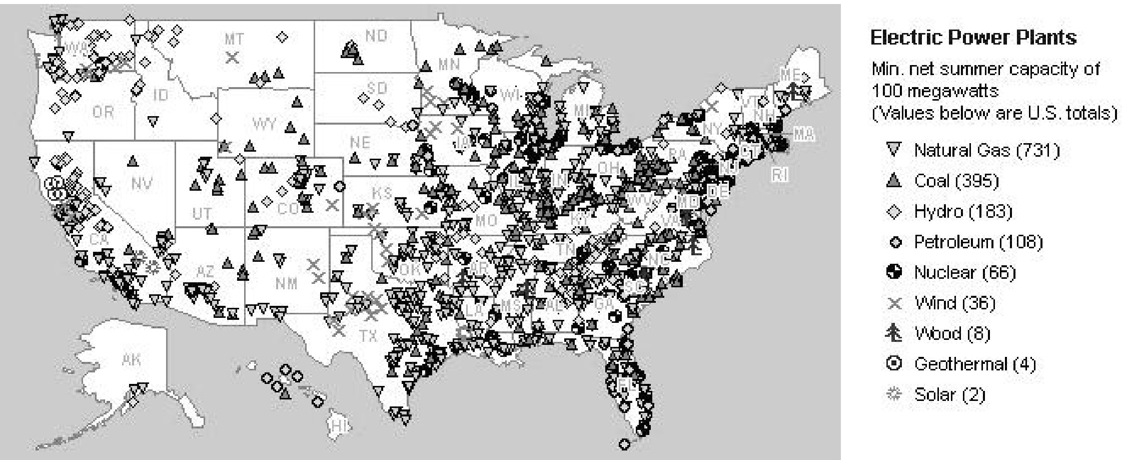
4.7.6 Summary

It follows, then, the hypothetical firm's facility would be ideally located next to a large coal or gas fired power plant with approximately 2,000 acres of vacant land adjacent in an area with high solar potential. The ideal site would also be as close as possible to an existing petroleum products pipeline (if not co-located, perhaps close enough to build a lateral line). If pipeline tariffs do not allow B100 due to minimum batch sizes or compatibility issues, a blending facility must also be close by. Low rates for industrial power are also important. The climate should include mild winters to allow year round microalgae production without the need for climate control equipment.

4.8 Site Evaluation

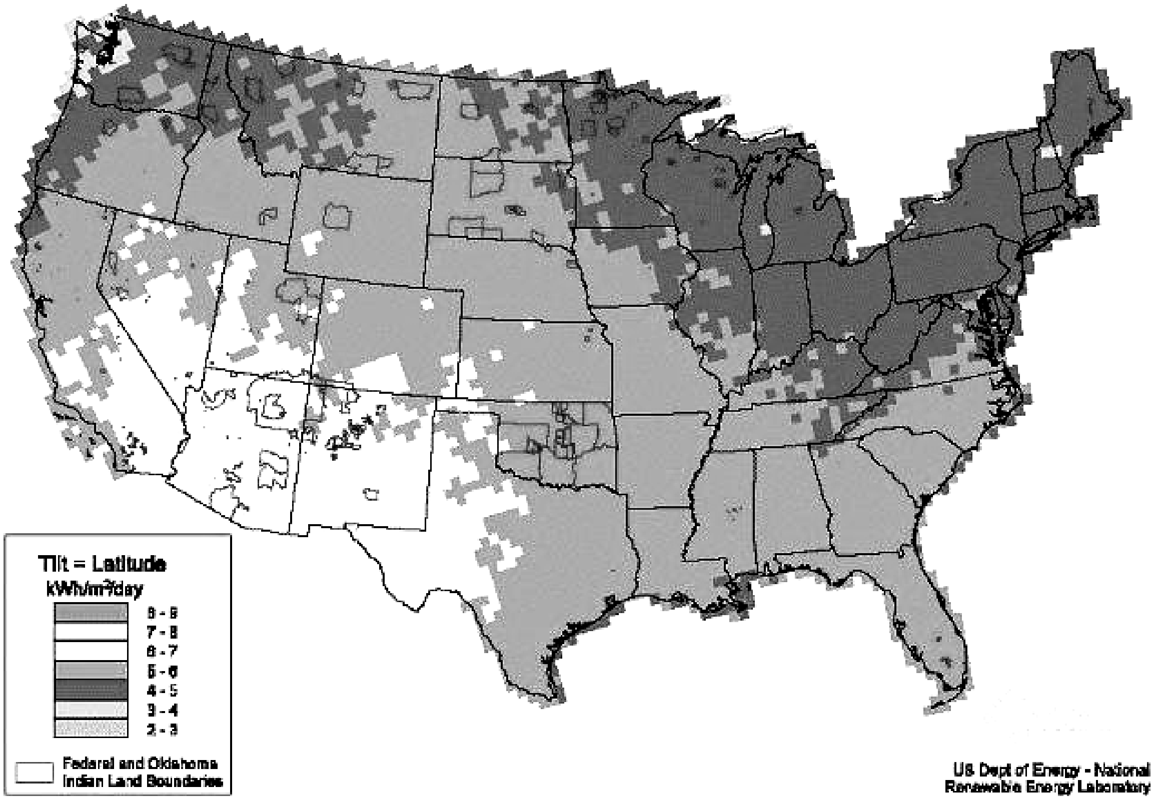
Figures 4.4 and 4.5 show the location of major coal and gas fired power plants and solar potential. Initially Arizona appears to be a good location. Kinder Morgan is the only petroleum products pipeline serving the area. (Office of Arizona Governor; see also Figure 6.2.) A review of Kinder Morgan's Tariffs revealed that the pipelines serving Phoenix from the east (Kinder Morgn, "FERC No. 173") and west (Kinder Morgan, "FERC No. 171") both flow into Phoenix. Therefore, transportation via existing petroleum products pipeline will not be possible, if the facility is located in Arizona, with the possible exception of Tucson.

Figure 4.4: U.S. Electric Power Plants



Source: EIA, “Power Plants.”

Figure 4.5: Solar Potential



Source: EIA, “Solar Potential.”

Shipping via rail or truck could be cost effective, if the facility is located close enough to a petroleum products terminal. Kinder Morgan’s terminal in Phoenix has rail and truck offload capability. (Kinder Morgan, “Phoenix Terminal”) Although their terminal in Tucson is called a petroleum products terminal, only ethanol offload capabilities are specified. (Kinder Morgan, “Tucson Terminal”)

A review of coal and gas fired power plants in Arizona determined the following candidate locations. (APS) All are wholly or partly owned by APS.

Table 4.2: Coal and Gas Fired Power Plants in Arizona

Name	Location	Size (*MW*)	Fuel	Distance to Terminal (*mi*)
Cholla	Holbrook	995	Coal	192
Navajo	Page	2,250	Coal	278
Redhawk	Palo Verde	1,060	Gas	55
West Phoenix	SW Phoenix	1,000	Gas	Unknown
Four Corners	Fruitland, NM	2,040	Coal	410

Note: All distances, except from Redhawk, computed using www.mapquest.com.

The West Phoenix plant is located in southwest Phoenix. Although an aerial view is not available, it is unlikely that sufficient unimproved land is available for the photobioreactor. The Redhawk plant is the best candidate, since it has both adequate unimproved land and is a short drive for truck transport. However, APS is already working with GreenFuel Technologies to install a photobioreactor at the Redhawk plant. (Gotfried and Bane)

The Cholla plant is next closest. To estimate the cost to deliver B100 by truck to Kinder Morgan's Phoenix terminal, assume $100,000 per year for labor and equipment, 330 operating days per year, one trip per day per truck, $2.50 per gallon fuel cost, 5 mpg, and 7,200 gallons per delivery. The cost to transport via truck is 6.9 cents per gallon of B100 delivered. This compares to 2.9 cents per gallon for 2 trips per truck per day from Redhawk and 9.9 cents per gallon from Four Corners (plus any additional for overnight requirements). According to BNSF, it would cost $1,829 to ship a 30,000-gallon rail car (6.1 cents per gallon) from Holbrook to Phoenix. (BNSF) This excludes the cost of leasing the rail car. The climate at Holbrook could present a problem. Winter temperatures could be too cold for maximum microalgae production year round.

Although APS is actively partnering with GreenFuel Technologies to install microalgae systems at their power plants, the Four Corners and Cholla plants have generating units owned by other companies. (APS)

Unfortunately, the location of suitable power plants does not make it possible to co-locate the photobioreactor and blending operations with a pipeline terminal (at least in Arizona, where solar potential is the greatest).

An additional candidate site is Desert Rock, which is a 1,500-MW coal fired plant under construction 30 miles west of Farmington, New Mexico, on Navajo lands. (Desert Rock, "FAQ") It has vast uninhabited land surrounding it. It is also an ideal candidate in that the owners are actively seeking to incorporate carbon capture and sequestration. It is 390 miles from the Phoenix terminal. Water could be an issue, but the developers plan to use a non-potable source from deep wells for cooling. A thorough test is necessary to ensure the microalgae could survive in an environment that includes whatever it is that makes this water source non-potable. Desert Rock Energy Project is a joint venture between Sithe Global Power, LLC and Diné Power Authority (a Navajo Nation enterprise). (Desert Rock, "Homepage")

The above discussion is by no means an exhaustive evaluation of potential sites. It is a preliminary analysis of a few possible locations.

CHAPTER V

ECONOMIC OUTLOOK

In order to compare the hypothetical biodiesel firm in Chapter IV to existing petroleum diesel firms, we must first consider a few relevant projections: demand for petroleum diesel, refining capacity, and the cost and supply of crude oil.

5.1 Demand for Petroleum Diesel

The EIA projects U.S. demand for petroleum diesel at 3.854 million barrels per day for 2009, continuing the downward trend which began in February 2008. They project demand will begin to increase February 2010 and end that year with an aggregate of 3.906 million barrels per day. (EIA, "CTB")

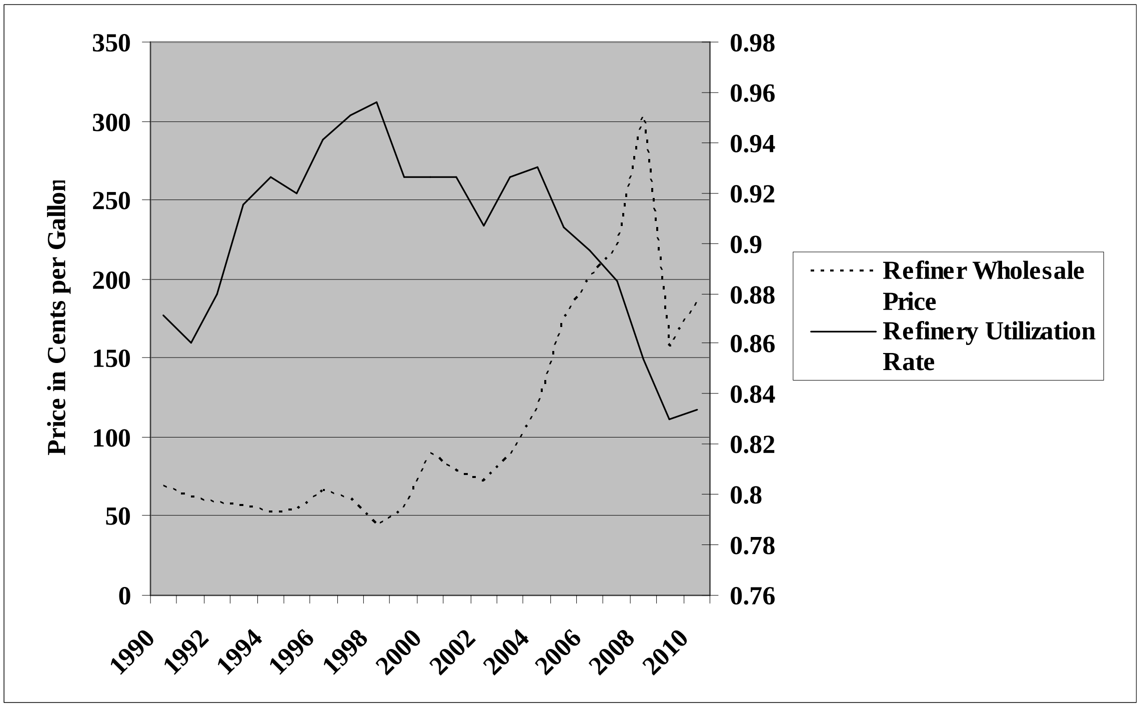
The EIA's data for 2008 indicates the U.S. became a net exporter of diesel fuel for the first time since 1995. (EIA, "CTB") The STEO (October 2008) claimed that growth in worldwide demand for distillates led to diesel fuel prices increasing faster than crude oil prices throughout 2008. However, it is uncertain which prices they meant—wholesale or retail; certain sectors or weighted averages. The prices relevant to this thesis are the refiner average crude oil acquisition cost and the refiner wholesale price of the diesel fuel. Using the more recent STEO of February 2009, there is no such relationship between the refiner wholesale price and the refiner average crude oil acquisition cost during 2008. (See Appendix E) The EIA's longer term Annual Energy Outlook (AEO) predicts different demand and price levels for 2009 and 2010, but they do not differ substantially from the STEO. The AEO predicts steady growth in demand and prices thereafter. The International Energy Agency forecasts similar steady growth in worldwide demand. (IEA, "World Energy Outlook")

5.2 Refining Capacity

The EIA explains there is an interesting relationship between refining capacity and worldwide demand for diesel. (EIA, "Diesel Fuel Prices") As refinery utilization rates increase above 90%, international demand exerts increasingly greater influence on U.S. prices.

