California Environmental Protection Agency
Air Resources Board

California Modified GREET Pathway for the Production of Biodiesel from Corn Oil at Dry Mill Ethanol Plants

Stationary Source Division

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Preliminary draft version developed by Alternative Fuels Section of the California Air Resources Board for the Low Carbon Fuel Standard Methods 2A-2B Process

When reviewing this document, please submit comments directly to:

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These comments will be compiled, reviewed, and posted

to the LCFS website in a timely manner.

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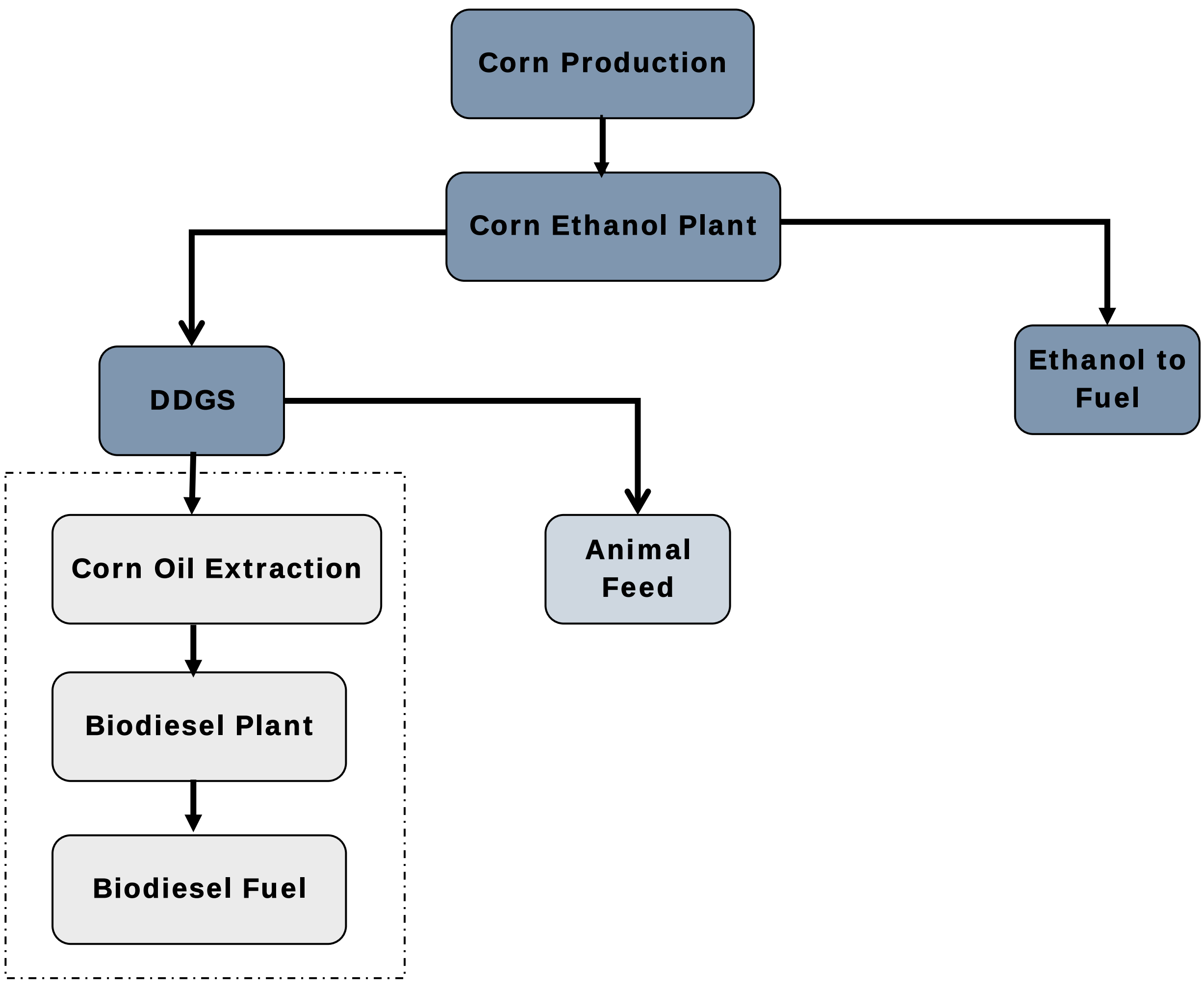
1. Pathway Summary

This document contains the ARB's estimate of the carbon intensity for the production of biodiesel fuel produced from corn oil that is produced at dry mill ethanol plants. The ARB's analysis is for corn oil extraction at dry mill ethanol plants producing Dry Distillers' Grains with Solubles (DDGS), and using natural gas as a process fuel. Using information provided by Greenshift Corporation, the ARB has estimated the energy use and carbon intensity associated with the extraction of corn oil at dry mill ethanol plants, and the energy savings that would also occur during this extraction process. In this analysis, the ARB assumes that corn oil extraction facilities will be added to pre-existing corn ethanol plants. It is assumed that the corn oil is extracted from the thin stillage after fermentation and distillation. For this type of process, the ARB's estimated carbon intensity is 4.02 grams of CO2 equivalent emissions per megajoule of biodiesel produced. This value does not include any emissions resulting from the conversion of land to agricultural land. These emissions are generally referred to as Indirect Land Use Change (ILUC) emissions. The corn oil produced at the ethanol plant is sent to a biodiesel plant where the corn oil in transesterified to fatty acid methyl ester (FAME) biodiesel. Figure 1 illustrates the corn oil biodiesel production process.

The combination of corn oil extraction processes and ethanol production processes at the same plant can complicate the estimation of carbon intensity values for each of the two products. The emissions associated with agricultural chemical production, corn farming operations, and corn transportation, for example, could be allocated in whole or in part to each of the two different products. A number of allocation schemes have been conceived for allocating these emissions. For example, emissions could be allocated on the basis of the total energy content of the product produced. In this analysis, the ARB has decided to allocate all of emissions associated with agricultural chemical production, corn farming operations, and corn transportation to the carbon intensity value of the ethanol produced at the ethanol plant, and none of the emissions to the carbon intensity of the corn oil. The reason for this allocation scheme lies in the nature of the corn oil extraction facilities that the ARB expects will be used as part of the compliance strategies for the Low Carbon Fuel Standard. Currently there are very few corn oil extraction facilities at corn ethanol plants. The ARB expects that, as corn oil becomes an increasingly attractive option for biodiesel fuel production, corn oil extraction facilities will be added to the pre-existing corn ethanol plants. However, ethanol will always be the primary product produced at the corn ethanol plant, and the reason for the construction of any new corn ethanol plants. The addition of corn oil extraction facilities to pre-existing corn ethanol plants and corn oil's secondary importance as a product suggest to the ARB that the carbon intensity of the corn oil should be regarded as a marginal carbon intensity. The carbon intensity of the corn oil should be calculated by considering only the incremental emissions that occur from adding the corn oil extraction facility. For the same reason, the ARB believes also that all ILUC emissions should be assigned to the carbon intensity of corn ethanol. For the corn used in existing corn ethanol plants, any emissions resulting from land use

