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ABSTRACT

Biodiesel is produced by adding methyl ester products to diesel fuel. Base catalyzed transesterification of oil with methanol is the primary process used today. Current dry mill ethanol production facilities allow the corn oil to pass through the process where it becomes part of the dried distiller's grain with solubles (DDGS), a lower valued feed co-product. This study evaluated the economic feasibility of integrating a biodiesel production facility with existing and/or new dry mill ethanol plants. The following methods for corn oil separation were considered: hexane extraction of corn oil from the dried distiller's grain stream, initial germ separation and subsequent oil extraction from the germ, and extraction of oil from the thin stillage stream using a centrifuge.

Currently the majority of research in the economics of biodiesel is focused on the use of soybean or canola oil to produce the product. Studies in Georgia (Shumaker et al.), Kansas (Coltrain), and North Dakota (Van Wechel et al.) have all focused on using soybeans as the initial oil source. This study is the initial evaluation for the use of corn oil as the feed stock.

The study found that all methods for oil separation showed potential for payback of capital investment in less than five years. This study found that producing biodiesel with corn oil, from a dry mill ethanol plant, as a feed stock is economically feasible. Additionally, using corn oil to the production of renewable fuels can help to decrease our nation's dependence on imported oil.

INTRODUCTION

Production of fuel from renewable energy sources has been of growing importance recently as a result of rising energy prices. Shrinking fossil fuel resources and concerns about greenhouse gas emissions has increased demand for cost effective, environmentally friendly, renewable fuels.

Our nation's current annual ethanol production capacity of 4 billion gallons is more than double the capacity of 1.8 billion gallons in 2001 (RFA, 2006). Plans for future construction of biodiesel production facilities indicate that the U.S. annual production capacity will jump from 350 million to 1.15 billion gallons by December of 2007 (Feltes, 2006). The use of corn oil as a feed stock for biodiesel production would integrate these rapidly growing industries. Profitability of ethanol production facilities can be enhanced by incorporating the separation of corn oil and its corresponding conversion to biodiesel.

OBJECTIVE

The overall goal of this study was to determine the economic feasibility of harvesting corn oil from a dry mill ethanol plant and using it as a feed stock for biodiesel production.

Methods

The data for this study was gathered from numerous sources. A large amount of time was spent searching for industries that offered those technologies relevant to this study. Many companies were reluctant to divulge proprietary information about equipment costs, process efficiencies, and product yields. Fortunately, a few industry representatives provided economic and technical information on biodiesel production, corn fractionation, and centrifugal oil extraction. Those industry representatives wished to keep their anonymity to avoid the risk of exposing proprietary information. Professor Mike Twedt, Director of the Energy Analysis Lab – SDSU, provided the information for hexane extraction.

The data collected included costs for process implementation, operational costs, product yields, and market values. Each of the corn oil separation methods were evaluated based on the amount of corn oil that could be harvested. The corn oil yields for each extraction method were adjusted by a size factor to take into account the quantity of oil needed for a biodiesel plant with annual production capacity of 30 million gallons. Once all of the associated costs and revenues were calculated, a payback analysis was conducted on each of the three corn oil separation methods mentioned above.

Economic Analysis

The following will describe the economic analysis of each corn oil obtainment method.

METHOD 1: CORN OIL REMOVAL VIA FRACTIONATION

Process Description

Fractionation is the separation of the three primary components (endosperm, pericarp or bran, and germ) of the corn kernel. The starch is found in the endosperm portion of the kernel. Corn starch is fermentable and is used to produce ethanol. The bran and germ are non-fermentable and are comprised of fiber and oil respectively. The corn bran would be sold as a food source and is an excellent source of dietary fiber. The corn oil is separated from the germ and would be used for biodiesel production, livestock feed, or refined and sold as food-grade oil.

The fractionation adds value to the ethanol production process through the generation of marketable co-products. The designer of the fractionation system provided the yields and market values of co-products generated by the fractionation process (Table 1).