During the 1980's and 1990's no new refineries were built. Domestic demand for petroleum products increased about 17% since 1995, but refinery expansions only increased capacity by 10%. (Federal Trade Commission) Until recently refining capacity has not affected diesel prices very much (Fig. 5.1). Refining capacity can become a bottleneck in the supply chain, as demonstrated by the refinery shut-ins following hurricanes Katrina, Rita, Gustav, and Ike, which contributed to price increases. (EIA, "Katrina," "Rita," "Gustav," and "Ike") Figure 5.1 is a little misleading, because the utilization rate is based on nameplate rating, rather than available (reduced) capacity.

Figure 5.1: Refiner Wholesale Price and Refinery Utilization Rate



Sources: EIA, “STEO February 2009.”

In the summer of 2005, ICF Consulting examined the International Energy Agency’s (IEA) data for 2000 through 2020, regarding demand and refining capacity. They correctly forecasted the dramatic price increases seen in 2008, and attributed them to tight refining capacity. They concluded that an additional 30-40 world scale refineries with an aggregate capacity of 8 million barrels per day were necessary just to keep pace with steady growth through 2010. In order to maintain the surplus capacity rates experienced from 1990 to 2000, the number of new refineries required increases to 50 – 70. Their point of emphasis is that those refineries should “already be in the engineering phase to be operational by 2010.” (Rosenberg and O’Connor)

Since 2005, only 2 refineries have been built, increasing U.S. refining capacity by 468,977 barrels per day. (EIA, "Petroleum Refineries") Worldwide refinery start ups should add 8.8 million barrels per day by 2013. (IEA, "Despite")

A prediction ICF made in 2005, regarding the potential for refining capacity to become a bottleneck in the supply chain sounds ominous and may have begun to play out in 2008.

> "Barring a radical and immediate initiation of major refinery projects, there will be a competition for available supply as the decade draws to a close. The 'winning' bidders will pay a premium for products which could make today's prices look very reasonable; the 'losers' may be required to slow down economic growth. The overall effect of both may be that global economies will suffer until refinery capacity gets back in alignment with demand." (Rosenberg and O'Connor)

The scenario depicted by ICF's assessment will have a much more enduring effect on diesel prices than the refinery shut-ins caused by the hurricanes. Restoration of the shut-in capacity took much less time than it will take to design, permit, and build new capacity on the scale needed. Interestingly, in 1996, the EIA stated that due to the operating characteristics of a petroleum refinery, the importance of capacity constraints "only becomes apparent when refiners push to the last few increments of capacity, and then the results can be dramatic." (Hackworth and Shore, "Petroleum") This is supported by the regression analysis in Table 5.1, which indicates refinery distillate utilization factor is statistically insignificant, even though common sense tells us that lack of capacity can create a supply shortage.

ICF's projections weren't perfect. They expected imports to increase. (Rosenberg and O'Connor) As mentioned above, the U.S. became a net exporter of distillates in 2008, and is projected to remain so through at least 2010.

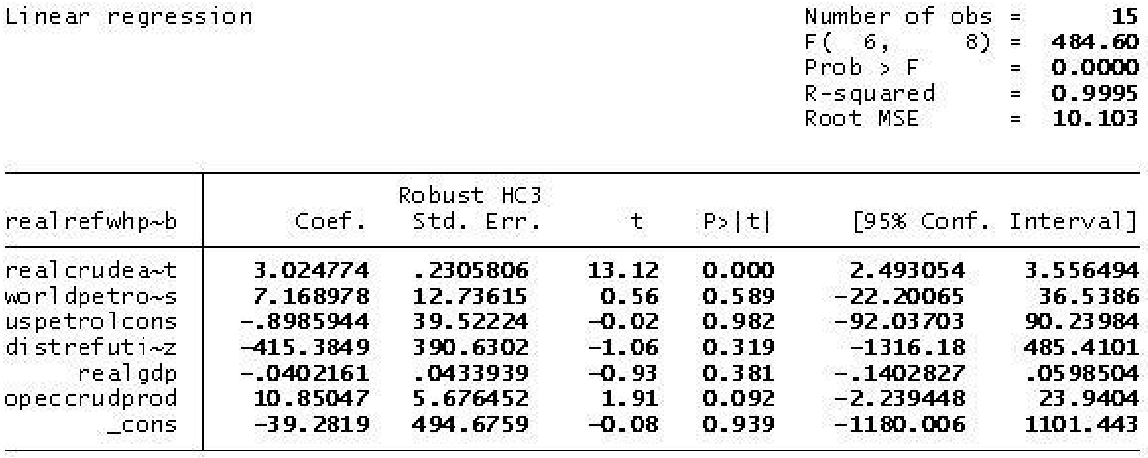
China is significantly increasing its own refining capacity through 2012, but it is directed at satisfying domestic demand. It is not likely to result in a significant increase in exports. (Yang)

It appears that, even though the supply of crude oil (discussed below) may be adequate, refining capacity could again become a bottleneck as the U.S. economy recovers.

5.3 Cost and Supply of Crude Oil

The price of diesel fuel is heavily dependent upon the price of crude oil. A least squares regression of real refiner wholesale price on real crude oil acquisition cost (holding constant world petroleum consumption, U.S. petroleum consumption, refinery distillation utilization factor, real GDP, and OPEC crude oil production) using STATA yields the following.

Table 5.1: STATA Output from Regression of Real Refiner Wholesale Price on Real Crude Oil Acquisition Cost



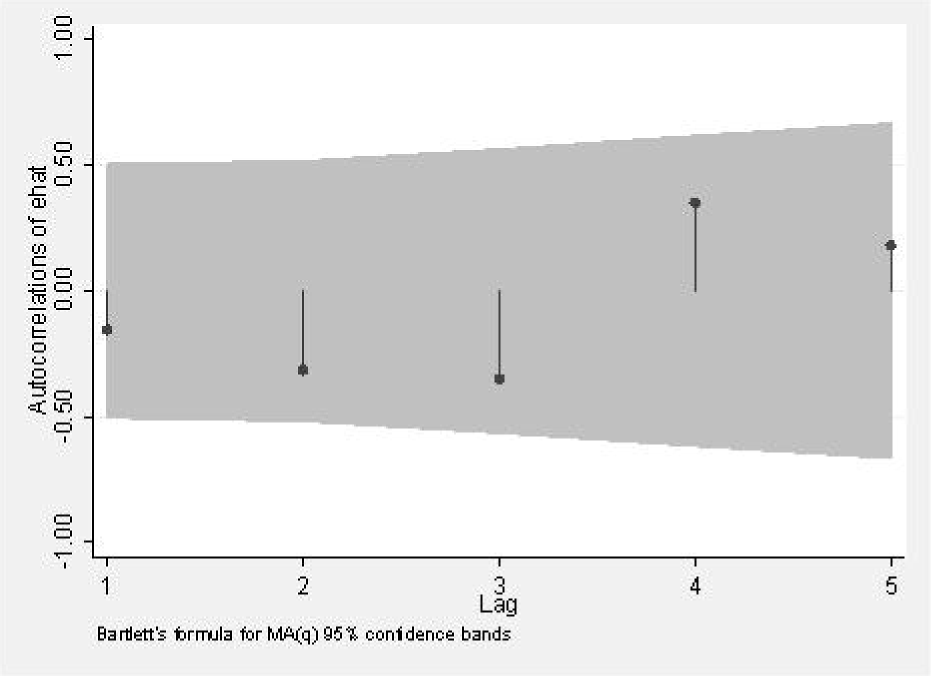
```
Linear regression                                      Number of obs =      15
                                                       F(  6,     8) =  484.60
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9995
                                                       Root MSE      =  10.103

------------------------------------------------------------------------------
             |             Robust HC3
realrefwhp~b |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
realcrudea~t |   3.024774   .2305806    13.12   0.000     2.493054    3.556494
worldpetro~s |   7.168978   12.73615     0.56   0.589    -22.20065     36.5386
uspetrolcons |  -.8985944   39.52224    -0.02   0.982    -92.03703    90.23984
distrefuti~z |  -415.3849   390.6302    -1.06   0.319     -1316.18    485.4101
     realgdp |  -.0402161   .0433939    -0.93   0.381    -.1402827    .0598504
opeccrudprod |   10.85047   5.676452     1.91   0.092    -2.239448     23.9404
       _cons |  -39.2819    494.6759    -0.08   0.939    -1180.006    1101.443
------------------------------------------------------------------------------
```

The regression is based on EIA annual data from 1994 to 2008 using the Custom Table Builder in the Short Term Energy Outlook of February 2009. Real dollars were calculated using the CRB Index. See Appendix F for input data.

Only real crude oil acquisition cost is statistically significant. The regression indicates that on average a one-dollar increase in the cost of crude oil will result in a 3.02-cent per gallon increase in the price the refiner receives for the diesel fuel.

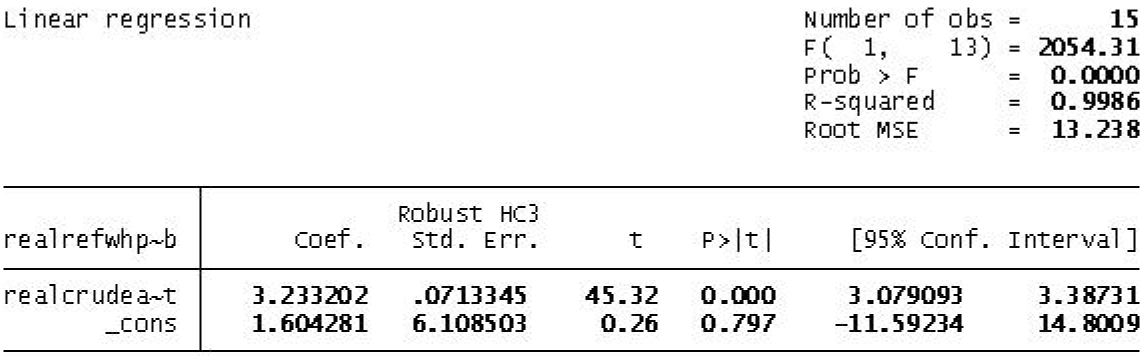
Since panel data is subject to autocorrelation, we must test to see if the heteroskedasticity-robust standard errors are sufficient, or if we must use heteroskedasticity- and autocorrelation-consistent standard errors. STATA provides the answer graphically in Figure 5.2. Since all the points are within the shaded area, none are significant at the 5% level. Therefore, heteroskedasticity-robust standard errors are sufficient, and we may use the results of the regression above.

Figure 5.2: Autocorrelation Test Results



If we modify the regression, such that none of the other variables are included, the coefficient for real crude oil acquisition cost changes only slightly to 3.2.