Figure 1

Corn Oil Biodiesel Production Process



conversion will have already occurred before the installation of a corn oil extraction facility at the plant. Therefore, all the ILUC emissions should be assigned to the corn ethanol. The carbon intensity of 4.02 grams of CO_2 equivalent per megajoule of biodiesel produced could be used by any corn oil producer who demonstrates that the net energy savings from the extraction of corn oil at his facility is not less than the value used in the calculation of the 4.02 gram per megajoule carbon intensity. As will be discussed later in Section 4 of this analysis, this value is 3,070 Btu per gallon of ethanol produced. This value is equal to the energy savings of corn oil extraction of 3,700 Btu per gallon of ethanol less the additional thermal energy requirements of 290 Btu per gallon of ethanol and the additional electrical energy requirements of 340 Btu per gallon that are required for corn oil extraction. The net energy savings of 3,070 Btu per gallon of ethanol produced is equal to 47,231 Btu per gallon of corn oil produced. If a corn oil producer's net energy savings at the ethanol plant from corn oil production is less than this value, the producer would have to use the Method 2A compliance option of the LCFS.

2. Description of Corn Oil Extraction Process

Fuel-grade corn oil can be produced at corn ethanol plants by extracting the oil from the stillage produced at the plants. The extraction follows fermentation and distillation and occurs before drying of the plant's Distiller's Grains with Solubles (DGS). Corn Oil extraction systems can be added to existing corn ethanol plants to increase plant energy efficiency and to increase fuel yields. The addition of corn oil extraction to an existing corn ethanol plant will generally have no effect on the plant's ethanol production.

It is the ARB's understanding that a number of companies have developed, or are developing, technologies to extract corn oil from stillage. However, there is much more public information available on the energy requirements for corn oil extraction for a process developed by Greenshift Corporation than for any of the other corn oil extraction processes that are being developed. For this reason, the ARB's analysis in this document is based on the Greenshift process and Greenshift's estimates of energy consumption and energy savings for corn oil extraction. The technology commercialized by Greenshift can be retrofitted into existing dry mill ethanol plants. Greenshift's systems are of two types. The first system, referred to as Corn Oil Extraction 1, extracts corn oil from the thin stillage after it is removed from the whole stillage through centrifuging. In this system, the partially concentrated thin stillage is heated and the corn oil is extracted by separation in a second centrifuge. Steam is used in heat exchangers to raise the temperature of the thin stillage for extraction. After extraction of the corn oil, thermal energy from the stillage is recovered in heat exchangers to heat the incoming stillage. Appendix C contains a more detailed discussion of the Greenshift process.

The thin stillage generally contains about 30 percent of the oil available in the corn. Corn Oil Extraction 1 can recover most of this corn oil, depending on site-specific conditions. A typical ethanol plant uses corn that contains about four percent by weight corn oil, which, in the absence of corn oil extraction, passes through the process to the DGS. For a 50 million gallon per year ethanol plant, the incoming corn oil is about 5 million gallons per year, and Corn Oil Extraction 1 can recover about 1.5 million gallons per year.

Green Shift's second corn oil extraction system, referred to as Corn Oil Extraction 2, is an extraction extension that frees another 30 percent of the corn oil that is bound in the whole stillage prior to the separation of wet grain and thin stillage in the plant's centrifuge. As more than 40 percent of the total oil within the corn is trapped within the wet cake, Greenshift developed a washing technique to free this oil from the wet cake so that it is recoverable in the Corn Oil Extraction 1 system. The additional oil made available to the Corn Oil Extraction 1 system generally doubles the production of corn oil. Corn Oil Extraction 1 and 2 systems together can extract 60 to 70 percent of the corn oil passing through the plant, which translates to about six to seven gallons of corn oil per 100 gallons of ethanol produced. In this analysis, and for purposes of calculating total energy requirements, energy savings, and carbon intensity for corn oil extraction, it is assumed that both Corn Oil Extraction 1 and Corn Oil Extraction 2 systems are being used.

3. Energy Use for Corn Oil Extraction

Electric power and steam are supplied to the corn oil extraction system from the ethanol plant utilities. However, incorporation of corn oil extraction systems into an existing dry mill corn ethanol facility that produces dry DGS achieves energy savings which are greater than the energy needed to extract the corn oil. Therefore, no increase in the size of the ethanol plant's boiler or its fuel consumption is needed as a result of the addition of corn oil extraction systems. According to GreenShift, operating a Corn Oil Extraction 1 system requires about 0.01 kWhr per gallon of ethanol produced. This electrical energy is used to power motors on the centrifuge and the pumps. This electricity use is about 34 Btu per gallon of ethanol produced. A Corn Oil Extraction 2 system will use 0.09 kWhr per gallon of ethanol produced, or about 306 Btu per gallon of ethanol produced. The greater electricity use for Corn Oil Extraction 2 system arises from the operation of much larger centrifuges. Thus, the total additional electricity demands for operating Corn Oil Extraction 1 and 2 systems together would be about 340 Btu per gallon of ethanol produced.

Both Corn Oil Extraction 1 and Corn Oil Extraction 2 systems use steam from the ethanol plant's utility system to provide operating heat. The heat needed to operate a Corn Oil Extraction 1 system is about 180 Btu per gallon of ethanol produced, while for a Corn Oil Extraction 2 system it is about 110 Btu per gallon of ethanol produced. This energy generally comes from a boiler burning natural gas. The total additional thermal energy requirements for operating Corn Oil Extraction 1 and 2 systems together would be about 290 Btu per gallon of ethanol produced. Thus, the total additional electrical and thermal energy requirements at the ethanol plant for operation of both Corn Oil Extraction 1 and 2 systems would be about 630 Btu per gallon of ethanol produced.

As in all life-cycle pathway analyses performed by the ARB, it is also necessary to include the upstream feedstock energy uses. For the corn oil-to-biodiesel pathway, upstream energy use was estimated using the same methodology that was used to estimate energy use for the ARB's pathway for the production of ethanol from corn (See ARB's "Detailed Modified California GREET Pathway for Corn Ethanol" for additional details). The CA-GREET model was used in these analyses as the basis for these upstream energy use estimates. More details of how the upstream energy uses were calculated are shown in Appendix A.

