UNIVERSITY OF ILLINOIS
AT CHICAGO
Energy Resources Center (MC 156)
College of Engineering
1309 South Halsted Street, 2nd Floor
Chicago, Illinois 60607

April 15, 2009

California Environmental Protection Agency
Air Resources Board
Byron Sher Auditorium, Second Floor
1001 I Street
Sacramento, California 95814

Subject: **Comments on Corn Ethanol Pathway Description**

Dear Air Resources Board:

Table IV-20 of the "Proposed Regulation to Implement the Low Carbon Fuel Standard" shows eleven different pathways for corn ethanol production. We propose that the pathway list be expanded to recognize advanced energy technologies (combined heat and power, gasification) as well as advanced process technologies (fractionation, corn oil extraction, etc.). The attached study documents the current use of these technologies.

Best Regards,

Steffen Mueller, PhD
Principal Economist

UIC
Steffen Mueller, PhD
Phone (312) 355-3982 • Fax (312) 996-5620 • muellers@uic.edu

AN ANALYSIS OF MODERN CORN ETHANOL TECHNOLOGIES

<u>Prepared for:</u>
Illinois Corn Marketing Board

<u>Prepared by:</u>
Steffen Mueller
Ken Copenhaver

<u>Technical Review Provided by:</u>
Martha Schlicher, GTL Resources USA, Inc.

February 16, 2009

UIC COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS AT CHICAGO

Energy Resources Center, 1309 South Halsted Street, Chicago, IL 60607
http://www.erc.uic.edu

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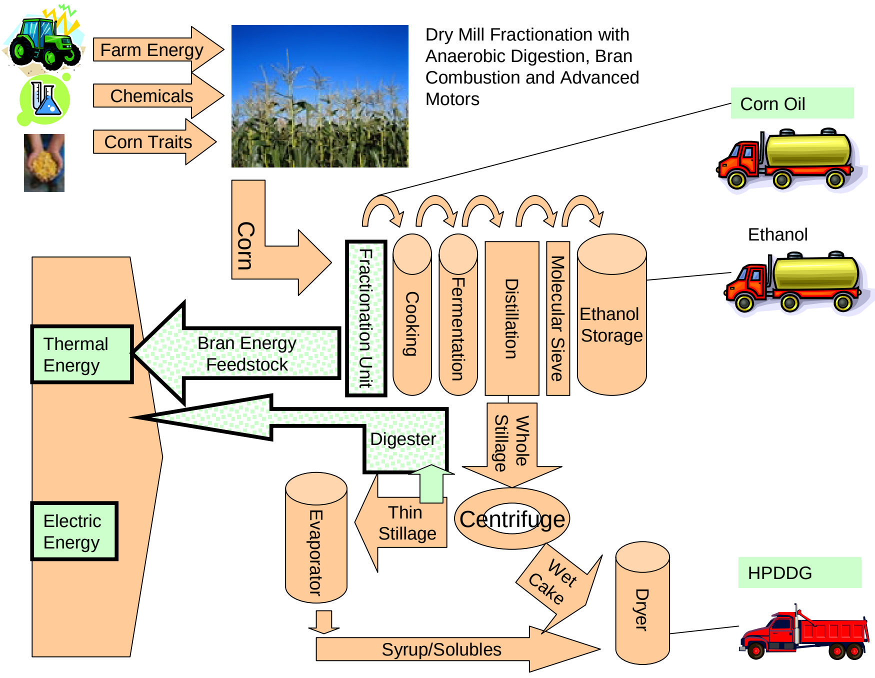
Executive Summary

This study conducted by the University of Illinois at Chicago assesses emerging technologies that reduce the energy consumption and the Global Warming Impact (GWI) of corn ethanol production. These new technologies have emerged for corn production as well as for ethanol processing at the biorefinery. The study documents that many ethanol plants have already adopted energy/environmental footprint reducing technologies such as corn oil extraction, fractionation, cold cook processes, advanced motors, combined heat and power systems, anaerobic digesters, biomass combustion/gasification systems, and other renewable energy systems. In summary, a total of 25 out of the 160 operating ethanol plants in the US, or 16%, have adopted one or the other of the described technologies. Furthermore, the study documents that advanced technologies in corn agriculture such as GPS and Auto-Steer systems in farm equipment, slow release fertilizers, nitrification inhibitors, N-application based on soil testing and remotely sensed imagery, and N-side dressing reduce the energy/environmental footprint of corn ethanol.

In addition to reducing the energy and environmental footprint these technologies greatly expand the diversity of products from a corn ethanol plant. The traditional dry mill process produces ethanol and a co-product called distillers grain with solubles, which is sold either wet (as WDGS) or dried (as DDGS) to the feed market. Depending on the configuration, modern ethanol plants can produce many more co-products including high protein DDG, bran cake, corn oil, corn gluten feed, bran energy feedstock, zein protein for bio-plastics, and fertilizer products.