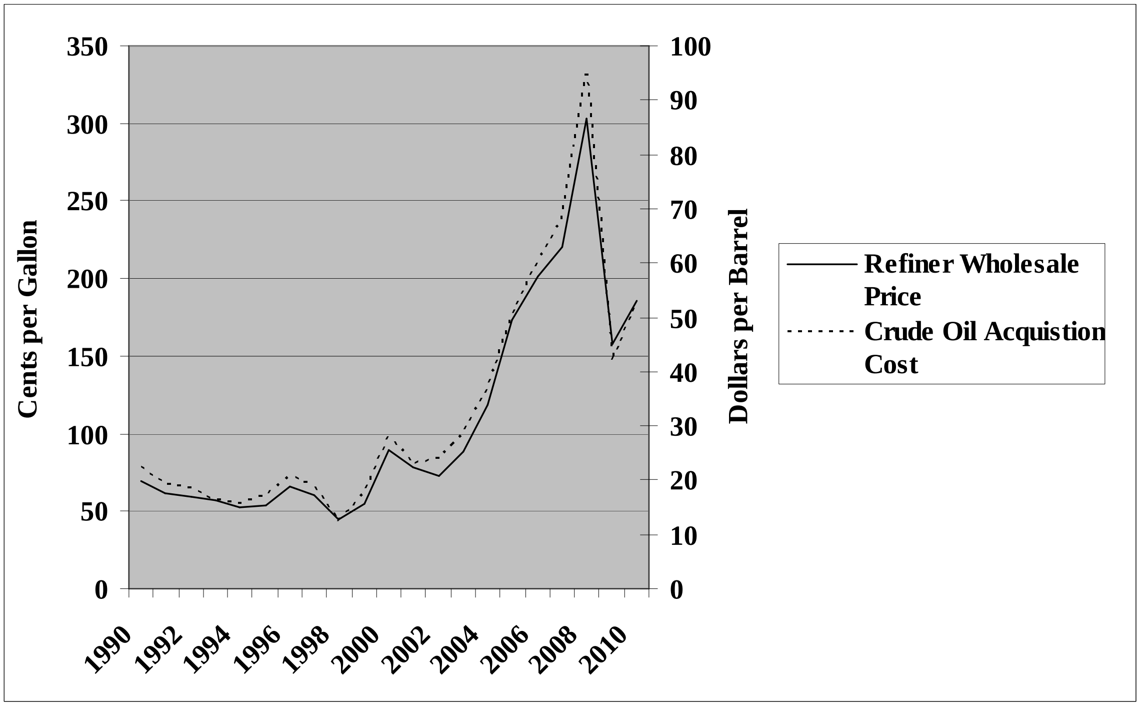
Table 5.2: STATA Output from Regression of Real Refiner Wholesale Price on Real Crude Oil Acquisition Cost (Modified)



```
Linear regression                                      Number of obs =      15
                                                       F(  1,    13) = 2054.31
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9986
                                                       Root MSE      =  13.238

------------------------------------------------------------------------------
             |             Robust HC3
realrefwhp~b |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
realcrudea~t |   3.233202   .0713345    45.32   0.000     3.079093     3.38731
       _cons |   1.604281   6.108503     0.26   0.797    -11.59234     14.8009
------------------------------------------------------------------------------
```

Figure 5.3 shows how closely the price the refiner receives for diesel fuel follows the cost of acquiring the feedstock.

Figure 5.3: Refiner Wholesale Price Follows Crude Oil Price



Source: Energy Information Administration (EIA, “CTB”).

Prices for West Texas Intermediate (WTI) fell precipitously from $133 per barrel in July 2008 to $41 per barrel in December 2008 (EIA, “CTB”). Prices should level off in 2009, averaging $43 per barrel, and increase to an average of $55 per barrel in 2010. (EIA, “STEO Feb 09”) Forecasting prices over a 2-year horizon is very difficult. As recently as the October 2008 STEO, the EIA believed prices would average $112 per barrel in both 2008 and 2009. They did qualify this by adding, “Absent a major worldwide economic downturn that significantly impacts global demand…,” which evidently occurred.

The drop in prices followed the drop in demand, and OPEC responded accordingly (EIA, "STEO Feb 09"). OPEC cut crude production by about 1 million barrels per day by the end of 2008. The EIA expects additional cuts totaling 1.6 million barrels per day in the first quarter of 2009. This represents a significant downward revision of daily production from the October 2008 STEO estimates. Consistent with their WTI price projections, they also expect OPEC to begin increasing production in 2010. The EIA also believes that OPEC's lack of surplus production capacity played a major role in the dramatic increase in the price of crude oil during the first half of 2008. The recent and projected cuts in production should bring OPEC's surplus production capacity to 5 million barrels per day as compared to an average of 1 to 2 million barrels per day during the 5 years preceding the price run-up. This should help keep prices stable during any supply disruptions and the economic recovery expected in 2010. (EIA, "STEO Feb 09") OPEC's surplus production capacity is crucial, because its member countries account for virtually all of the world's surplus capacity. (EIA, "Diesel Fuel Prices")

For the first time since 1991, the EIA expects domestic crude oil production to increase in 2009, and again in 2010 (EIA, "CTB").

5.4 Price of Petroleum Diesel

Given the above factors, we can expect the refiner wholesale price of diesel fuel to gradually increase during the balance of 2009 and throughout 2010.

The refiner wholesale price averaged $3.03 per gallon in 2008 and is projected to average $1.57 in 2009 and $1.86 in 2010. The EIA also expects refining margins to narrow as retail prices average $2.28 per gallon in 2009 and $2.55 in 2010, while U.S. demand declines and worldwide demand growth slows. (EIA, “STEO Feb 09”)

5.5 Other Factors

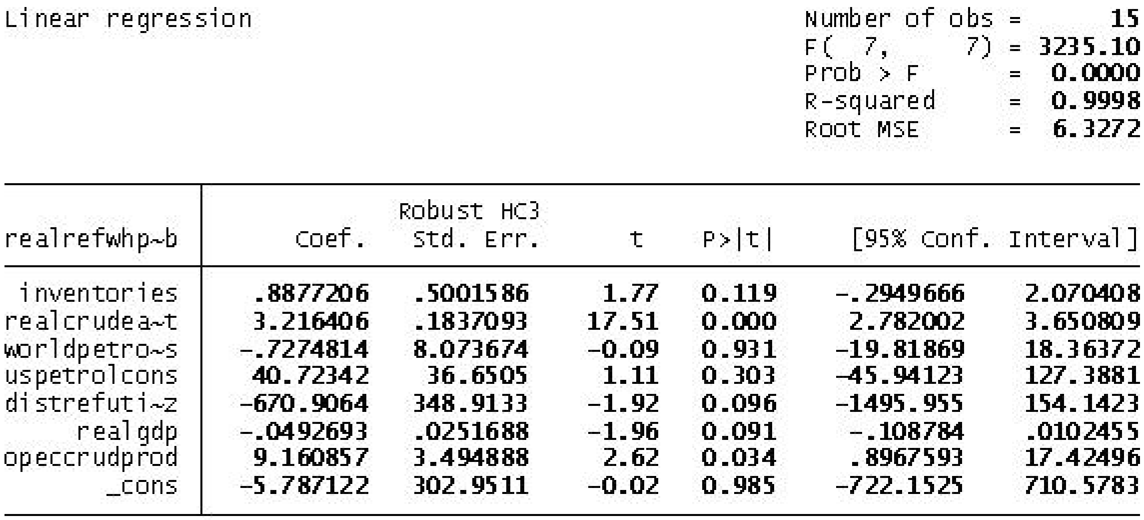
5.5.1 ULSD Phase In

Costs associated with the transition to ULSD (not the additional costs to produce ULSD) should have little continuing effect on petroleum diesel prices. With the phase in of ULSD largely complete by 2010 (Hackworth and Shore, “Ethanol”), any costs borne by the petroleum diesel firm associated with multiple grades of diesel, should be essentially eliminated by the time a new biodiesel facility could be operational.

5.5.2 Inventory Levels

The National Petroleum Council cautions that, although U.S. petroleum inventories respond to market forces, there is little correlation between inventories and prices. The interaction is complex, and should not be used to forecast prices. (Shackouls) A regression of real refiner wholesale price on inventories (holding constant real crude oil acquisition cost, world petroleum consumption, U.S. petroleum consumption, refinery distillate utilization factor, real GDP, and OPEC crude oil production) using STATA and the same data set (plus inventories) as Table 5.1 agrees that inventories are not statistically significant (Table 5.3).

Table 5.3: STATA Output from Regression of Real Refiner Wholesale Price on Distillate Fuel Oil Inventories



```
Linear regression                                      Number of obs =      15
                                                       F(  7,     7) = 3235.10
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9998
                                                       Root MSE      =  6.3272

------------------------------------------------------------------------------
             |             Robust HC3
realrefwhp~b |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 inventories |   .8877206    .5001586     1.77   0.119    -.2949666    2.070408
realcrudea~t |   3.216406    .1837093    17.51   0.000     2.782002    3.650809
worldpetro~s |  -.7274814    8.073674    -0.09   0.931    -19.81869    18.36372
uspetrolcons |   40.72342     36.6505     1.11   0.303    -45.94123    127.3881
distrefuti~z |  -670.9064    348.9133    -1.92   0.096    -1495.955    154.1423
     realgdp |  -.0492693    .0251688    -1.96   0.091     -.108784    .0102455
opeccrudprod |   9.160857    3.494888     2.62   0.034     .8967593    17.42496
       _cons |  -5.787122    302.9511    -0.02   0.985    -722.1525    710.5783
------------------------------------------------------------------------------
```

5.6 Summary

The economic outlook indicates that the competitive environment for biodiesel in the short term will be comparable to years other than 2007 and 2008. As the U.S. economy commences its recovery, the competitive environment for biodiesel should improve as petroleum prices steadily increase.

Of course, all of these projections are based on a recovery beginning some time in 2010. Prices will deviate from this base case depending on the severity and duration of the recession and actions by OPEC and other major crude oil producers. (EIA, “STEO Feb 09”)

CHAPTER VI

THE HYPOTHETICAL FIRM COMPARED TO PETROLEUM FIRMS

6.1 Introduction

Biodiesel faces a formidable task. The petroleum industry enjoys significant competitive advantage due to its scale and cost structure.

The EIA includes the following as the costs to produce and deliver diesel fuel to the customer: "crude oil, refinery processing, marketing and distribution, and retail station operation." (EIA, "Diesel Fuel Prices") Since biodiesel will be sold by the same retailers that currently sell petroleum diesel, we assume the costs to the retailer are identical. The cleaning properties of biodiesel may dislodge impurities in the retailers' tanks and pumps, resulting in some initial cost to convert to biodiesel. However, we assume this cost to be nominal and limited to frequent filter replacement until dislodged impurities are removed. The potential need to educate the public on the merits of biodiesel notwithstanding, we also assume the cost of marketing biodiesel is identical to that of petroleum diesel.

Supply shortages resulting from refinery outages, transportation issues, adverse weather conditions, or pipeline problems also affect prices in the short-run. (API, "Facts") All of these are true or analogous for biodiesel, as well. Therefore, they do not contribute to any distinction between a biodiesel producer and petroleum diesel producer.

Tax policies at all levels of government can change on an annual basis. Therefore, we assume the taxes on biodiesel and petroleum diesel are identical. If biodiesel succeeds in the market place and shows evidence that it can compete without government intervention (the scenario considered in this thesis), there will be no incentive to continue any tax policies favorable to biodiesel.

Consequently, there are 4 areas in which to compare costs for the hypothetical biodiesel firm and a petroleum diesel firm: 1) feedstock 2) processing (refining) 3) distribution and 4) capital.

6.2 Feedstock Costs

The projected production costs for the microalgae projects listed in Table 4.1 vary widely and are unverifiable, sometimes even indeterminable. However, the entrepreneur will have access to the actual data for a given project. This section provides a basis from which to evaluate a biodiesel project.

As mentioned above, the refiner wholesale price of petroleum diesel tends to follow that of feedstock (crude oil). Some of the firms that produce petroleum diesel, such as ExxonMobil (www.exxonmobil.com) are vertically integrated from exploration and production all the way through to retail sales. These companies are not subject to the risk of high prices associated with procuring their feedstock on the open market. However, they are subject to downside price risk and incur an opportunity cost, if the market value of the crude oil falls below their cost to produce it. Other companies, such as Valero Energy Corporation (www.valero.com), do not produce their own crude oil. They purchase it on the open market to supply their refineries. These firms are subject to the risk of high procurement prices. The hypothetical firm produces its own feedstock. It is not exposed to high procurement prices. The business model is similar to that of vertically integrated petroleum firms.