4. Ethanol Plant Energy Savings

Significant energy savings result from the installation of Corn Oil Extraction 1 systems at corn ethanol plants that dry their DGS. There are three main sources of these savings. These are: 1) Improved heat transfer efficiency in the evaporators as a result of the removal of oil and its insulating characteristics; 2) Increased drying efficiency resulting from a lower mass flow through the dryers; 3) Improved flow characteristics of DGS after corn oil removal, which results in less drying time. These three effects, according to Greenshift, combine to reduce the energy used by the ethanol plant DGS dryers by about 3,700 Btu per gallon of ethanol produced. This energy savings is discussed in more detail in Appendix C. Deducting from this energy savings the additional energy consumption for Corn Oil Extraction 1 and 2 systems of 630 Btu per gallon gives a net plant energy savings of about 3,070 Btu per gallon of ethanol produced. This is the energy saved at the ethanol plant only and does not include the upstream feedstock energy uses and savings. Inclusion of the upstream feedstock energy uses and savings results in a lower total energy savings of 2,634 Btu per gallon of ethanol produced from the use of Corn Oil Extraction 1 and 2 systems at a dry mill ethanol plant producing dry DGS. The savings reduction is due mostly to the inclusion of the additional energy needed to produce electricity for use in the ethanol plant. This document presents the natural gas and electricity results for oil extraction separately from the credit due to the 3,700 Btu per gallon natural gas savings. Table 1 shows the estimated energy use and savings from the installation of Corn Oil 1 and Corn Oil 2 systems at an existing corn ethanol plant producing dry DGS. More details of the calculations of the energy use savings are shown in Appendix A.

Table 1

Energy Use and Savings from Corn Oil Extraction Installation at Dry Mill EtOH Plants

Source of Energy	Energy Use (Btu/gal EtOH produced)
1. Thermal Energy Use at the EtOH Plant (Natural Gas)	290
2. Thermal Energy, Upstream Feedstock (Natural Gas)	20
3. Electrical Energy Use at the EtOH Plant	340
4. Electrical Energy, Upstream Stationary Electricity Feedstock Stage Energy (Energy to Produce the Fuel Used to Produce Electricity)	34
5. Electrical Energy, Upstream Stationary Electricity Fuel Stage Energy (Energy to Produce Electricity)	982
6. Energy Savings Due to Reduced DGS Drying Energy at Ethanol Plant (Natural Gas)	(3,700)
7. Energy Savings Due to Reduced DGS Drying, Upstream Natural Gas Feedstock	(260)
8. Net Energy Savings at the Ethanol Plant Due to Corn Oil Production (6 – 1 – 3)	(3,070)
9. Net Energy Savings Due to Corn Oil Production, Including Upstream Energy Uses (6 + 7 – 1 – 2 – 4 – 5)	(2,634)

5. Carbon Intensities for Corn Oil Extraction

The calculated carbon intensities for the extraction of corn oil using Corn Oil Extraction 1 and 2 systems are shown in Table 2. The greenhouse gas emission factors used to calculate the carbon intensities are the same as those used in the ARB's pathway for the production of ethanol from corn, which are based on the CA-GREET model (See ARB's "Detailed Modified California GREET Pathway for Corn Ethanol" for additional details). As shown in Table 1 and discussed before, the addition of Corn Oil 1 and Corn Oil 2 systems at a corn ethanol plant reduces the total energy consumption at the ethanol plant by about 3,070 Btu per gallon of ethanol produced, which translates to about a 9.4 percent reduction in the energy used at the ethanol plant (assuming the GREET ethanol plant energy value of 36,000 Btu per gallon of ethanol produced). The net reduction in total energy consumed (at the ethanol plant and upstream) results in reduced greenhouse gas emissions and a corresponding carbon intensity credit of about 1.838 gCO_2 per MJ of ethanol produced. Assuming that about 6.5 gallons of corn oil are produced per 100 gallons of ethanol, and taking into account the energy differences between corn oil and ethanol, this credit is equivalent to about 18.06 gCO_2 per MJ of corn oil produced. The details of this calculation are shown in Appendix B.

Table 2

Greenhouse Gas Emission Factors and Carbon Intensities for Corn Oil Extraction

Source of Energy Use	GHG Emissions Factor ($gCO_2e/mmBtu$)	Carbon Intensity (gCO_2e/MJ of EtOH)	Carbon Intensity (gCO_2e/MJ of Biodiesel)
1. Thermal Energy Use at the EtOH Plant, Natural Gas, (CO_2 emissions)	58,188	0.200	1.97
2. Thermal Energy, Upstream Feedstock, Natural Gas, (CO_2 emissions)	5,245	0.018	0.18
3. Electrical Energy, Upstream Stationary Electricity Feedstock Stage Energy, (Energy to Produced the Fuel Used to Produce Electricity), (CO_2 emissions)	7,794	0.031	0.30
4. Electrical Energy, Upstream Stationary Electricity Fuel Stage Energy (Energy to Produce Electricity), (CO_2 emissions)	233,154	0.936	9.19
5. Electrical Energy and Thermal Energy, Direct and Upstream Use of Natural Gas and Electricity (CH_4, VOC, CO, N_2O Emissions)	Please See Table in Appendix B, Calculation 5.	0.050	0.49
6. Total Carbon Intensity for Corn Oil Extraction (1+2+3+4+5)		1.235	12.13
7. Carbon Intensity of Energy Savings Due to Reduced DGS Drying Energy at Ethanol Plant, Natural Gas, (CO_2 emissions)	58,188	-2.674	-26.27
8. Carbon Intensity of Energy Savings Due to Reduced DGS Drying at the Ethanol Plant, Upstream Natural Gas Feedstock, (CO_2 emissions)	5,245[1]	-0.241	-2.37
9. Carbon Intensity of Energy Savings Due to Reduced DGS Drying Energy at Ethanol Plant, Direct and Upstream Energy Use (CH_4, VOC, CO, N_2O emissions)	Please See Table in Appendix B, Calculation 5.	-0.158	-1.55
10. Carbon Intensity of Total Energy Savings Due to Reduced DGS Drying (7+8+9)		-3.073	-30.19
11. Net Carbon Intensity for Corn Oil Extraction (Including Energy Savings) (6+10)		-1.838	-18.06

Note: 1. The units of this emission factor are gCO2e upstream emissions per Btu downstream energy use. Therefore, the total greenhouse gas emissions are calculated by taking the product of the emission factor and the downstream energy use of 290 Btu per gal.

6. Effect on Corn Oil Extraction on DGS Production

As mentioned earlier, the use of both Corn Oil Extraction 1 and 2 systems would remove about six to seven gallons of corn oil per 100 gallons of corn ethanol produced. This equates to about 0.50 pounds of corn oil per gallon of ethanol produced. The removal of the corn oil from the dry DGS (DDGS) reduces the DDGS co-product credit for corn ethanol. Because DDGS yields without the use of corn oil extraction are typically 5.34 pounds per gallon of ethanol produced, a reduction of 0.50 pounds per gallon of ethanol represents about a 9.4 percent reduction in the DDGS yield. This 9.4 percent reduction in DDGS yield would translate into a 9.4 percent reduction in the DDGS co-product credit. Because the DDGS co-product credit for corn ethanol without corn oil extraction is about 11.5 gCO_2e per MJ of ethanol produced, a 9.4 percent reduction in the credit due to corn oil extraction would translate into a reduction in the co-product credit of about 1.08 gCO_2e per MJ of ethanol produced. This reduction in the credit can be considered as an increase in the carbon intensity of corn oil-based biodiesel. Converting the value of the credit reduction of 1.08 gCO_2e per MJ of ethanol to a gCO_2e per MJ biodiesel basis gives a reduction in the credit of 10.61 gCO_2 per MJ of biodiesel. The details of this calculation are shown in Appendix B. The reduction in the co-product credit is included as an emission component in the carbon intensity of the biodiesel.