Table 1. Co-product yields and market values. (Prices as of 6/10/05)

By-products	Yield (lbs/Bushel)	Price/lb	Value/Bushel
Corn Bran	3.05	$ 0.07	$ 0.21
Corn Germ Meal	4.09	$ 0.04	$ 0.14
Corn Oil	1.01	$ 0.27	$ 0.27

Payback Analysis

The anticipated annual return, AR, was determined by the following equation:

$$AR = [(MF) \times (FR - FC)] + BR - BC$$

where,

MF = plants required to feed biodiesel plant at design capacity
FR = revenues generated from the fractionation facility, \$/yr
BR = revenues generated from the biodiesel production facility, \$/yr
FC = cost to operate the fractionation facility, \$/yr
BC = cost to operate the biodiesel production facility, \$/yr

Fractionation Revenues

The annual value for the revenues generated by the fractionation facility was found as follows:

$$FR = CPR + IPR + OS$$

where,

CPR = co-product revenue, \$/yr
IPR = increased ethanol production revenue, \$/yr
OS = operational savings, \$/yr

In this study the corn oil was used as the feedstock for biodiesel production. Therefore, the total value of the marketable co-products (bran and germ meal) was \$0.35/bushel. The fractionation facility is sized for an ethanol plant with production capacity of 40 million gallons per year (40,000 bushel/day for 350 days/yr). The annual value for co-products is shown:

$$CPR = (\$0.35/\text{bushel}) \times (40{,}000\ \text{bushel/day}) \times (350\ \text{days/yr}) = \$4{,}900{,}000/\text{yr}$$

Fractionation decreases the amount of non-fermentable components of the corn kernel sent to the fermentation process. An industry representative stated that a 1.5% - 2.0% increase in ethanol yield (gallons/bushel) can be expected. The increased value of ethanol production was found as follows:

$$IPR = (40{,}000{,}000\ \text{gallons/yr}) \times (\$2.40/\text{gallon}) \times (1.5\%) = \$1{,}440{,}000/\text{yr}$$

The dried distiller's grains with solubles (DDGS) must be dried to an acceptable moisture level for storage and transport purposes. The absence of oil in the DDGS reduces the volume of DDGS that require drying. The cost of the energy-intensive process of drying the DDGS is decreased as a result of this volume decrease. Material handling requirements are also lowered which leads to additional cost savings. Subsequently, operational savings are realized in lower energy requirements. A fractionation industry representative provided the following estimate for operational savings due to lower DDGS volume:

OS = $750,000/yr

The total revenues that can arise from implementing a fractionation process are:

FR = CPR + IPR + OS
= $4,900,000/yr + $1,440,000/yr + $750,000/yr
= $7,090,000/yr

Biodiesel Production Revenues

The revenues generated from the biodiesel production facility were found as follows:

BR = BDS + GS + FS + SS

where,

BDS = value of biodiesel sales, $/yr
GS = value of glycerin sales, $/yr
FS = value of fatty acid sales, $/yr
SS = value of soapstock sales, $/yr

A biodiesel industry expert provided values for biodiesel and co-product yields. Table 2 displays the expected product yields and revenues for the 30 million gallon per year biodiesel production plant.

Table 2. Product yields, market values, and revenues for biodiesel production. (Prices as of 3/21/05)

Marketable Products	Yield (% of feed stock)	Annual Production	Market Value	Annual Revenues
Biodiesel	70%	30,000,000 gallons	$2.81/gallon	$84,300,000
Fatty Acid	15%	49,665,000 lb	$0.05/lb	$2,483,250
Glycerin	10%	33,110,000 lb	$0.08/lb	$2,648,800
Soapstock	5%	16,555,000 lb	$0.02/lb	$331,100
			TOTAL	**$89,763,150**

Therefore, the annual revenues for the biodiesel production operation as shown:

BR = BDS + GS + FS + SS
= $84,300,000/yr + $2,648,800/yr + $2,483,250 /yr + $331,100/yr
= $89,763,150/yr

Fractionation Facility Operation Costs

The annual cost to operate the fractionation facility includes the cost of natural gas, electricity, water/sewer, labor, repairs & maintenance, marketing, and other miscellaneous expenses. The total annual costs were provided by an industry representative and are listed as follows:

FC = \$6,680,000/yr

Biodiesel Production Facility Operation Costs

The cost to operate the biodiesel facility is estimated to be \$0.36 for every gallon of biodiesel produced. This value includes the cost of process chemicals, electricity, water/sewer, labor, repairs & maintenance, marketing and other miscellaneous expenses. The total annual costs associated with operating the biodiesel production facility were found as follows:

BC = (\$0.36/gallon) x (30,000,000 gallons)
= \$10,800,000/yr

Ethanol Plant Multiplication Factor

Using the data from Table 1, the amount of corn oil produced is found to be 14,140,000 lb/yr. The proposed biodiesel production facility is designed to produce 30 million gallons of biodiesel annually. The amount of feed stock (corn oil) required to keep the plant operating at design capacity is defined by the following equation:

FS = BP / BY

where,

BP = Annual biodiesel production, gallons/yr
BY = Biodiesel yield, %

A biodiesel industry representative stated that approximately 70% of the incoming feed stock is typically converted into biodiesel. The biodiesel feed stock requirement was found to be:

FS = (30,000,000 gallons/yr) / (0.7)
= 43,000,000 gallons/yr

Since the amount of corn oil available was less than the amount required for operating the biodiesel operation at full capacity, the following multiplication factor was defined:

MF = FS / CO

where,

FS = 43,000,000 gallons/yr (from above)
CO = Annual corn oil harvested via fractionation method, gallons/yr

By using 7.7 lb/gallon for the density of corn oil the multiplication factor was found as:

MF = (43,000,000 gallon/yr) / ([(14,140,000 lb/yr) / (7.7 lb/gallon)]
= 23.4

The multiplication factor (MF) represents the theoretical number of identical plants that would be required to supply an adequate amount of corn oil to the biodiesel production facility.

The anticipated annual return, AR, was found to be:

AR = [(MF) x (FR – FC)] + BR – BC
= [23.4 x (\$7,090,000/yr - \$6,680,000/yr)] + \$89,763,150/yr - \$10,800,000/yr
= \$88,557,150

Implementation Cost

The estimated cost for biodiesel production is based on the construction of a plant with the capacity to produce 30 million gallons of biodiesel annually. The costs for engineering and construction of the fractionation and biodiesel production facilities were obtained from valid sources in each respective industry and are estimated as shown:

Biodiesel Facility: $20,000,000
Fractionation Facility: $16,000,000

Simple Payback Period

The simple payback period for this process was found as follows:

SP = (FIC + BIC)/ AR

where,

FIC = fractionation facility implementation cost (multiplied by MF)
= (23.4) x (16,000,000)
= $374,400,000
BIC = biodiesel production implementation cost
= $20,000,000
AR = annual return due to fractionation and biodiesel production
= $88,557,150

Therefore, the simple payback period was found to be:

SP = ($374,400,000 + $20,000,000) / $88,557,150
= 4.5 years

METHOD 2: EXTRACTION OF CORN OIL FROM STILLAGE STREAM

Process Description

Concentrated thin stillage is a by-product of the distillation process stream of a dry mill ethanol plant. The whole stillage is processed through a centrifuge and separated into two streams, wet distiller's grain and thin stillage. The thin stillage is concentrated by evaporation to syrup which is added to the DDGS stream. The corn oil obtainment method evaluated here involves diverting the syrup through a centrifugal separator before it enters the DDGS stream. The centrifuge can extract 15% - 20% of the corn oil that is present in the thin stillage stream.

Payback Analysis

The anticipated annual return, AR, was determined by the following equation:

AR = [(MF) x (OR – OC)] + BR – BC

where,

MF = plants required to feed biodiesel plant at design capacity
OR = revenues generated from the oil separation facility, $/yr
BR = revenues generated from the biodiesel production facility, $/yr

OC = cost to operate the oil separation facility, \$/yr
BC = cost to operate the biodiesel production facility, \$/yr

Oil Separation Revenues

In this study, the corn oil will be used as the feedstock for biodiesel production. The remaining thin stillage will be concentrated and sold as DDGS. There are not any co-products generated through the oil separation process. However, it should be noted that the absence of oil will raise the level of protein in the DDGS. Although the available mass of marketable DDGS will be decreased, the increase in protein percentage should cause the value of the DDGS to increase. It is assumed that the increase in value of the de-fatted DDGS should offset the decrease in available tons of DDGS for sale. For the purpose of this study, no value was allotted for increased revenue due to oil separation. Therefore,

OR = \$0

Biodiesel Production Revenues

Since the biodiesel plant is the same as described in Method 1, the total revenues are identical and defined as:

BR = \$89,763,150/yr

Oil Separation Process Operation Costs

The annual cost to operate the oil process separation equipment includes the cost of natural gas, electricity, water/sewer, labor, repairs & maintenance, marketing, and other miscellaneous expenses. An industry representative stated that 1,300,000 gallons of corn oil can be extracted at an ethanol plant with operating capacity of 40 million gallons per year. Industry information also indicated that the corn oil can be extracted at an operating cost of \$0.01/gallon. The total annual costs were estimated as follows:

OC = (\$0.01/gallon) x (1,300,000 gallon/yr)
= \$13,000/yr

Biodiesel Production Facility Operation Costs

Once again, since the biodiesel plant is the same as described in Method 1, the operation costs are identical and defined as:

BC = (\$0.36/gallon) x (30,000,000 gallons)
= \$10,800,000/yr

Ethanol Plant Multiplication Factor

The amount of feed stock (corn oil) required to keep the plant operating at design capacity was found above in the analysis of Method 1 to be:

FS = 43,000,000 gallons/yr

Since the amount of corn oil available was less than the amount required for operating the biodiesel operation at full capacity, the following multiplication factor was defined:

MF = FS / CO

where,

FS = 43,000,000 gallons/yr (from above)

CO = Annual corn oil harvested via centrifugation method, gallons/yr

The multiplication factor was found to be:

MF = (43,000,000 gallon/yr) / (1,300,000 gallon/yr)
= 33.1

The multiplication factor (MF) represents the theoretical number of identical plants that would be required to supply an adequate amount of corn oil to the biodiesel production facility.

The anticipated annual return, AR, was found to be:

AR = [(MF) x (OR – OC)] + BR – BC
= [33.1 x ($0/yr - $13,000 /yr)] + $89,763,150/yr - $10,800,000/yr
= $78,532,850

Implementation Cost

The estimated cost for biodiesel production is based on the construction of a plant with the capacity to produce 30 million gallons of biodiesel annually. The costs for engineering and construction of the centrifugation and biodiesel production facilities are as follows:

Biodiesel Facility:	$20,000,000
Oil Separation Equipment:	$2,000,000

The simple payback period for this process was found as follows:

SP = (OIC + BIC)/ AR

where,

OIC = centrifugation facility implementation cost (multiplied by MF)
= (33.1) x (2,000,000)
= $66,200,000

BIC = biodiesel production implementation cost
= $20,000,000

AR = annual return due to oil separation and biodiesel production
= $78,532,850

Therefore, the simple payback period was found to be:

SP = ($66,200,000+ $20,000,000) / $78,532,850
= 1.1 years

METHOD 3: CORN OIL EXTRACTION FROM DDGS USING HEXANE

Process Description

This process involves the use of liquid Hexane to extract corn oil from the dried distiller's grains with solubles stream in dry grind ethanol production (Twedt, 2006). The following information is based on a study of an ethanol plant with a capacity of 50 million gallons per year.

Payback Analysis

The anticipated annual return, AR, was determined by the following equation:

AR = [(MF) x (HR – HC)] + BR – BC

where,

MF = plants required to feed biodiesel plant at design capacity
HR = revenues generated from the hexane extraction facility, $/yr
BR = revenues generated from the biodiesel production facility, $/yr
HC = cost to operate the hexane extraction facility, $/yr
BC = cost to operate the biodiesel production facility, $/yr

Oil Extraction Revenues

As in the previously mentioned methods, the corn oil will be used as the feedstock for biodiesel production. The hexane extraction method yields 13,914,432 pounds of corn oil per year. There are not any co-products generated through the oil separation process. However, it should be noted that the absence of oil will raise the level of protein in the DDGS. Although the available mass of marketable DDGS will be decreased, the increase in protein percentage should cause the value to increase as well. It is assumed that the increase in value of the de-fatted DDGS should offset the decrease in available tons of DDGS for sale. For the purpose of this study, no value was allotted for increased revenue due to oil separation. Therefore,

OR = $0

Biodiesel Production Revenues

Since the biodiesel plant is the same as described in Method 1, the total revenues are identical and defined as:

BR = $89,763,150/yr

Oil Extraction Process Operation Costs

The annual cost to operate the oil process separation equipment includes the cost of hexane, natural gas, electricity, labor, and repairs & maintenance. Professor Mike Twedt provided the total annual operation costs for the hexane extraction process as shown:

HC = $510,661/yr

Biodiesel Production Facility Operation Costs

Since the biodiesel plant is the same as described in Method 1, the operation costs are identical and defined as:

BC = ($0.36/gallon) x (30,000,000 gallons)
= $10,800,000/yr

Ethanol Plant Multiplication Factor

The amount of feed stock (corn oil) required to keep the plant operating at design capacity was found above in the analysis of Method 1 to be:

FS = 43,000,000 gallons/yr

Since the amount of corn oil available was less than the amount required for operating the biodiesel operation at full capacity, the following multiplication factor was defined:

MF = FS / CO

where,

FS = 43,000,000 gallons/yr (from above)

CO = Annual corn oil harvested via hexane extraction method, gallons/yr

By using 7.7 lb/gallon for the density of corn oil the multiplication factor was found as:

MF = (43,000,000 gallon/yr) / ([(13,914,432 lb/yr) / (7.7 lb/gallon)]

= 23.8

The multiplication factor (MF) represents the theoretical number of identical plants that would be required to supply an adequate amount of corn oil to the biodiesel production facility.

The anticipated annual return, AR, was found to be:

AR = [(MF) x (OR – OC)] + BR – BC

= [23.8 x ($0/yr - $510,661/yr)] + $89,763,150/yr - $10,800,000/yr

= $66,809,418

Implementation Cost

The estimated cost for biodiesel production is based on the construction of a plant with the capacity to produce 30 million gallons of biodiesel annually. The costs for engineering and construction of the hexane extraction and biodiesel production facilities are as follows:

Biodiesel Facility:	$20,000,000
Hexane Extraction Equipment:	$3,200,000

Simple Payback Period

The simple payback period for this process was found as follows:

SP = (HIC + BIC)/ AR

where,

HIC = hexane extraction operation implementation cost (multiplied by MF)

= (19) x (3,200,000)

= $60,800,000

BIC = biodiesel production implementation cost

= $20,000,000

AR = annual return due to oil separation and biodiesel production

= $66,809,418

Therefore, the simple payback period was found to be:

SP = ($60,800,000+ $20,000,000) / $66,809,418

= 1.2 years

SUMMARY AND CONCLUSION

Based on the economic analysis, all of the evaluated systems for integrating biodiesel production (from corn oil) into a dry mill ethanol plant have simple payback periods of less than five years. The method that uses centrifugation to extract the corn oil from the thin stillage stream proved to have the lowest simple payback period of 1.1 years. Although the centrifugation method resulted in the quickest return of capital investment, it required the largest (33) number of plants. The centrifugation process also had the lowest equipment implantation cost per plant. The use of fractionation to obtain the corn oil had a simple payback period of 4.5 years and revealed the highest implementation cost. A plant multiplication factor of 23.4 was required. The hexane extraction method provided a simple payback period of 1.2 years and required 23.8 plants.

The findings of this study support the integration of value-added agricultural production in order to increase efficiency. Fractionation is an especially important example of how to utilize each component of the corn kernel for its most suitable application. The co-products generated through the use of fractionation provide additional revenue streams and supported the overall profitability of ethanol production.

This study found that producing biodiesel with corn oil as a feed stock is economically feasible and can provide an additional profit enterprise to existing and/or new dry mill ethanol plants. However, no consideration was given to the cost of transporting the corn oil to the biodiesel plant. Such profitability could make increases in ethanol and biodiesel production more financially attractive. Furthermore, the increased use of corn oil as a feed stock for the production of renewable fuels can help to decrease our country's dependence on imported oil.

FUTURE RESEARCH

Future plans for this study are to evaluate the sensitivity of each investment possibility based on changing market prices. The alterations in the nutritional characteristics of the DDGS need to be technically evaluated in order to determine the economic impact associated with DDGS sales. The economic benefits of selling the corn oil as a commodity rather than using it for a biodiesel feed stock should also be considered. The level of refinement of the corn oil in each of the evaluated oil obtainment methods differs because of the difference in original location and the corresponding amount of processing the oil has been exposed to. It is suspected that the oil that is obtained from the germ will have higher quality with fewer impurities than the oil that is obtained from the thin stillage and DDGS stream. Therefore, more detailed research needs to be conducted in order to determine the effect of the corn oil quality on the biodiesel and co-product yields.

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