Since the hypothetical firm must build feedstock production from scratch, capital costs must be offset by reduced operating costs, as compared to existing biodiesel firms, which do not produce their own feedstock. Capital costs and operating costs represent a cost bundle. A rational investor is indifferent among alternative bundles that produce the same return. The objective is to design production in which the combination of capital costs and operating costs is minimized. The petroleum refiner's crude oil acquisition cost ($68.09 per barrel—$1.62 per gallon—in 2007, per the February 2009 STEO CTB) is the benchmark. Capital costs are discussed more fully in Section 6.5.

6.3 Processing (Refining) Costs

The EIA reports petroleum refiners' margin was $4.78 per barrel in 2007. Of course, petroleum refiners produce more than just diesel fuel. We will assume the margin of $4.78 per barrel ($0.114 per gallon) of aggregate products applies to a barrel of diesel fuel. Total variable costs of $82.00 ($1.95 per gallon) (EIA, "Table T18") less $68.09 ($1.62 per gallon) for the crude oil, means all other variable costs were $13.91 per barrel ($0.331 per gallon).

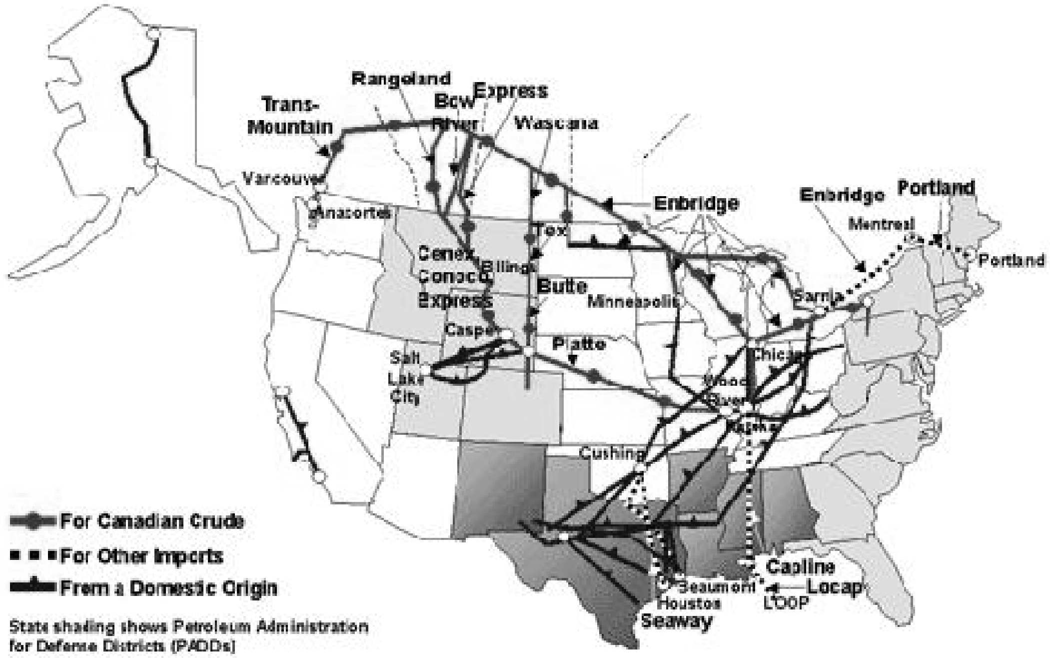
The hypothetical firm employs the same processing equipment for trans-esterification as do existing biodiesel firms. Therefore, production costs are the same. Using Radich's methodology, but updating the input costs based on November 2008 EIA reports on national average retail prices of natural gas and electricity industrial customers, total biodiesel production costs other than feedstock are $0.584 per gallon. This is based on $7.20 per thousand cubic feet of natural gas (EIA, “Industrial Price”) and 7.06 cents per kilowatt-hour of electricity (EIA, “Retail Price of Electricity”) using the EIA’s natural gas conversion calculator. (EIA, “Calculator”)

Thus, the hypothetical firm suffers a competitive disadvantage of $0.253 per gallon. Adjusting for the 11 per cent lower energy content in biodiesel (Radich), the net difference is $0.281 per gallon.

6.4 Distribution Costs

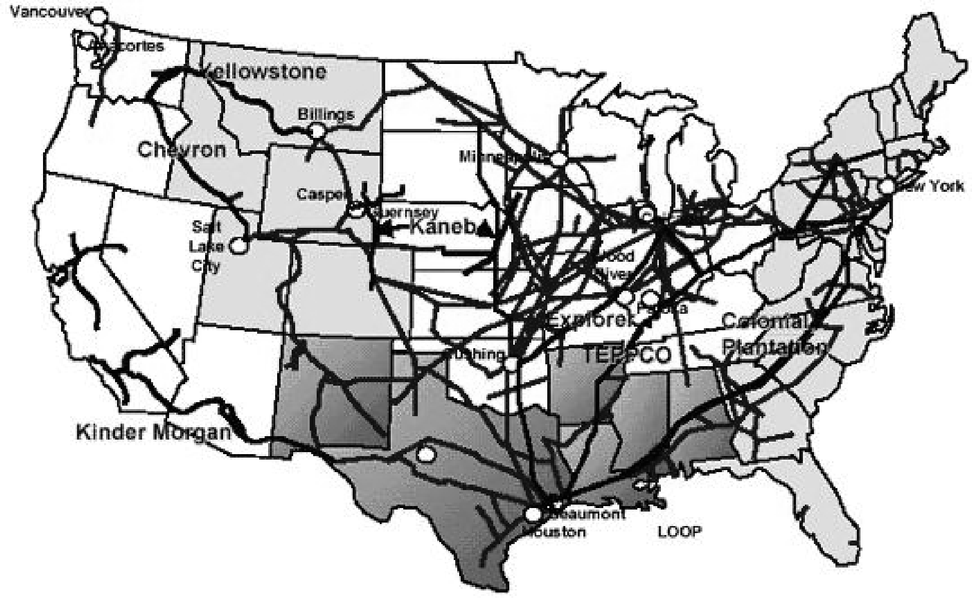
The petroleum diesel distribution system consists of approximately 50,000 miles of crude oil trunk lines (Fig. 6.1) and another 30,000 to 40,000 miles of gathering pipelines. (API, “Crude”) There is an additional 95,000 miles of petroleum products pipelines that transport refined products, such as diesel fuel, from refineries to terminals or local distribution centers (Fig. 6.2). (API, “Petroleum”) There are approximately 1,500 to 2,000 petroleum product bulk terminals. (Hadder and McNutt) They are generally located near major urban areas and receive fuel from refineries primarily by pipeline with the balance received by rail or barge. (EIA, “Diesel Fuel Prices”) There are also around 10,000 smaller petroleum product bulk plants in the secondary distribution system. Over-the-road tanker trucks haul to retailers at distances usually not exceeding 100 miles. Hauling biodiesel by truck at distances greater than that could add as much as 10 cents per gallon. (Hadder and McNutt)

Figure 6.1: Major Crude Oil Pipelines



Source: American Petroleum Institute and Association of Oil Pipelines (API, "Crude").

Figure 6.2: Major Refined Products Pipelines



Source: American Petroleum Institute and Association of Oil Pipelines (API, "Petroleum").

The hypothetical firm does not participate in the supply chain downstream from the distributor. Therefore, a comparison of distribution costs between the hypothetical firm and a petroleum diesel firm consists of costs incurred from the feedstock production site (microalgae photobioreactor or crude oil well) to the processor (refinery), and shipping costs incurred from there to the delivery point. For the hypothetical firm the delivery point is the distributor. For the petroleum firm the delivery point is the terminal, which the Bureau of Labor Statistics (BLS) states is the most common for the petroleum refining industry. (BLS, "PPI for Refining")

Distribution costs for transportation from the crude oil well to the petroleum refinery are captured in the "Refiner Average Crude Oil Acquisition Cost" data in the STEO of February 2009. Therefore, they are ignored in this section. However, for reference purposes, the Association of Oil Pipelines states that it costs about 2.5 cents per gallon to ship crude oil "across country." (API, "Small Price")

Microalgae production is co-located with the processor. We assume onsite transportation is nominal.

The hypothetical firm's delivery cost to the distributor is based on the location data from Chapter IV and is $0.061 per gallon. Table 6.1 summarizes distribution costs for the two firms.

Table 6.1: Comparative Distribution Costs (*cents per gallon*)

Segment	Hypothetical Biodiesel Firm	Petroleum Diesel Firm
Feedstock Production Site to Processor (Refiner)	$0.00	Included in crude oil acquisition cost.
Processor (Refiner) to Distributor/Terminal	$0.061	$0.020

Note: Costs from refinery to terminal for the petroleum diesel firm is based on Colonial Pipeline Tariff for shipping from Houston to Birmingham (roughly mid-way on the system). (Colonial, "Local")

6.5 Capital Costs

Comparison of capital costs is difficult, because the costs incurred by the hypothetical firm are different than the petroleum firm's. Further complicating the task is the fact microalgae production via photobioreactors is still in development. Developers are understandably reluctant to part with cost data. Consequently, it is not possible to determine the most significant single capital cost: the photobioreactor.

We can still make a useful comparison of costs. The question is whether the start up firm can employ its capital in such a way, that it can achieve the required rate of return while competing with the petroleum firm on price. This is more appropriate than a direct comparison of capital costs.

As of September 29, 2008, total biodiesel production capacity in the U.S. is 2.61 billion gallons per year at 176 plants (NBB, "Plants") with an additional 195,000,000 gallons per year under construction at 39 new plants and one plant expansion. (NBB, "Construction") Total production in 2007, was 491,000,000 (Alternative Fuels and Advanced Vehicles Data Center) and was projected at 766,500,000 for 2008. (EIA, "AEO") Total production capacity is more than double the ambitious federal mandates calling for 1 billion gallons of annual biodiesel consumption by 2012. (Carriquiry and Babcock) The excess capacity could allow the hypothetical firm to purchase an existing facility. Some producers are shutting down (Carriquiry and Babcock), so it may be possible to purchase a facility much more cheaply than building a new one. Of course, a candidate facility is subject to the location constraints in Chapter IV. Considering the location of biodiesel processors has traditionally been near farms or oilseed crushing facilities, it is unlikely an existing facility will meet those criteria, in particular, proximity to a substantial source of carbon dioxide.

The hypothetical firm has well defined disadvantages in processing and distribution costs (Table 6.2). The firm must also reduce feedstock costs enough to offset the higher processing and distribution costs.

Table 6.2: Cost Competitiveness

Item	Hypothetical Biodiesel Firm (*$ per gallon*)	Petroleum Diesel Firm (*$ per gallon*)
Feedstock Costs	Unknown	1.621
Processing or Refining Costs	0.584	0.331
Distribution Costs (upstream)	0.000	(Note 1)
Distribution Costs (downstream)	0.061	0.020 (Note 3)

Notes:

1. Upstream costs are those incurred for shipping from crude oil well to refinery. They are included in the cost of feedstock for the petroleum refiner, but are similar to downstream costs.
2. Downstream costs are those incurred for shipping from processor (or refinery) to delivery point.

3. Based on Colonial Pipeline Tariff for shipping from Houston to Birmingham (roughly mid-way on the system). (Colonial, “Local”)
4. Petroleum feedstock and refining costs are based on figures from 2007.

CHAPTER VII

FINDINGS

7.1 Introduction

Biodiesel has advantages over other alternative fuels. In particular, it works in existing diesel vehicles without the need to modify the engines. Its performance is similar enough to the fuel it replaces, that vehicles using biodiesel can use the existing refueling infrastructure without concern for operating range. (Hadder and McNutt) Therefore, given the availability of cold weather additives, the only real obstacle for biodiesel is competitive pricing.

7.2 Financial Objective

The hypothetical firm must achieve competitiveness through major reductions in the cost of feedstock. An entrepreneur considering a biodiesel start up project must consider whether the firm will generate enough total cash flow to justify the investment. That is the essence of commercial viability. As long as the firm achieves the required rate of return, a comparison of individual costs with the competitor’s are irrelevant other than to identify advantages to exploit or disadvantages to overcome. For example, by itself it does not matter if the biodiesel firm’s distribution costs are greater than the petroleum firm’s. The only thing that matters is the combination of 1) total cash flow 2) total investment and 3) required rate of return. Of course, distribution and other costs are important, but not in isolation. The idea is to design the biodiesel firm in such a way that its product is competitive on price (total cash flow) using technology (total investment) that achieves the required rate of return.