Removal of corn oil also affects the nutritional profile of the DGS. The removal of the corn oil reduces the fat and energy content, and increases the protein content of the DGS. For some animals, it might be more important to have higher fat and energy content, while for others it might be more important to have higher protein content. Thus, for some animals, the loss in the DGS volume and the reduction in the corn ethanol co-product credit might be offset by a higher protein content of the DGS. The ARB has not attempted to estimate the effects of these nutritional values on the extent to which DGS displaces other feeds in the marketplace, nor the carbon intensity associated with this displacement change.

7. Complete Pathway Carbon Intensities

In addition to the carbon intensity associated with extraction of corn oil at the dry mill ethanol plant, there are other greenhouse gas emissions associated with the corn oil-to-biodiesel pathway. These other emissions originate from the transport of corn oil from the ethanol plant to the biodiesel production facility, the transesterification of the corn oil at the biodiesel facility, the transportation and distribution of biodiesel, and the emissions associated with burning the biodiesel in vehicles. In this pathway analysis, it is assumed that the emissions associated with the corn oil transport, transesterification, and biodiesel transportation and distribution are the same as estimated in the ARB's Soybean-to-Biodiesel Pathway document (See ARB's "Detailed California-Modified

GREET Pathway Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters (FAME).

Many of the emissions associated with the growing of corn and the production of agricultural chemicals could be included in the carbon intensity of the corn oil-to-biodiesel pathway instead of including all of these emissions in the carbon intensity of corn ethanol. However, the ARB determined that all of these emissions should be attributed to the corn ethanol rather than the corn oil pathway. This decision was based on the probability that most of the fuel-grade corn oil that will be produced in the future to help fuel suppliers meet the requirements of the ARB's Low Carbon Fuel Standard will be produced from corn oil extraction facilities that will have been added on to preexisting corn ethanol plants. Under this assumption, the carbon intensity of corn oil should be viewed as a marginal carbon intensity resulting from the addition of a corn oil extraction system to a corn ethanol plant. Also, the ARB allocates the entire DDGS co-product credit to a reduction in the carbon intensity of corn ethanol. Similarly, the reduced DDGS credit resulting from the removal of corn oil is to be accounted for as an increment to the corn oil carbon intensity value.

In this analysis, all indirect emissions resulting from land use changes are allocated to corn ethanol and not to corn oil. The basis for this allocation is also the assumption that corn oil will be produced from pre-existing corn ethanol facilities, and that any emissions resulting from land use conversion will have already occurred before the installation of a corn oil extraction facility at the corn ethanol plant.

Table 3 shows the individual components and the total carbon intensity for the entire corn oil-to-biodiesel pathway. Note that the carbon intensity for the corn oil extraction component is now expressed in units of grams of CO_2 equivalent per MJ of biodiesel produced instead of grams of CO_2 equivalent per MJ of EtOH produced, as shown in Table 2. Detailed calculations of these carbon intensity values are shown in Appendix B.

Table 3

Corn Oil-to-Biodiesel Pathway Carbon Intensity

Component	Carbon Intensity (gCO_2e/MJ biodiesel)
Corn Oil Extraction	12.13
Corn Oil Transport	1.37[1]
Biodiesel Transesterification	4.89[2]
Biodiesel Transportation and Distribution	0.76[3]
Fossil Carbon in Fuel	3.67[4]
Vehicle CH4 and N2O	0.78[5]
Reduction in Corn Ethanol DDGS Co-product Credit	10.61
Total Corn Oil Biodiesel (without credits)	34.21
Total Corn Oil Extraction Energy Savings Credit	-30.19
Total Corn Oil Biodiesel (with credits)	4.02

1 - Air Resources Board, Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME), Page 11

2 - Air Resources Board, Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME), Page 12

3 - Air Resources Board, Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME), Page 13

4 - Air Resources Board, Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME), Page 49

5 - Air Resources Board, Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME), Page 50

Appendix A - Energy Use Estimates

1. Corn Oil Extraction, Upstream Well-to-Tank Natural Gas Feedstock Use

This estimate is derived from the CA-GREET-based methodology, which is illustrated in the calculations shown on page 42 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol."

Upstream natural gas energy use is 70,154 Btu/mmBtu of natural gas produced. For 290 Btu/gal ethanol of natural gas used at the ethanol plant, the upstream natural gas use is:

(70,154 Btu/mmBtu) / (1,000,000 Btu/mmBtu) x 290 Btu/gal ethanol = 20 Btu/gal ethanol

2. Corn Oil Extraction, Electrical Energy, Upstream Stationary Electricity Feedstock Stage Energy Use (Energy to Produce the Fuel Used to Produce Electricity)

This estimate is derived from the CA-GREET-based methodology, which is illustrated in the calculations shown on page 42 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol."

The stationary electricity feedstock energy is 99,970 Btu/mmbtu. For a total electrical energy use at the ethanol plant of 340 Btu per gallon of ethanol produced, the upstream stationary electricity feedstock stage energy is:

(340 Btu/gal) x (99,970 Btu/mmBtu) / (1,000,000 Btu/mmbBtu) = 34 Btu/gal

3. Corn Oil Extraction, Electrical Energy, Upstream Stationary Electricity Fuel Stage Energy (Energy to Produce Electricity)

This estimate is derived from the CA-GREET-based methodology, which is illustrated in the calculations shown on page 42 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol."

The stationary electricity fuel stage energy is 2,887,173 Btu/mmBtu. For a total electrical energy use at the ethanol plant of 340 Btu per gallon of ethanol produced, the upstream stationary electricity fuel stage energy is:

(340 Btu/gal) x (2,887,173 Btu/mmBtu) / (1,000,000 Btu/mmbBtu) = 982 Btu/gal

4. Corn Oil Extraction, Energy Savings Due to Reduced DGS Drying, Upstream Natural Gas Feedstock Use

This estimate is derived from the CA-GREET-based methodology, which is illustrated in the calculations shown on page 42 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol."

The upstream natural gas energy use is 70,154 Btu/mmBtu of natural gas produced. Therefore, this is also the savings for the use of less fuel natural gas downstream. For a natural gas energy savings of 3,700 Btu/gal of ethanol produced at the ethanol plant, the upstream natural gas savings is:

(70,154 Btu/mmBtu) / (1,000,000 Btu/mmBtu) x 3,700 Btu/gal ethanol = 260 Btu/gal ethanol

Appendix B - Emissions Factors and Carbon Intensity Estimates

1. Corn Oil Extraction Carbon Intensity, Direct Emissions, Thermal Energy, Natural Gas (CO2 emissions)

This estimate is derived from the CA-GREET-based methodology and on the values shown on page 44 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol." The emission factor of 58,188 gCO_2/mmBtu represents direct emissions per Btu downstream energy use. Therefore, the total direct greenhouse gas emission carbon intensity from natural gas feedstock use is calculated by taking the product of the emission factor and the downstream energy use of 290 Btu/gal ethanol).

