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:

![Process Flow Diagram](image)

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 10^6 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.