We can consider the technology to produce microalgae oil as an investment bundle. A rational investor is indifferent between 1) a strategy that employs technology having high start up costs, but low operating costs and 2) a strategy that employs technology having low start up costs, but high operating costs, if they both achieve the same rate of return. This assumes enough capital to cover the higher start up costs.

Reducing the cost of producing or procuring biodiesel feedstock is the area of greatest need. The photobioreactor is not only the distinguishing feature of the hypothetical biodiesel firm, in all likelihood it is also by far the most costly due to its immense size. With no way to determine the hypothetical firm's feedstock production start up cost with any degree of accuracy at this point in the industry's development, what can we do now to assist a future entrepreneur to evaluate the merit of a proposed biodiesel project? We can calculate the investment bundle described above, which is necessary to compete with the petroleum diesel firm.

Using Net Present Value (NPV) as the method for evaluating a proposed biodiesel investment, the criterion, of course, is that NPV must be greater than zero. Otherwise, the proposed project will not achieve the required rate of return.

The formula for NPV is

$$NPV = \sum_{i=1}^{T} \frac{C_i}{(1+r)^i} - C_0 , \qquad (1)$$

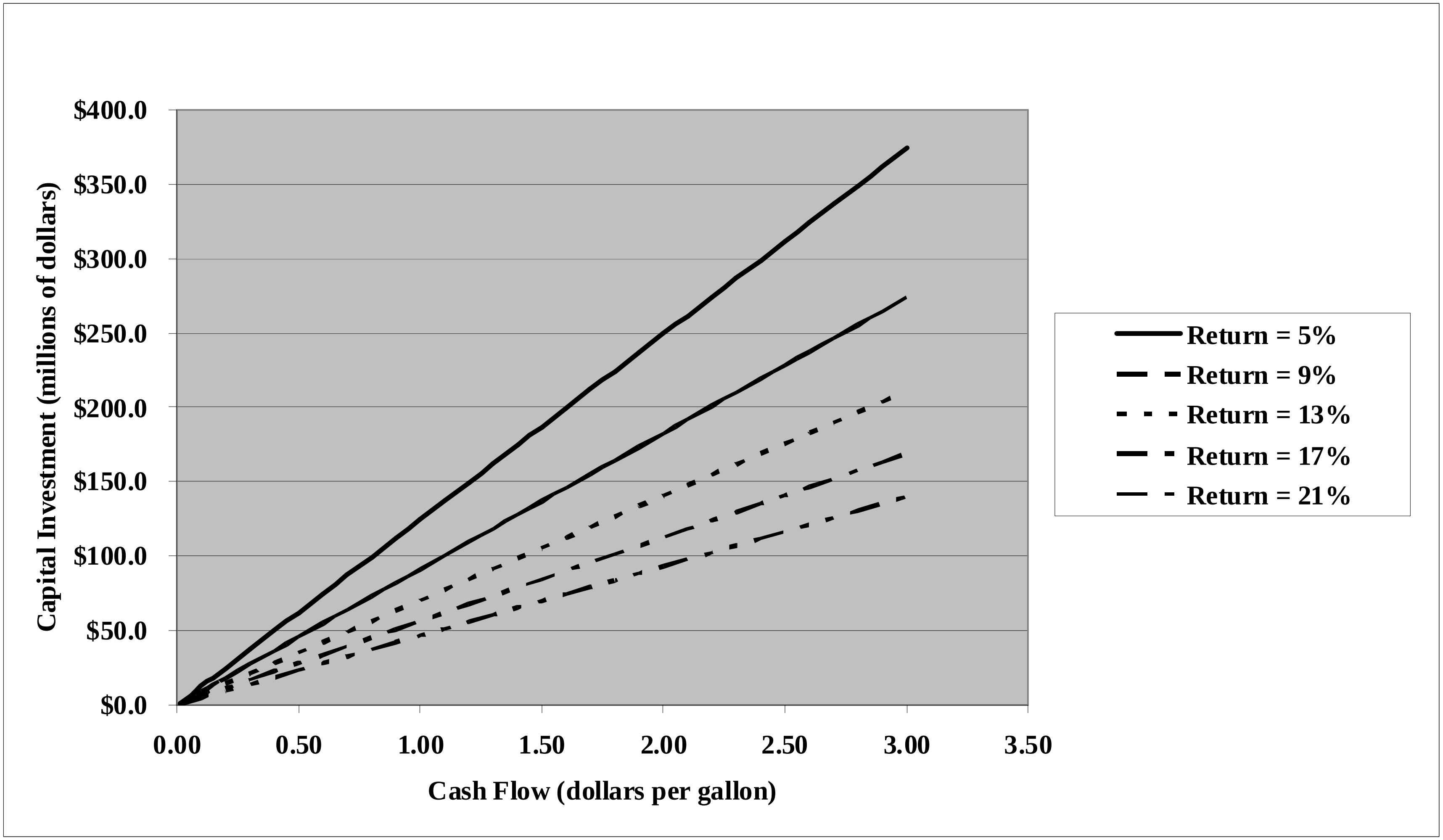
where *i* is the period, *T* is the total number of periods, *C* is cash flow in period *i*, *r* is the discount rate, C_0 is the initial investment, and the summation is the present value of future cash flows. (Ross, *et al*)

If we set NPV equal to zero, the initial investment equals the present value of future cash flows. This initial investment represents the maximum an investor should commit to a project at a given required rate of return and future cash flows.

Since production costs and cash flows are inversely proportional, it follows that an investor is also indifferent between technology that requires a large capital investment but produces high cash flows, and a technology which requires a small capital investment but suffers from low cash flows. Again, this assumes enough capital to cover the larger investment.

Setting future cash flows in terms of dollars per gallon of biodiesel sold, we can build a table of investment bundles. Cash flow per gallon, in this context, is the competitive target. It is based on the forecast wholesale price for the petroleum diesel refiner. For a given required rate of return and future cash flow there is a corresponding initial investment, which produces an NPV equal to zero. Figure 7.1 shows indifference curves for sample rates of return. These are based on a facility with an annual production capacity of 10,000,000 gallons and 20 years of annual cash flows.

Figure 7.1: Investment Bundles



See Appendix G for the data accompanying Figure 6.3.

This methodology accounts for changes in the forecast wholesale price of petroleum diesel. Using production cost on the X-axis would limit the graph in Figure 7.1 to a single forecast price. Placing cash flow on the X-axis permits its use in multiple scenarios. The entrepreneur need only compute his future cash flows per gallon, once he has determined all fixed and variable costs.

An example investment bundle is r = 13%, C_i = \$1.00 per gallon, and C_0 = \$70.2 million. The investor must select an investment bundle that lies at a point on or below the indifference curve for a given rate of return. Of course, this assumes the exit strategy includes a 20-year horizon.

7.3 Cash Flow Model and Analysis

The price levels of petroleum crude oil forecast over the next several years (EIA, “AEO”) and the STATA regression in Chapter V indicate a refiner wholesale price in the range of \$2.50 to \$3.50 (nominal dollars) per gallon during 2011 to 2013, with a steady increase thereafter. The AEO forecasts retail prices at \$3.06 to \$3.54 for the same years. The AEO does not forecast the refiner wholesale price.

If we set the biodiesel firm’s sale price equal to the refiner wholesale price (the benchmark for competitiveness), we can model the biodiesel firm’s cash flows according to the following methodology.

- Sale price is a normally distributed random variable with \$2.50 and \$3.50 representing a 95% confidence interval for the first year—2012.

- Since the refiner wholesale price very closely follows the price of crude oil, the sale price for subsequent years is indexed to the year over year percent change in the AEO's projected price of crude oil.
- Since feedstock production and biodiesel processing are heavily dependent on electric power, those costs are indexed to the year over year percent change in the AEO's projected price of industrial electricity.
- See Appendix H for the income statement and statement of cash flows for the firm.

One thousand trials of Monte Carlo Simulation determined the expected NPV of the equity investment in a hypothetical firm with capacities of 5 million, 10 million (base case), and 15 million gallons per year. The results are summarized in Tables 7.1 through 7.3.

Table 7.1: Monte Carlo Simulation Results (10 million-gallon facility)

Base Case

Production Cost (*$/gal*)	Investment (*$/gal*) ▶	28.31	20.00	15.00	10.00	5.00
0.10	Avg NPV (*million $*)	-181.5	-98.1	-48.2	1.7	51.9
	% of trials NPV > 0	0.0	0.0	0.0	58.2	100.0
	t-stat (left tail)	-182.1	-98.7	-48.8	1.2	51.4
0.20	Avg NPV (*million $*)	-184.2	-101.1	-50.9	-1.5	48.9
	% of trials NPV > 0	0.0	0.0	0.0	43.4	100.0
	t-stat (left tail)	-184.7	-101.7	-51.4	-2.0	48.4
0.40	Avg NPV (*million $*)	-191.1	-107.0	-57.0	-6.7	42.8
	% of trials NPV > 0	0.0	0.0	0.0	22.7	100.0
	t-stat (left tail)	-191.6	-107.6	-57.6	-7.2	42.3
0.60	Avg NPV (*million $*)	-196.1	-113.5	-64.0	-13.2	36.7
	% of trials NPV > 0	0.0	0.0	0.0	7.5	100.0
	t-stat (left tail)	-196.7	-114.1	-64.6	-13.7	36.1
0.80	Avg NPV (*million $*)	-202.8	-119.2	-69.8	-20.0	30.2
	% of trials NPV > 0	0.0	0.0	0.0	1.7	100.0
	t-stat (left tail)	-203.3	-119.8	-70.4	-20.6	29.6
1.00	Avg NPV (*million $*)	-208.5	74.1	73.9	74.9	74.6
	% of trials NPV > 0	0.0	0.0	0.0	0.2	99.4
	t-stat (left tail)	-209.1	-126.5	-76.7	-25.7	24.0
1.20	Avg NPV (*million $*)	-215.1	69.0	68.2	68.4	68.2
	% of trials NPV > 0	0.0	0.0	0.0	0.0	98.2
	t-stat (left tail)	-215.6	-131.6	-82.3	-32.1	17.6
1.40	Avg NPV (*million $*)	-220.8	-138.0	-88.1	-38.0	12.4
	% of trials NPV > 0	0.0	0.0	0.0	0.0	91.2
	t-stat (left tail)	-221.3	-138.6	-88.7	-38.5	11.8
1.60	Avg NPV (*million $*)	-227.5	-143.8	-93.9	-44.5	6.2
	% of trials NPV > 0	0.0	0.0	0.0	0.0	74.6
	t-stat (left tail)	-228.0	-144.4	-94.5	-45.1	5.6
1.80	Avg NPV (*million $*)	-233.1	-149.6	-100.3	-50.8	-0.2
	% of trials NPV > 0	0.0	0.0	0.0	0.0	50.3
	t-stat (left tail)	-233.6	-150.2	-100.8	-51.3	-0.7
2.00	Avg NPV (*million $*)	-239.5	-155.8	-106.1	-56.3	-6.4
	% of trials NPV > 0	0.0	0.0	0.0	0.0	23.8
	t-stat (left tail)	-240.1	-156.3	-106.7	-56.8	-7.0

Table 7.2: Monte Carlo Simulation Results (5 million-gallon facility)