(290 Btu/gal ethanol) x (58,188 gCO_2/mmBtu) / (76,330 Btu/gal) / (1,055 J/Btu) = 0.210 gCO_2/MJ EtOH

An adjustment to this carbon intensity must be made to account for the glycerine co-product credit. The adjustment is made by multiplying the carbon intensity by 0.951, as was done in the ARB's soy bean-to-biodiesel pathway analysis (Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME). Doing this multiplication gives a carbon intensity of 0.200 gCO2/MJ.

2. Corn Oil Extraction Carbon Intensity, Upstream Well-to-Tank Natural Gas Feedstock Energy Use (CO_2 emissions)

This estimate is derived from the CA-GREET-based methodology and on the values shown on page 44 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol." The emission factor of 5,245 gCO_2/mmBtu represents upstream emissions per Btu of downstream energy use. Therefore, the total upstream emissions greenhouse gas carbon intensity from natural gas feedstock use is calculated by taking the product of the emission factor and the downstream energy use of 290 Btu/gal ethanol).

(290 Btu/gal ethanol) x (5,245 gCO_2/mmbtu) / (76,330 Btu/gal) / (1,055 J/Btu) = 0.0189 gCO_2/MJ ethanol. Multiplying by the glycerine co-product adjustment factor of 0.951 gives a carbon intensity of 0.0180 gCO_2/MJ.

3. Corn Oil Extraction, Carbon Intensity of Electrical Energy, Upstream Stationary Electricity Feedstock Stage Energy (Energy Used to Produce the Fuel Used to Produce Electricity) (CO_2 emissions)

This estimate is derived from the CA-GREET-based methodology and on the values shown on page 44 of the ARB's "Detailed Modified California GREET Pathway for Corn

Ethanol." The emission factor of 7,794 gCO_2/mmBtu represents the upstream emissions per Btu of downstream electricity use. Therefore, the upstream stationary electricity feedstock carbon intensity is:

(7,794 gCO_2/mmBtu) / (1,000,000 Btu/mmBtu) x (340 Btu/gal ethanol) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) = 0.033 gCO_2/MJ ethanol. Multiplying by the glycerine co-product adjustment factor of 0.951 gives a carbon intensity of 0.0313 gCO_2/MJ.

4. Corn Oil Extraction, Carbon Intensity of Electrical Energy, Upstream Stationary Electricity Fuel Stage Energy (Energy to Produce Electricity) (CO2 emissions)

This estimate is derived from the CA-GREET-based methodology and on the values shown on page 44 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol." The emission factor of 233,154 gCO_2/mmBtu represents the emissions from the natural gas fuel burned to generate electricity. The carbon intensity value is:

(233,154 gCO_2/mmBtu) / (1,000,000 Btu/mmBtu) x (340 Btu/gal EtOH) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) = 0.984 gCO_2/MJ EtOH. Multiplying by the glycerine co-product adjustment factor of 0.951 gives a carbon intensity of 0.936 gCO_2/MJ.

5. Corn Oil Extraction, Carbon Intensity of Electrical Energy and Thermal Energy, Direct Use of Natural Gas and Electricity (CH_4, VOC, CO, N_2O Emissions)

This estimate is derived from the CA-GREET-based methodology shown on page 44 of the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol." The CA-GREET emissions factors for direct and upstream use of natural gas and electricity are as shown in the table below.

Pollutant (g/MMBtu)	Natural Gas			Electricity		
	Direct	Upstream	Total	Direct	Upstream	Total
VOC	1.987	6.283	8.27	18.855	4.762	23.62
CO	22.621	11.611	34.23	17.691	200.550	218.24
CH4	1.100	128.837	129.94	317.44	7.261	324.70
N2O	0.315	0.067	0.382	0.303	3.308	3.61

notes: 1)Direct emission factors are in units of direct emissions per unit direct energy use. Upstream emission factors are in units of upstream emissions per unit direct energy use. Because both direct and upstream emission factors are in units of emissions pre direct energy use, they can be added. 2) These emission factors can be found on the following tabs and cells in the CaGREET spreadsheet: Natural Gas, Direct: EF Tab, Cells B6:C14; Natural Gas, Upstream: NG Tab, Cells B129:B137; Electricity, Direct: Electric tab, Cells B89:B97. 3) The emissions factors are for the CaGREET Midwest electricity profile.

Carbon Intensity Calculations:

Natural Gas VOC: (8.27 g/mmBtu) x (290 Btu/gal) / (1,000,000) x (0.85/0.27) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.000089 gCO_2e/MJ

Natural Gas CO: (34.23 g/mmBtu) x (290 Btu/gal) / (1,000,000) x (0.43/0.27) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) 1 = 0.000187 gCO_2e/MJ

Natural Gas CH_4: (129.94 g/mmBtu) x (290 Btu/gal) / (1,000,000) x (25 GWP) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.011125 gCO_2e/MJ

Natural Gas N_2O: (0.382 g/mmBtu) x (290 Btu/gal) / (1,000,000) x (298 GWP) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.000390 gCO_2e/MJ

Electricity VOC: (23.62 g/mmBtu) x (340 Btu/gal) / (1,000,000) x (0.85/0.27) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.000299 gCO_2e/MJ

Electricity CO: (218.24 g/mmBtu) x (340 Btu/gal) / (1,000,000) x (0.43/0.27) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.001396 gCO_2e/MJ

Electricity CH_4: (324.70 g/mmBtu) x (340 Btu/gal) / (1,000,000) x (25 GWP) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.032594 gCO_2e/MJ

Electricity N_2O: (3.61 g/mmBtu) x (340 Btu/gal) / (1,000,000) x (298 GWP) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) x (0.951) = 0.004320 gCO_2e/MJ

Total Carbon Intensity (gCO2e/MJ): 0.000089 + 0.000187 + 0.011125 + 0.000390 + 0.000299 + 0.001396 + 0.032594 + 0.004320 = 0.050400 gCO_2e/MJ

6. Total Carbon Intensity of Corn Oil Extraction (CO_2e emissions)

Carbon intensity of corn oil extraction is the sum of the above components, which is equal to: 0.200 + 0.018 + 0.031 + 0.936 + 0.050 = 1.235 gCO_2e/MJ ethanol.

gCO_2e/MJ biodiesel = (1.235 gCO_2e/MJ ethanol) x (76,330 Btu/gal ethanol) x (1 gal ethanol/0.065 gal corn oil) x (1 gal corn oil/1 gal biodiesel) x (1 gal biodiesel/119,550 Btu) = 12.13 gCO_2e/MJ biodiesel