Production Cost (*$/gal*)	Investment (*$/gal*) ▶	28.31	20.00	15.00	10.00	5.00
0.10	Avg NPV (*million $*)	-90.5	-49.0	-24.2	0.8	25.8
	% of trials NPV > 0	0.0	0.0	0.0	57.4	100.0
	t-stat (left tail)	-90.8	-49.3	-24.5	0.5	25.5
0.20	Avg NPV (*million $*)	-92.0	-50.6	-25.3	-0.6	24.2
	% of trials NPV > 0	0.0	0.0	0.0	45.7	100.0
	t-stat (left tail)	-92.2	-50.8	-25.6	-0.9	23.9
0.40	Avg NPV (*million $*)	-95.1	-53.8	-28.7	-3.7	21.4
	% of trials NPV > 0	0.0	0.0	0.0	19.8	100.0
	t-stat (left tail)	-95.4	-54.1	-29.0	-4.0	21.1
0.60	Avg NPV (*million $*)	-98.4	-56.7	-32.0	-6.7	18.3
	% of trials NPV > 0	0.0	0.0	0.0	6.5	100.0
	t-stat (left tail)	-98.7	-56.9	-32.3	-7.0	18.0
0.80	Avg NPV (*million $*)	-101.2	-59.7	-34.9	-9.8	15.4
	% of trials NPV > 0	0.0	0.0	0.0	1.8	99.9
	t-stat (left tail)	-101.5	-60.0	-35.2	-10.1	15.1
1.00	Avg NPV (*million $*)	-104.7	37.0	37.0	37.2	37.2
	% of trials NPV > 0	0.0	0.0	0.0	0.3	99.9
	t-stat (left tail)	-105.0	-63.3	-38.2	-13.1	11.9
1.20	Avg NPV (*million $*)	-107.3	34.1	34.3	34.1	34.3
	% of trials NPV > 0	0.0	0.0	0.0	0.0	97.9
	t-stat (left tail)	-107.6	-66.2	-41.0	-16.2	9.0
1.40	Avg NPV (*million $*)	-110.5	-69.1	-43.9	-18.8	6.1
	% of trials NPV > 0	0.0	0.0	0.0	0.0	92.6
	t-stat (left tail)	-110.8	-69.4	-44.1	-19.1	5.8
1.60	Avg NPV (*million $*)	-113.6	-72.0	-46.9	-21.8	3.2
	% of trials NPV > 0	0.0	0.0	0.0	0.0	76.4
	t-stat (left tail)	-113.9	-72.3	-47.2	-22.1	2.9
1.80	Avg NPV (*million $*)	-116.6	-75.0	-49.8	-25.1	-0.1
	% of trials NPV > 0	0.0	0.0	0.0	0.0	48.9
	t-stat (left tail)	-116.8	-75.3	-50.1	-25.4	-0.4
2.00	Avg NPV (*million $*)	-119.8	-77.9	-53.1	-28.1	-2.9
	% of trials NPV > 0	0.0	0.0	0.0	0.0	26.0
	t-stat (left tail)	-120.0	-78.2	-53.4	-28.3	-3.2

Table 7.3: Monte Carlo Simulation Results (15 million-gallon facility)

Production Cost (*$/gal*)	Investment (*$/gal*) ▶	28.31	20.00	15.00	10.00	5.00
0.10	Avg NPV (*million $*)	-271.7	-147.4	-71.9	2.9	77.3
	% of trials NPV > 0	0.0	0.0	0.0	59.0	100.0
	t-stat (left tail)	-272.6	-148.2	-72.7	2.1	76.5
0.20	Avg NPV (*million $*)	-276.1	-151.6	-77.1	-2.1	72.8
	% of trials NPV > 0	0.0	0.0	0.0	44.6	100.0
	t-stat (left tail)	-276.9	-152.4	-78.0	-3.0	71.9
0.40	Avg NPV (*million $*)	-286.0	-160.7	-86.7	-11.0	64.1
	% of trials NPV > 0	0.0	0.0	0.0	19.0	100.0
	t-stat (left tail)	-286.9	-161.5	-87.6	-11.8	63.3
0.60	Avg NPV (*million $*)	-294.5	-170.3	-95.5	-20.2	55.3
	% of trials NPV > 0	0.0	0.0	0.0	6.2	100.0
	t-stat (left tail)	-295.3	-171.1	-96.3	-21.1	54.4
0.80	Avg NPV (*million $*)	-304.2	-179.8	-103.9	-28.4	46.1
	% of trials NPV > 0	0.0	0.0	0.0	1.4	100.0
	t-stat (left tail)	-305.0	-180.6	-104.7	-29.3	45.3
1.00	Avg NPV (*million $*)	-313.7	112.1	111.7	111.5	111.5
	% of trials NPV > 0	0.0	0.0	0.0	0.1	99.3
	t-stat (left tail)	-314.5	-188.8	-114.2	-39.3	35.7
1.20	Avg NPV (*million $*)	-322.4	102.3	102.8	102.4	102.3
	% of trials NPV > 0	0.0	0.0	0.0	0.0	97.3
	t-stat (left tail)	-323.3	-198.6	-123.0	-48.5	26.4
1.40	Avg NPV (*million $*)	-332.5	-206.0	-132.2	-56.5	17.9
	% of trials NPV > 0	0.0	0.0	0.0	0.0	91.4
	t-stat (left tail)	-333.3	-206.8	-133.0	-57.3	17.0
1.60	Avg NPV (*million $*)	-341.1	-215.4	-141.0	-65.9	9.1
	% of trials NPV > 0	0.0	0.0	0.0	0.0	75.3
	t-stat (left tail)	-341.9	-216.3	-141.8	-66.7	8.3
1.80	Avg NPV (*million $*)	-349.8	-225.6	-150.2	-75.2	0.0
	% of trials NPV > 0	0.0	0.0	0.0	0.0	49.1
	t-stat (left tail)	-350.7	-226.5	-151.0	-76.0	-0.8
2.00	Avg NPV (*million $*)	-358.4	-234.1	-158.9	-84.5	-9.3
	% of trials NPV > 0	0.0	0.0	0.0	0.0	25.1
	t-stat (left tail)	-359.2	-234.9	-159.7	-85.3	-10.1

Notes:

- Investment levels were selected in consideration of the one data point available (GreenFuel Technologies’ plant in Spain), which is $28.31 per gallon of annual capacity.

- Feedstock production costs were selected following a preliminary calculation using a sale price in the low end of the range ($2.50 per gallon).
- Cash flows were discounted using a WACC of 20.12% and the following parameters.
  - $\beta = 1.5$
  - Risk free rate (R_f) = 0.15%
  - Expected return on a market portfolio (R_m) = 20%
  - Cost of debt (R_B) = 9%
  - Debt-to-equity ratio = 0.67
- We did not consider payback period, because the decision criterion is a function of the individual investor.

The results show a near linear relationship in the three cases. This was expected, because many costs are aggregated into feedstock and processing costs. Analyzing economy of scale would require more detailed cost analysis among the three facilities. For example, Orbitek's processing equipment would require no additional labor to operate the 15 million-gallon facility as compared to the 5 million-gallon facility. Therefore, processing costs are lower, on a per gallon basis, for the larger facility.

Easily the most significant finding is that level of investment has a far greater effect on NPV than does production cost. The only cases in which the 95% confidence interval for average NPV fell entirely above zero were those in which investment level was $5.00 per gallon of annual capacity. Investment of $10.00 per gallon is acceptable only if the technology can produce microalgae oil for $0.10 or less. As long as investment level was

$5.00, feedstock production cost could go above $1.00 with no appreciable number of trials having NPV less than zero. The t-stat is positive for production cost as high as $1.60 and becomes negative in all three cases as it approaches close to $1.80.

The dominance of level of investment on NPV holds true until R_m is as low as 10%. Then the t-stat is positive for investment level of $10 for production costs up to $1.20. For investment level of $15, the t-stat is positive for production costs up to $0.20.

We can use GreenFuel Technologies' plant in Spain to determine the maximum start up cost of the photobioreactor for the hypothetical firm. From the data in Section 4.4.2 and Table 4.1 Notes, the facility sits on 247 acres and will produce a little more than 3 million gallons per year. Let's assume the photobioreactor employs 12-inch diameter tubes set at a 60-degree angle from horizontal. Each tube is 10 feet long. One acre would total 14 arrays of tubes 210 feet long and 15 feet wide, each consisting of 70 tubes. The 10-million gallon per year hypothetical firm would need approximately 3 times the acreage. Therefore, the hypothetical firm would need 7,261,800 feet of tubes, which is about 1,375 miles.

At a $10 per gallon level of investment, if we assume start up costs other than feedstock production total $20 million (Reuters, "Biodiesel" and Riggin), the equity investment in feedstock production is $53 million. This equates to $7.30 per linear foot of tube and includes all start up costs. At a $5 per gallon level of investment, total start up cost for the photobioreactor is $20 million dollars or $2.75 per linear foot of tube.

CHAPTER VIII

CONCLUSION

8.1 Summary

While reducing microalgae production costs is important, it is even more important to reduce photobioreactor material and construction costs. Reducing the per gallon level of investment in photobioreactors is the single greatest factor in achieving commercial viability of biodiesel. The entrepreneur must be able to achieve total start up costs for feedstock production in the range of $2.75 to $7.30 per linear foot of photobioreactor tube.

Reducing the costs associated with the photobioreactor allow production costs as high as $1.00 per gallon or more, while still achieving positive NPV.

If petroleum refining capacity becomes the problem depicted in Chapter VI, it is difficult to estimate how high petroleum diesel prices might rise. If they reach 2008 price levels, microalgae based biodiesel would more easily compete on price with petroleum diesel.

8.2 Recommendations

The best approach to making biodiesel competitive on price with petroleum diesel is twofold.

1) Invest in development of high yield microalgae production techniques. The photobioreactor holds greater promise than the racetrack pond method. Current photobioreactors appear to be marginal at best.
2) Invest in material and manufacturing process technology to decrease photobioreactor start up costs.

8.3 Future Research

Renewable diesel uses the same feedstocks as biodiesel. The difference is the feedstock is processed in a petroleum refinery, yielding fuel that is chemically identical to petroleum diesel. Therefore, there are no issues introducing it to existing petroleum diesel storage, pipelines, or pumps.

Since biodiesel and renewable diesel are produced from the same feedstocks, any improvement in yield per acre will benefit both. It may be that the best alternative is to dedicate microalgae based feedstock production to renewable diesel, thereby phasing out petroleum crude oil as feedstock for diesel fuel.

The major obstacle for renewable diesel is that the photobioreactor has to be near a source of carbon dioxide. If the refinery is not close to the same location, the firm will incur a transportation cost. The petroleum industry's crude oil gathering system, which brings crude oil from the wellhead to the pipelines depicted in Figure 6.1, was developed over many decades. An analogous system for microalgae based biodiesel would be long range carbon dioxide pipelines gathering flue gasses from power plants and other emitters and transporting it to very large scale photobioreactors near petroleum refineries or pipelines dedicated to transporting the oil to refineries.

Such an approach would exchange the initial cost of the carbon dioxide pipeline for economy of scale, lower processing costs via use of existing petroleum refineries, and lower distribution costs via use of existing refined products pipelines. The business model would change slightly, because the firm would process no fuel. The oil would be the product, which it would sell to the petroleum refiner.

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APPENDICES

Appendix A

Table A.1: Soybean Oil Price

Year beginning October 1	Soybean Oil (Crude) price, Decatur (c/lb)
1980	22.73
1981	18.95
1982	20.62
1983	30.55
1984	29.52
1985	18.02
1986	15.36
1987	22.67
1988	21.09
1989	22.28
1990	20.98
1991	19.13
1992	21.24
1993	26.96
1994	27.51
1995	24.70
1996	22.51
1997	25.83
1998	19.80
1999	15.59
2000	14.09
2001	16.46
2002	22.04
2003	29.97
2004	23.01
2005	23.41
2006	31.02
2007 (1)	53.0-57.0

(1)Forecast

Source: Energy Information Administration (DOE)
<http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290>

Downloaded February 9, 2009.

Appendix B

Table B.1: Soybean Oil Futures Settlement (March 18, 2009)

Expiration	Opening	High	Low	Closing	Settle	Net Change
09May	31.10	31.20	30.85		30.92	-0.39
09Jul	31.29	31.47	31.12		31.19	-0.40
09Aug	31.43	31.47	31.33		31.35	-0.39
09Sep	31.60	31.60	31.50		31.50	-0.39
09Oct	31.73	31.80	31.65		31.65	-0.39
09Dec	32.15	32.17	31.90		31.94	-0.40
10Jan	0.00	32.60	32.20		32.20	-0.40
10Mar	0.00	32.85	32.45		32.45	-0.40
10May	0.00	33.10	32.70		32.70	-0.40
10Jul	0.00	33.30	32.90		32.90	-0.40
10Aug	0.00	33.40	33.00		33.00	-0.40
10Sep	0.00	33.45	33.05		33.05	-0.40
10Oct	0.00	33.50	33.10		33.10	-0.40
10Dec	33.50	33.55	33.15		33.15	-0.40
11Jan	0.00	33.55	33.15		33.15	-0.40
11Mar	0.00	33.55	33.15		33.15	-0.40
11Jul	0.00	33.55	33.15		33.15	-0.40
11Oct	0.00	33.55	33.15		33.15	-0.40
11Dec	0.00	33.55	33.15		33.15	-0.40

Table generated March 18, 2009 16:53 CDT

Price Unit: c/lb (60,000 lbs)

Appendix C

Table C.1: Projected Production Costs for Diesel Fuel by Feedstock, 2004-2013

(*2002 Dollars per Gallon*)

Marketing Year	Soybean Oil	Yellow Grease	Petroleum
2004/05	2.54	1.41	0.67
2005/06	2.49	1.39	0.78
2006/07	2.47	1.38	0.77
2007/08	2.44	1.37	0.78
2008/09	2.52	1.40	0.78
2009/10	2.57	1.42	0.75
2010/11	2.67	1.47	0.76
2011/12	2.73	1.51	0.76
2012/13	2.80	1.55	0.75

Source: Radich, Anthony. "Biodiesel Performance, Costs, and Use," U.S. Department of Energy, Energy Information Administration, June 8, 2004. February 20, 2009. <http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/>

Appendix D

Table D.1: Average Retail Price of Electricity to Industrial Customers

November 2008 and 2007

Census Division and State	Industrial[1]	
	Nov-08	Nov-07
New England	13.53	12.83
Connecticut	14.30	13.26
Maine	11.88	14.31
Massachusetts	14.46	13.03
New Hampshire	13.09	12.05
Rhode Island	15.42	11.96
Vermont	9.05	8.92
Middle Atlantic	8.23	7.60
New Jersey	12.38	10.33
New York	9.60	8.21
Pennsylvania	7.01	6.72
East North Central	6.60	5.85
Illinois	7.78	6.65
Indiana	5.88	4.97
Michigan	6.81	6.23
Ohio	6.47	5.73
Wisconsin	6.72	6.03
West North Central	5.14	4.74
Iowa	4.58	4.42
Kansas	5.62	4.96
Minnesota	5.81	5.31
Missouri	4.79	4.33
Nebraska	4.69	4.33
North Dakota	5.37	5.24
South Dakota	5.24	5.00
South Atlantic	6.52	5.70
Delaware	9.40	9.33
District of Columbia	9.91	9.02
Florida	8.85	7.97
Georgia	6.63	5.22
Maryland	9.35	9.69
North Carolina	5.58	5.46
South Carolina	5.82	4.80
Virginia	6.54	5.26
West Virginia	4.41	4.13

East South Central	6.40	4.98
Alabama	7.12	5.22
Kentucky	5.14	4.34
Mississippi	7.51	5.80
Tennessee	7.06	5.23
West South Central	7.84	6.96
Arkansas	6.03	5.30
Louisiana	8.26	6.13
Oklahoma	5.93	5.47
Texas	8.26	7.66
Mountain	5.42	5.40
Arizona	5.89	5.80
Colorado	6.34	5.93
Idaho	4.13	3.57
Montana	5.65	5.18
Nevada	6.29	7.18
New Mexico	5.31	5.86
Utah	4.12	3.91
Wyoming	4.35	3.99
Pacific Contiguous	8.31	7.87
California	10.49	9.78
Oregon	5.61	5.53
Washington	4.99	4.74
Pacific Noncontiguous	23.01	18.47
Alaska	12.75	12.72
Hawaii	26.72	20.61
U.S. Total	7.06	6.28

Price Unit: Cents per Kilowatthour

Notes (from EIA website):

[1] See Technical notes for additional information on the Commercial, Industrial, and Transportation sectors.

NM = Not meaningful due to large relative standard error or excessive percentage change.

See Glossary for definitions.

Values for 2007 are final. Values for 2008 are preliminary estimates based on a cutoff model sample.

See Technical Notes for a discussion of the sample design for the Form EIA-826.

Utilities and energy service providers may classify commercial and industrial customers based on either NAICS codes or usage falling within specified limits by rate schedule.

Changes from year to year in consumer counts, sales and revenues, particularly involving the commercial and industrial consumer sectors, may result from respondent implementation of changes in the definitions of consumers, and reclassifications.

Retail sales and net generation may not correspond exactly for a particular month for a variety of reasons (i.e., sales data may include imported electricity).

Net generation is for the calendar month while retail sales and associated revenue accumulate from bills collected for periods of time (28 to 35 days) that vary dependent upon customer class and consumption occurring in and outside the calendar month.

Totals may not equal sum of components because of independent rounding.

Source:

Energy Information Administration (DOE)

<http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html> February 13, 2009. Downloaded February 25, 2009.

Appendix E

Table E.1: Comparison of Refiner Wholesale Price of Diesel Fuel and Refiner Average Crude Oil Acquisition Cost

	2008 Jan	Feb	Mar	Apr	May	Jun
Diesel Fuel Refiner Wholesale Price (*cents per gallon*)	258.1	273.8	315.9	335.8	371.2	385.9
Refiner Average Crude Oil Acquisition Cost (*dollars per barrel*)	86.48	89.07	97.94	106.23	117.93	127.31
% change in price of diesel - % change in price of crude oil (1)		0.03	0.05	-0.02	0.00	-0.04

Table E.1 (continued)

	Jul	Aug	Sep	Oct	Nov	Dec
Diesel Fuel Refiner Wholesale Price (*cents per gallon*)	387.6	333.9	316.1	251.6	195.6	148.2
Refiner Average Crude Oil Acquisition Cost (*dollars per barrel*)	129.03	113.71	98.91	74.22	53.32	39.00
% change in price of diesel - % change in price of crude oil (1)	-0.01	-0.02	0.08	0.05	0.06	0.03

(1) Data row added by William J. Davis.

Source: Energy Information Administration (U.S. Department of Energy) Web site. "Short-Term Energy Outlook Custom Table Builder," February 10, 2009. February 14, 2009. <http://tonto.eia.doe.gov/cfapps/STEO_TableBuilder/index.cfm>

Appendix F

Table F.1: STATA Input Data

STEO ID >	COPR_OPEC	GDPQXUS	ORUTCUS	PATC_US
	OPEC Total Crude Production	Real GDP	Refinery Utilization Factor	U.S. Petroleum Consumption
Year	*million bbls/day*	*billion chained 2000 dollars - SAAR*	*Operating Factor*	*million bbls/day*
STATA ID >	OPECCrudProd	RealGDP	DistRefUtiliz	USPetrolCons
1994	24.90	7,835	0.93	17.72
1995	24.79	8,032	0.92	17.72
1996	25.28	8,329	0.94	18.31
1997	26.55	8,704	0.95	18.62
1998	27.63	9,067	0.96	18.92
1999	26.48	9,470	0.93	19.52
2000	28.19	9,817	0.93	19.70
2001	27.35	9,891	0.93	19.65
2002	25.57	10,049	0.91	19.77
2003	27.20	10,301	0.93	20.03
2004	29.50	10,676	0.93	20.73
2005	30.83	10,990	0.91	20.80
2006	30.45	11,295	0.90	20.69
2007	30.06	11,524	0.89	20.68
2008	31.27	11,657	0.85	19.48

Continued on next page.

Table F.1 (Continued)

STEO ID >			DFPSPUS
	Real Diesel Fuel Refiner Wholesale Price (using CRB) (1)	Real Refiner Average Crude Oil Acquisition Cost (using CRB Index) (1)	Distillate Fuel Oil Total U.S. Inventory
Year	*c/gal*	*$/bbl*	*million bbls, end of period*
STATA ID>	RealRefWhPriceCRB	RealCrudeAcqCost	Inventories
1994	138.94	40.95	145.20
1995	156.43	50.10	130.20
1996	196.31	61.78	126.70
1997	177.35	55.57	138.40
1998	115.80	32.63	156.10
1999	124.15	39.75	125.50
2000	201.45	63.40	118.00
2001	175.97	51.53	144.50
2002	165.45	55.07	134.10
2003	228.71	73.92	136.50
2004	352.40	109.73	126.30
2005	513.99	148.69	136.00
2006	676.06	202.48	143.70
2007	880.23	272.06	133.90
2008	1,274.23	398.10	145.90

Continued on next page.

Table F.1 (Continued)

STEO ID >	PATC_WORLD World Petroleum Consumption	Soy Oil (2)	Real Diesel Fuel Retail Incl Taxes U.S. Average (using CRB Index) (1)
Year	*million bbls/day*	*c/lb*	*c/gal*
STATA ID>	WorldPetrolCons	Soy	RealRetDiesel
1994	68.93	27.51	291.80
1995	70.13	24.70	322.46
1996	71.67	22.51	367.90
1997	73.43	25.83	350.01
1998	74.05	19.80	272.56
1999	75.73	15.59	255.13
2000	76.71	14.09	335.37
2001	77.44	16.46	315.35
2002	78.10	22.04	300.73
2003	79.66	29.97	390.85
2004	82.41	23.01	536.46
2005	84.00	23.41	709.29
2006	84.98	31.02	907.91
2007	85.90	53.00	1,150.33
2008	85.87	N/A	1,590.48

Source: Energy Information Administration (U.S. Department of Energy) Web site. "Short-Term Energy Outlook Custom Table Builder," February 10, 2009. February 11, 2009. <http://tonto.eia.doe.gov/cfapps/STEO_TableBuilder/index.cfm>

Notes: (1) Data in this column added by William J. Davis.

(2) Soy oil prices are from Economic Research Service (USDA) at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290, February 19, 2009.

Note: Soy oil price information for 2008 was not available at ERS as of March 17, 2009.

Appendix G

Table G.1: Input Data for Investment Bundle Indifference Curves

Required Rate of Return	Capital Investment (*millions of dollars*)	Cash Flow (*$/gal*)
0.05	1.25	0.01
0.05	12.46	0.10
0.05	24.92	0.20
0.05	37.39	0.30
0.05	49.85	0.40
0.05	62.31	0.50
0.05	74.77	0.60
0.05	87.24	0.70
0.05	99.70	0.80
0.05	112.16	0.90
0.05	124.62	1.00
0.05	137.08	1.10
0.05	149.55	1.20
0.05	162.01	1.30
0.05	174.47	1.40
0.05	186.93	1.50
0.05	199.40	1.60
0.05	211.86	1.70
0.05	224.32	1.80
0.05	236.78	1.90
0.05	249.24	2.00
0.05	261.71	2.10
0.05	274.17	2.20
0.05	286.63	2.30
0.05	299.09	2.40
0.05	311.56	2.50
0.05	324.02	2.60
0.05	336.48	2.70
0.05	348.94	2.80
0.05	361.40	2.90
0.05	373.87	3.00
0.09	0.91	0.01
0.09	9.13	0.10
0.09	18.26	0.20
0.09	27.39	0.30
0.09	36.51	0.40
0.09	45.64	0.50
0.09	54.77	0.60
0.09	63.90	0.70
0.09	73.03	0.80

0.09	82.16	0.90
0.09	91.29	1.00
0.09	100.41	1.10
0.09	109.54	1.20
0.09	118.67	1.30
0.09	127.80	1.40
0.09	136.93	1.50
0.09	146.06	1.60
0.09	155.19	1.70
0.09	164.31	1.80
0.09	173.44	1.90
0.09	182.57	2.00
0.09	191.70	2.10
0.09	200.83	2.20
0.09	209.96	2.30
0.09	219.09	2.40
0.09	228.21	2.50
0.09	237.34	2.60
0.09	246.47	2.70
0.09	255.60	2.80
0.09	264.73	2.90
0.09	273.86	3.00
0.13	0.70	0.01
0.13	7.02	0.10
0.13	14.05	0.20
0.13	21.07	0.30
0.13	28.10	0.40
0.13	35.12	0.50
0.13	42.15	0.60
0.13	49.17	0.70
0.13	56.20	0.80
0.13	63.22	0.90
0.13	70.25	1.00
0.13	77.27	1.10
0.13	84.30	1.20
0.13	91.32	1.30
0.13	98.35	1.40
0.13	105.37	1.50
0.13	112.40	1.60
0.13	119.42	1.70
0.13	126.45	1.80
0.13	133.47	1.90
0.13	140.50	2.00
0.13	147.52	2.10
0.13	154.54	2.20