7. Carbon Intensity of Energy Savings Due to Reduced DGS Drying Energy at Ethanol Plant, Direct Energy Use (Natural Gas) (CO_2 emissions)

The emission factor of 58,188 gCO_2/mmBtu for the natural gas savings is the same as the emission factor for the natural gas use shown in Calculation 1 above. The carbon intensity of these savings is as follows:

(3,700 Btu/gal ethanol energy savings) x (58,188 gCO_2/mmBtu) / (76,330 Btu/gal) / (1,055 J/Btu) = 2.674 gCO_2/MJ

8. Carbon Intensity of Energy Savings Due to Reduced DGS Drying Energy, Upstream Natural Gas Feedstock (CO_2 emissions)

The emission factor of 5,245 gCO_2/mmBtu for the natural gas savings is the same as the emission factor for the natural gas use shown in Calculation 2 above. The carbon intensity of these savings is as follows:

(3,700 Btu/gal ethanol energy savings) x (5,245 gCO_2/mmBtu) / (76,330 Btu/gal) / (1,055 J/Btu) = 0.241 gCO_2/MJ

9. Carbon Intensity of Energy Savings Due to Reduced DGS Drying Energy at Ethanol Plant, Direct and Upstream Energy Use (CH_4, VOC, CO, N_2O Emissions)

These calculations are performed the same way as in 5., but for natural gas only, using the same emission factors and the ethanol plant thermal energy savings of 3,700 mmBtu/gal.

Carbon Intensity Calculations:

Natural Gas VOC: (8.27 g/mmBtu) x (3,700 Btu/gal) / (1,000,000) x (0.85/0.27) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) = 0.001196 gCO2e/MJ

Natural Gas CO: (34.23 g/mmBtu) x (3,700 Btu/gal) / (1,000,000) x (0.43/0.27) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) = 0.002505 gCO2e/MJ

Natural Gas CH_4: (129.94 g/mmBtu) x (3,700 Btu/gal) / (1,000,000) x (25 GWP) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) = 0.149258 gCO2e/MJ

Natural Gas N_2O: (0.382 g/mmBtu) x (3,700 Btu/gal) / (1,000,000) x (298 GWP) / (76,330 Btu/gal) / (1,055 J/Btu) x (1,000,000 J/MJ) = 0.005231 gCO2e/MJ

Total Carbon Intensity from VOC, CO, CH_4, and N_2O = 0.001196 + 0.002505 + 0.149258 + 0.005231= 0.158 gCO_2e/MJ

10. Total Carbon Intensity of Energy Savings Due to Reduced DGS Drying Energy (CO_2, VOC, CO, CH_4, N_2O emissions)

The total carbon intensity of the energy savings due to reduced DGS drying energy is the sum of the carbon intensities in calculations 7, 8, and 9. This is: 2.674 + 0.241 + 0.158 = 3.073 gCO_2e/MJ of ethanol

The carbon intensity is converted from a gCO_2e/MJ of ethanol basis to a gCO2e/MJ of biodiesel fuel basis as follows:

gCO_2e/MJ biodiesel = (3.073 gCO_2e/MJ ethanol) x (76,330 Btu/gal ethanol) x (1 gal ethanol/0.065 gal corn oil) x (1 gal corn oil/1 gal biodiesel) x (1 gal biodiesel/119,550 Btu) = 30.19 gCO_2e/MJ biodiesel

11. Net Carbon Intensity Due to Due to Corn Oil Extraction (Including Energy Savings)

The net carbon intensity of corn oil extraction, including the energy savings, can be converted from the -1.838 gCO_2e/MJ of ethanol produced value shown in Table 2 to an equivalent gCO2e/MJ of biodiesel produced as follows:

gCO2e/MJ biodiesel = (-1.838 gCO_2e/MJ ethanol) x (76,330 Btu/gal ethanol) x (1 gal ethanol/0.065 gal corn oil) x (1 gal corn oil/1 gal biodiesel) x (1 gal biodiesel/119,550 Btu) = -18.06 gCO_2e/MJ Btu of biodiesel. This is equivalent to a credit of 18.06 gCO2e/MJ of biodiesel produced.

12. Carbon Intensity Due to Reduction in Corn Ethanol DDGS Co-product Credit

This carbon intensity is due to the reduction in the DDGS co-product credit for corn ethanol due to the addition of a corn oil extraction process. As mentioned above, the DDGS co-product for corn oil is reduced by about 9.4 percent when corn oil is extracted. The DDGS co-product credit for corn ethanol without the use of corn oil extraction is about 11.5 gCO_2e per MJ of ethanol produced, as discussed in the ARB's "Detailed Modified California GREET Pathway for Corn Ethanol." A reduction of this credit by about 9.4 percent is a reduction of about 1.08 gCO2e per MJ of ethanol produced. This value is converted to a gCO2e per MJ of biodiesel produced as follows:

gCO_2e/MJ of biodiesel = (1.08 gCO_2e/MJ of ethanol) x (76,330 Btu/gal ethanol) x (1 gal ethanol/0.065 gal corn oil) x (1 gal corn oil/1 gal biodiesel) x (1 gal biodiesel/119,550 Btu) = 10.61 gCO_2e/MJ of biodiesel.

Appendix C - Energy Use Reduction in the Production of Corn Ethanol from Adding Corn Oil Extraction By Greenshift Corporation

GreenShift Corporation ("GreenShift") is a company that develops and commercializes clean technologies that facilitate the efficient use of natural resources. As a particular focus, we are using innovative technologies to produce biofuel and other biomass-derived products by extracting and refining raw materials that other producers cannot access or process. A prime example of fundamental importance to the increased availability of renewable fuels is using the extracted corn oil from dry mill corn ethanol plants as a feedstock for biofuels, such as biodiesel. The technology also substantially decreases the energy and production costs of corn ethanol, thereby simultaneously reducing greenhouse gas ("GHG") emissions associated with corn ethanol and improving the economic viability of ethanol plants. Corn oil extraction systems, dubbed "COES" by GreenShift, thereby add even more to the renewable energy value of corn ethanol.

GreenShift presented testimony at the Public Hearing on the federal Renewable Fuel Standard Program ("RFS2") held in Washington DC on June 9, 2009 and submitted comments on the RFS2 rulemaking. GreenShift spoke of three of the most significant effects of extracting corn oil from any ethanol plant:

First: The energy savings from installing corn oil extraction are substantial, reducing energy use to manufacture ethanol by as much as 25 percent. As a result, GHG emissions are actually 29 percent less than gasoline.