0.13	161.57	2.30
0.13	168.59	2.40
0.13	175.62	2.50
0.13	182.64	2.60
0.13	189.67	2.70
0.13	196.69	2.80
0.13	203.72	2.90
0.13	210.74	3.00
0.17	0.56	0.01
0.17	5.63	0.10
0.17	11.26	0.20
0.17	16.88	0.30
0.17	22.51	0.40
0.17	28.14	0.50
0.17	33.77	0.60
0.17	39.39	0.70
0.17	45.02	0.80
0.17	50.65	0.90
0.17	56.28	1.00
0.17	61.91	1.10
0.17	67.53	1.20
0.17	73.16	1.30
0.17	78.79	1.40
0.17	84.42	1.50
0.17	90.04	1.60
0.17	95.67	1.70
0.17	101.30	1.80
0.17	106.93	1.90
0.17	112.56	2.00
0.17	118.18	2.10
0.17	123.81	2.20
0.17	129.44	2.30
0.17	135.07	2.40
0.17	140.69	2.50
0.17	146.32	2.60
0.17	151.95	2.70
0.17	157.58	2.80
0.17	163.21	2.90
0.17	168.83	3.00
0.21	0.47	0.01
0.21	4.66	0.10
0.21	9.31	0.20
0.21	13.97	0.30
0.21	18.63	0.40
0.21	23.28	0.50

0.21	27.94	0.60
0.21	32.60	0.70
0.21	37.25	0.80
0.21	41.91	0.90
0.21	46.57	1.00
0.21	51.22	1.10
0.21	55.88	1.20
0.21	60.54	1.30
0.21	65.19	1.40
0.21	69.85	1.50
0.21	74.51	1.60
0.21	79.16	1.70
0.21	83.82	1.80
0.21	88.48	1.90
0.21	93.13	2.00
0.21	97.79	2.10
0.21	102.45	2.20
0.21	107.10	2.30
0.21	111.76	2.40
0.21	116.42	2.50
0.21	121.07	2.60
0.21	125.73	2.70
0.21	130.39	2.80
0.21	135.04	2.90
0.21	139.70	3.00

Assume 10,000,000 gallon per year capacity.

Assume a 20-year horizon.

Appendix H

Table H.1: Income Statement for the Hypothetical Firm

	2011	2012	2013	2014	2015
IEA Crude Oil Price *($/bbl)*		89.98	94.21	104.16	107.64
% change in crude oil price			4.70	10.56	3.35
Sale Price		2.97	3.11	3.44	3.55
Total Operating Revenues		29,685,670	31,080,286	34,362,586	35,512,926
Operating Expenses					
Industrial Electricity Price (*cents per kwh*)		6.26	6.24	6.23	6.24
% change in industrial electricity price			-0.31	-0.17	0.27
Feedstock Production		1,000,000	996,888	995,161	997,838
Processing		5,840,000	5,821,827	5,811,741	5,827,371
Distribution		610,000	610,000	610,000	610,000
Total Expenses		7,450,000	7,428,715	7,416,902	7,435,209
MACRS 7-year Depreciation Schedule		14.29%	24.49%	17.49%	12.49%
Depreciation		8,574,000	14,694,000	10,494,000	7,494,000
Operating Income (EBIT)		13,661,670	8,957,571	16,451,684	20,583,718
Interest Expense		3,600,000	3,600,000	3,600,000	3,600,000
Pretax Income		10,061,670	5,357,571	12,851,684	16,983,718
Taxes		4,024,668	2,143,028	5,140,673	6,793,487
Net Income		6,037,002	3,214,543	7,711,010	10,190,231

Table H.1 (Continued)

	2016	2017	2018	2019	2020
IEA Crude Oil Price (*$/bbl*)	108.88	108.75	110.64	110.60	110.34
% change in crude oil price	1.15	-0.12	1.74	-0.03	-0.23
Sale Price	3.59	3.59	3.65	3.65	3.64
Total Operating Revenues	35,921,570	35,877,717	36,502,492	36,489,984	36,404,278
Operating Expenses					
Industrial Electricity Price (*cents per kwh*)	6.28	6.32	6.39	6.47	6.50
% change in industrial electricity price	0.53	0.72	1.10	1.23	0.39
Feedstock Production	1,003,115	1,010,304	1,021,427	1,034,028	1,038,104
Processing	5,858,190	5,900,176	5,965,134	6,038,722	6,062,527
Distribution	610,000	610,000	610,000	610,000	610,000
Total Expenses	7,471,305	7,520,480	7,596,561	7,682,750	7,710,631
MACRS 7-year Depreciation Schedule	8.93%	8.92%	8.93%	4.46%	
Depreciation	5,358,000	5,352,000	5,358,000	2,676,000	0
Operating Income (EBIT)	23,092,265	23,005,237	23,547,930	26,131,234	28,693,647
Interest Expense	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000
Pretax Income	19,492,265	19,405,237	19,947,930	22,531,234	25,093,647
Taxes	7,796,906	7,762,095	7,979,172	9,012,494	10,037,459
Net Income	11,695,359	11,643,142	11,968,758	13,518,741	15,056,188

Table H.1 (Continued)

	2021	2022	2023	2024	2025
IEA Crude Oil Price (*$/bbl*)	111.03	113.17	113.11	114.22	115.01
% change in crude oil price	0.62	1.93	-0.05	0.98	0.69
Sale Price	3.66	3.73	3.73	3.77	3.79
Total Operating Revenues	36,630,802	37,337,750	37,317,694	37,682,475	37,942,984
Operating Expenses					
Industrial Electricity Price (*cents per kwh*)	6.48	6.53	6.60	6.71	6.85
% change in industrial electricity price	-0.21	0.76	1.06	1.62	2.13
Feedstock Production	1,035,975	1,043,863	1,054,891	1,071,930	1,094,807
Processing	6,050,092	6,096,162	6,160,562	6,260,071	6,393,672
Distribution	610,000	610,000	610,000	610,000	610,000
Total Expenses	7,696,067	7,750,025	7,825,452	7,942,001	8,098,479
MACRS 7-year Depreciation Schedule					
Depreciation	0	0	0	0	0
Operating Income (EBIT)	28,934,734	29,587,725	29,492,242	29,740,475	29,844,505
Interest Expense	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000
Pretax Income	25,334,734	25,987,725	25,892,242	26,140,475	26,244,505
Taxes	10,133,894	10,395,090	10,356,897	10,456,190	10,497,802
Net Income	15,200,841	15,592,635	15,535,345	15,684,285	15,746,703

Table H.1 (Continued)

	2026	2027	2028	2029	2030
IEA Crude Oil Price (*$/bbl*)	116.02	118.90	120.17	121.91	123.81
% change in crude oil price	0.88	2.49	1.07	1.45	1.56
Sale Price	3.83	3.92	3.96	4.02	4.08
Total Operating Revenues	38,275,368	39,228,134	39,646,229	40,220,986	40,847,331
Operating Expenses					
Industrial Electricity Price (*cents per kwh*)	6.99	7.14	7.25	7.31	7.39
% change in industrial electricity price	2.07	2.13	1.47	0.88	1.10
Feedstock Production	1,117,443	1,141,252	1,158,033	1,168,221	1,181,019
Processing	6,525,865	6,664,910	6,762,910	6,822,413	6,897,153
Distribution	610,000	610,000	610,000	610,000	610,000
Total Expenses	8,253,307	8,416,162	8,530,943	8,600,635	8,688,173
MACRS 7-year Depreciation Schedule					
Depreciation	0	0	0	0	0
Operating Income (EBIT)	30,022,061	30,811,972	31,115,287	31,620,352	32,159,158
Interest Expense	3,600,000	3,600,000	3,600,000	3,600,000	3,600,000
Pretax Income	26,422,061	27,211,972	27,515,287	28,020,352	28,559,158
Taxes	10,568,824	10,884,789	11,006,115	11,208,141	11,423,663
Net Income	15,853,237	16,327,183	16,509,172	16,812,211	17,135,495

Table H.2: Statement of Cash Flows

	2011	2012	2013	2014	2015
EBIT		13,661,670	8,957,571	16,451,684	20,583,718
Depreciation		8,574,000	14,694,000	10,494,000	7,494,000
Current Taxes		4,024,668	2,143,028	5,140,673	6,793,487
Operating Cash Flow		18,211,002	21,508,543	21,805,010	21,284,231
Capital Investment	60,000,000				
Additions to Net Working Capital					
Horizon Value					
Total Cash Flow	-60,000,000	18,211,002	21,508,543	21,805,010	21,284,231

	2016	2017	2018	2019	2020
EBIT	23,092,265	23,005,237	23,547,930	26,131,234	28,693,647
Depreciation	5,358,000	5,352,000	5,358,000	2,676,000	0
Current Taxes	7,796,906	7,762,095	7,979,172	9,012,494	10,037,459
Operating Cash Flow	20,653,359	20,595,142	20,926,758	19,794,741	18,656,188
Capital Investment					
Additions to Net Working Capital					
Horizon Value					
Total Cash Flow	20,653,359	20,595,142	20,926,758	19,794,741	18,656,188

	2021	2022	2023	2024	2025
EBIT	28,934,734	29,587,725	29,492,242	29,740,475	29,844,505
Depreciation	0	0	0	0	0
Current Taxes	10,133,894	10,395,090	10,356,897	10,456,190	10,497,802
Operating Cash Flow	18,800,841	19,192,635	19,135,345	19,284,285	19,346,703
Capital Investment					
Additions to Net Working Capital					
Horizon Value					
Total Cash Flow	18,800,841	19,192,635	19,135,345	19,284,285	19,346,703

	2026	2027	2028	2029	2030
EBIT	30,022,061	30,811,972	31,115,287	31,620,352	32,159,158
Depreciation	0	0	0	0	0
Current Taxes	10,568,824	10,884,789	11,006,115	11,208,141	11,423,663
Operating Cash Flow	19,453,237	19,927,183	20,109,172	20,412,211	20,735,495
Capital Investment					
Additions to Net Working Capital					
Horizon Value					103,084,738
Total Cash Flow	19,453,237	19,927,183	20,109,172	20,412,211	123,820,233

Note: Tax rate is 40 %. Cash flows for the hypothetical firm assume the facility operates at full capacity. Therefore, the horizon value assumes any growth in cash flows beyond year 20 is due strictly to inflation. Accordingly, the formula for horizon value is

$$HV = \frac{OCF_{t=20}}{WACC}. \tag{2}$$

VITA

William J. Davis

Candidate for the Degree of

Master of Science

Thesis: OVERCOMING COMPETITIVE DISADVANTAGE: FUTURE COMMERCIAL VIABILITY OF MICROALGAE BASED BIODIESEL

Major Field: Quantitative Financial Economics

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Personal Data: Born in Tulsa, Oklahoma, the son of W.K. and Elizabeth Davis.

Education: Graduated from Nathan Hale Senior High School in Tulsa, Oklahoma, in May 1980; received Bachelor of Science degree in Aerospace Sciences from the United States Air Force Academy, Colorado, in May 1984. Completed the requirements for the Master of Science in Quantitative Financial Economics at Oklahoma State University, Stillwater, Oklahoma in May, 2009.

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Title of Study: OVERCOMING COMPETITIVE DISADVANTAGE: FUTURE COMMERCIAL VIABILITY OF MICROALGAE BASED BIODIESEL

Pages in Study: 106 Candidate for the Degree of Master of Science

Major Field: Quantitative Financial Economics

Scope and Method of Study: The purpose of this paper was to identify the reasons biodiesel fuel is not competitive on price with petroleum diesel and to evaluate the potential for biodiesel to compete on price in the future by indentifying improvements to cost structure. A hypothetical start up biodiesel production firm was created and compared to existing petroleum diesel producers. The basis of comparison was the cost to produce the respective fuels and the price received by the producers.

Findings and Conclusions: The most significant source of competitive disadvantage for the current biodiesel producer is the cost of feedstock. A promising alternative feedstock is any of several species of microalgae grown in an apparatus called a “photobioreactor.” Several firms are developing such an apparatus with varying degrees of success. However, to date, none have succeeded in deployment of a commercial scale facility. Level of investment per gallon of annual capacity has much greater effect on net present value than does production cost. The second greatest source of competitive disadvantage is production cost, due primarily to the scale of the petroleum industry. Distribution costs are also higher for the biodiesel firm. Successful deployment of commercial scale microalgae production may be able to overcome these three disadvantages.

ADVISER’S APPROVAL: Timothy L. Krehbiel