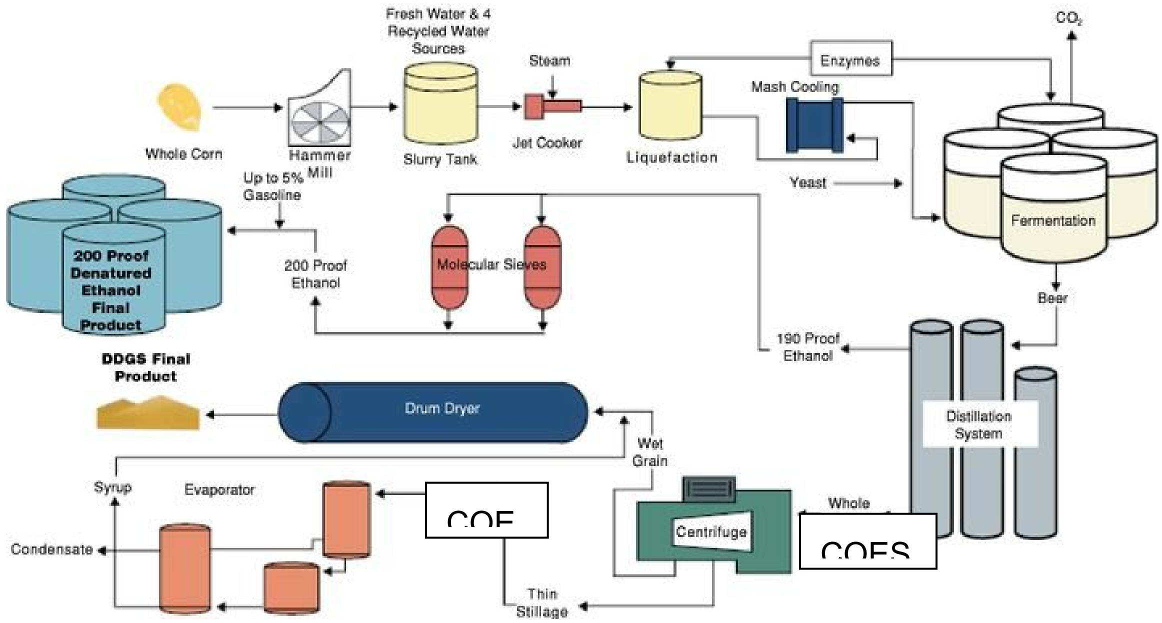
Second: Corn oil extraction after fermentation allows a dry mill ethanol plant to produce 11 percent more total fuel energy by manufacturing additional renewable biofuels from its corn oil byproduct. Corn oil is an excellent feedstock for biodiesel and renewable diesel.

Third: Success is just beginning. Additional corn oil extraction efficiency, coupled with corn varieties now available that have higher corn oil content (and the same starch content), have the potential to more than double these benefits.

In this report, GreenShift will focus on the first point, the significant reduction in energy needed by an ethanol plant to produce ethanol from a bushel of corn, when corn oil is extracted following fermentation and before drying of the ethanol plant's coproduct, distillers dried grains with solubles ("DDGS"). EPA has predicted a 70% penetration of corn oil extraction in ethanol production facilities.

COES Technology

COES are built to extract corn oil in the most efficient manner possible, keyed to each ethanol plant's specific design and operational characteristics, which vary from site to site. The exact configuration depends on the ethanol plant design vendor chosen by the ethanol company and the operating characteristics proven at the plant to optimize ethanol production. A general flow sheet is pictured on the next page.



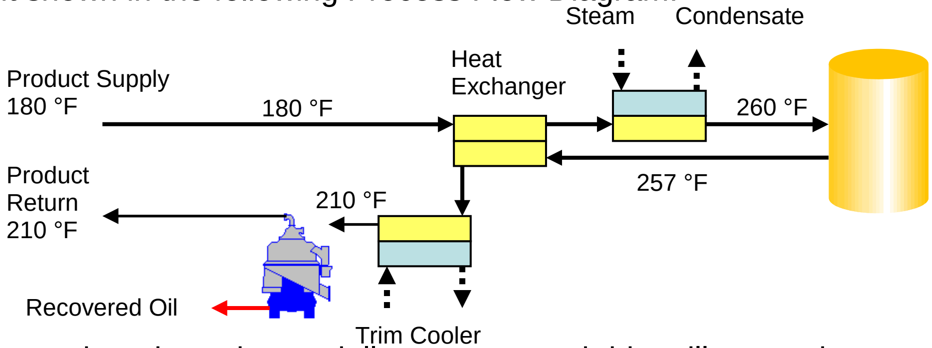
The COES placed in the ethanol plants are of two types. The first system, referred to as COES I, extracts corn oil from the thin stillage as it works its way through the evaporators. GreenShift has been awarded three patents on its COES I technology. The thin stillage generally contains about 30 percent of the oil available in the corn. COES I can recover most of that corn oil, depending on site-specific conditions. A typical ethanol plant uses corn that contains approximately 4% by weight corn oil, which in the absence of corn oil extraction, passes through the process to the DDGS. For a 50 million gallons per year ("MGY") ethanol plant, the corn oil incoming is about 5 MGY and COES I can recover about 1.5 MGY.

Patent-pending COES II is an extraction extension that frees another 30 percent of the corn oil that is bound in the whole stillage, prior to the separation of wet grain and thin stillage. The unbound oil is thus made available to COES I and generally increases production of corn oil by nearly 100 percent. COES I and II together therefore can extract on the order of 60% (up to 75%) of the corn oil passing through the plant, or about 3.0 MGY to 3.8 MGY of corn oil from a 50 MGY ethanol plant.

COES installations are similar from plant to plant. They consist of skid mounted equipment placed in the ethanol plant so as to become part of its operation, but in a manner transparent to the production of ethanol – except, that is, for the dramatic decrease in energy use at the ethanol plant.

An installed COES, either COES I or II, adds no new materials to the ethanol circuit and uses or consumes no reagents, solvents, or other chemicals. Both COES I and COES II are sealed processes. Only corn oil is taken out and no materials are added. Corn oil (CAS #: 8001-30-7) is a stable vegetable oil, with a very low vapor pressure (< 1.0 mmHg @ 20°C (68°F)). Its flash point is greater than 290°C (550°F), with a specific gravity of about 0.95 and negligible solubility in water. It is relatively viscous and biodegradable. Corn oil is a light to dark red with a mild corn odor.

COES I extracts the corn oil from the thin stillage. The entire flow of thin stillage is passed through the COES and returned, minus the extracted corn oil, just downstream of the extraction point in the evaporator circuit of the ethanol plant. A COES I consists of the equipment shown in the following Process Flow Diagram:

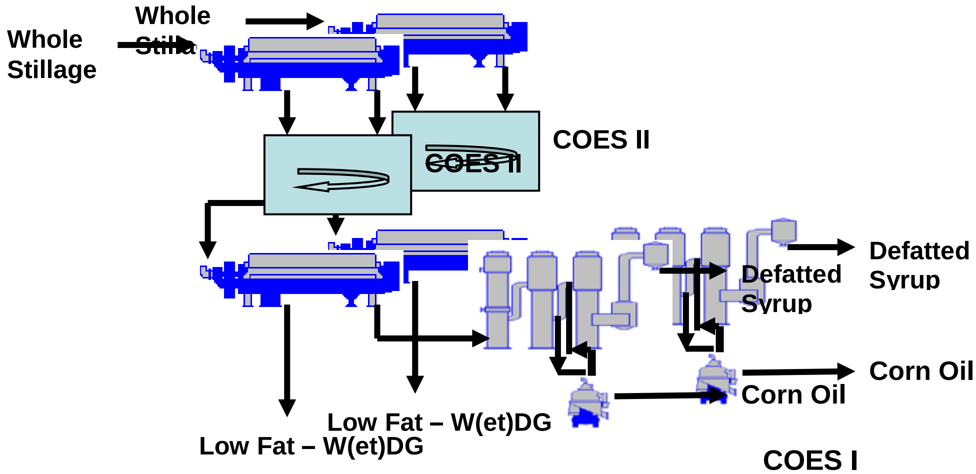


The main process is to heat the partially concentrated thin stillage and extract the corn oil by separation in a centrifuge. Steam is used in heat exchangers to raise the temperature of the thin stillage for extraction. As the temperature is reduced prior to returning the defatted stillage to the evaporators in the ethanol plant, energy is recovered in the heat exchangers to preheat the incoming thin stillage.

The COES-I equipment is mounted on three skids placed in the ethanol plant near the evaporators as shown in the photograph of a typical installation. The skids are manufactured offsite according to standard specifications and shipped to the ethanol plant as sub-systems to be interconnected and coupled to the evaporator circuit. Electric power and steam are supplied to the COES from the ethanol plant utilities. Since the COES operation reduces the ethanol facilities energy demand for drying the syrup (the concentrated thin stillage from the evaporators), the steam used is not additional to the demand for steam without the COES installation. Therefore, no increase in boiler size or boiler fuel consumption results from the COES. Instead, the ethanol plant experiences a decrease in energy demand, as mass (corn oil) has been removed from the process and in addition the defatted syrup dries more efficiently in the ethanol plant's drying system, as corn oil is an insulator.

GreenShift's patent-pending COES II is used to free additional oil from the wet cake so that it is able to exit with the thin stillage for final recovery via COES I. As more than 40 percent of the total oil within the corn is trapped within the wet cake, GreenShift developed a washing technique to free this oil from the cake so that it is recoverable by the already proven COES I. The COES I recovery system is not inhibited by oil volumetric flow rate and therefore no adjustments or additional hardware would be required by COES I to recover higher concentrations of oil.

An additional line of horizontal centrifuges is placed prior to the existing horizontal centrifuges as shown in the following diagram. One hundred percent of the whole stillage is routed to the additional line of horizontal centrifuges where the wet cake and thin stillage exit the centrifuges and are mixed again back into solution prior to being pumped to the currently installed horizontal centrifuges. The result of this practice is a reduction of oil within the wet cake by roughly 50%. The oil removed from the wet cake is now present in the thin stillage and available for COES I recovery.



COES Energy Use -- Electrical

An installed COES is not energy intensive. By calculation, operating a COES I requires about 0.01 kWh per gallon of ethanol produced, which is not much more than a one percent increase in the electricity demand in a typical dry mill ethanol plant. The electrical energy used is mostly to run motors, on the centrifuge and the pumps.

At a 50 MMGY ethanol plant, a COES I consumes about 60 kW. Running 350 days a year, 24 hours a day, that is 1.8 X 10^{12} Joules/year, or 3.6 X 10^{4} Joules/ethanol gallon. Expressed in Btu, that is approximately 34 Btu/ethanol gallon as electricity used by COES I. For comparison, ethanol contains about 78.000 Btu/ethanol gallon and a corn ethanol plant uses about 2,700 Btu/ethanol gallon in electrical energy.

To confirm the electrical demand calculations, a refereed COES performance test was run at a system in Indiana in October, 2008. During the three day test, the COES operated at capacity on the 50 MMGY ethanol plant, consuming about 63 kW, very close to the calculated rate of electrical energy usage.

A COES II system has not been available to corroborate similar calculations. It is estimated from electrical demand, however, that a COES II will require about 540 kW, again primarily for motors, since for a 50 MMGY ethanol plant, a COES II has two much larger centrifuges. COES I and II together will thus use about 340 Btu/ethanol gallon as electricity, which represents about a 12 percent increase in electrical energy for a 50 MMGY ethanol plant recovering from 60% to 75 percent of its corn oil.

COES Energy Use -- Thermal

Both COES I and II use steam from the ethanol plant's utility system to provide operating heat. Heat exchangers balance the load so as to maximize the use of energy and return syrup, minus the corn oil, to the ethanol circuit at approximately the same temperature as it was when diverted to COES. Consumed energy as heat is therefore limited to waste heat lost and heat retained in the extracted corn oil.

GreenShift has calculated the heat energy needed to run a COES I on a 50 MMGY ethanol plant to be about 1 million Btu/hr, obtained by using 900 lb/hr of steam. That is about 180 Btu/ethanol gallon. In most ethanol plants, as assumed here, this energy comes from a boiler burning natural gas. In the performance test mentioned above, the COES I consumed approximately 450 lbs/hr of steam, one half this rate at that particular plant.

The steam demand for a COES II is estimated by GreenShift to be about 550 lb/hr of steam, or 110 Btu/ethanol gallon. Taken together, the total thermal energy demand for operating COES I and II is just under 300 Btu/ethanol gallon produced.

Adding the electrical and thermal energy uses for COES I results in 34 plus 180, or about 210 Btu/gal ethanol. COES I and II require 640 Btu/ethanol gallon.

Ethanol Plant Energy Use Reduction

While electrical demand, which increases with COES installation, is a small component of an ethanol plant's energy use, large savings in the use of thermal energy result from the effects of extracting corn oil. First, corn oil is removed from the syrup stream in the evaporators, which increases their performance by improving heat transfer, since oil is an insulator and is hard to heat. Second, corn oil extraction improves the drying efficiency of the DDGS, as there is less mass passing through the dryers. Third, corn oil extraction improves the flowability and handling of DDGS, such that less drying is needed to produce a quality feed product.

To calculate the ethanol plant energy reductions resulting from COES, GreenShift has performed a mass balance on a typical 50 MMGY ethanol plant, with and without COES. COES I reduces the energy use in the ethanol plant dryers by about 3,700 Btu/ethanol gallon, due to the combined effects listed above. Subtracting the COES I consumption of energy from this reduction, the net energy savings produced by a COES I is 3,700 minus 210, or about 3,500 Btu/ethanol gallon.

EPA estimates that a total ethanol plant energy use is about 35,700 Btu/gal, as noted in the draft Regulatory Impact Analysis ("DRIA") of the Renewable Fuel Standard. (Reference is made here to the DRIA instead of the final RIA to be conservative, since energy efficiencies are included in the final that lower the total energy demand, which will increase the value of COES in reducing energy use.) Installation of a COES I therefore represents a 9.8 percent total energy savings (3,500 / 35,700). GreenShift feels these numbers are the expected savings in energy and should be considered along with the conservative 5.4% figure in the FRIA.