Integrated combinations of emerging technologies can substantially eliminate the natural gas energy consumption at an ethanol plant. One example includes combining fractionation with anaerobic digesters and advanced motor systems. Energy assessments performed as part of this study indicate that the base energy needs for such a system would drop from 30,000 Btu/gal to 22,010 Btu/gal of which 21,000 Btu/gal would be offset by biogas produced in the anaerobic digester. An additional 3,500 Btu would be offset by combusting bran (in an added solid fuel boiler) leaving a net surplus energy production of the plant of 2,490 Btu/gal. The figure provides a flow diagram of such a system. Besides corn ethanol, the plant would also co-produce 2.6 lbs of high protein



distillers grain (HPDDG) with a highly desirable protein content of 37-44% and 0.25 lbs/gal of NPK fertilizer for every gallon of ethanol (while only slightly reducing ethanol yield from 2.73 gallons per bushel to 2.64 gallons per bushel).

Studies that assess the energy and environmental differences between corn ethanol and cellulose ethanol should be based on a comparative technology stage, which means advanced cellulose systems must be compared against advanced corn ethanol systems like the zero energy and multiple co-product plants described here.

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1) Introduction

Over the last three years modern ethanol plants have started to adopt technologies that transform the industry into integrated biorefineries producing multiple fuel, feed, and bioplastic products. These technologies also alter the energy, environmental impact, and co-product balance from corn ethanol production. The Illinois Corn Marketing Board retained the University of Illinois at Chicago Energy Resources Center to assess emerging technologies that have the potential to reduce the energy consumption and the Global Warming Impact (GWI) of corn ethanol production.

The study looks at both corn production as well as ethanol processing technologies. As illustrated in Figure 1 corn is produced by combining the corn hybrid appropriate for the soil and climate conditions, with the corn transgenic traits desired for herbicide tolerance or pest control and the corresponding agro-economic practice (including fertilizer, pesticide, herbicide, tillage, irrigation, and other practices). The harvested corn is stored on farm or shipped from the farm directly to the ethanol plant or to a grain elevator first and then to the ethanol plant for processing.

Once arrived at the ethanol plant the traditional dry mill process consists of the following steps: Corn is cleaned, ground and slurried with water and enzymes (alpha amylase), followed by cooking of the slurry to gelatinize and liquefy the starch (liquefaction). After liquefaction, the mash is cooled, and another enzyme is added (gluco amylase) to convert the liquefied starch into fermentable sugars. The yeast is added to ferment the sugars to ethanol and carbon dioxide, followed by distillation and dehydration.[1] Besides ethanol a typical plant also processes the non-fermentable nutrients (protein, fat, and fiber) left over after the distillation and dehydration process. If dried these compounds are called distillers dried grain with solubles (DDGS), otherwise wet distillers grains with solubles (WDGS). DDGS and WDGS are generally used as animal feed. DDGS has a longer shelf life than WDGS and can be shipped more economically. The ratio of WDGS and DDGS production from a dry mill ethanol plant depends on local market conditions. Large lifestock operations in an area will often provide a high demand for WDGS.

The ethanol dry mill process is energy intensive and requires both thermal energy (mainly for cooking, distillation, and drying) as well as electricity (to operate motors, fans, and pumps). The natural gas fired dry mill base plant energy system consists of a boiler, a direct fired or steam tube drying system, and a regenerative thermal oxidizer (RTO).

Over the last 8 years, the natural gas consumption at dry mill ethanol plants has been steadily decreasing. The 2001 Ethanol Plant Development Handbook quotes a natural gas use of 40,000 Btu per denatured gallon (Higher Heating Value or HHV) and 1.4 kWh/gal of electricity (assumes 100% DDGS drying).[2] In 2006, ICM, Inc. a major ethanol plant process developer provided process guarantees for new natural gas fired ethanol plants in

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[1] Ethanol Producer Magazine. “Break it Down”; January 2006.

[2] Ethanol Plant Development Handbook, Third Edition; Published by BBI International; January 2001.

the range of 32,000-34,000 Btu per denatured gallon (thermal energy) and 0.75 kWh/gal (electricity) with 100% DDGS drying and 22,000 to 24,000 Btu per denatured gallon without DDGS drying. Today, the natural gas energy consumption of a modern ethanol plant is even lower. A recent energy balance conducted at the Illinois River Energy Center (IRE) documented a natural gas consumption of 29,000 Btu per denatured gallon (30,000 Btu per anhydrous gallon) and 0.69 kWh per denatured gallon (0.71 per anhydrous gallon) of electricity.[3,4] It should be noted that IRE is a modern ethanol plant, but with a standard layout consisting of a natural gas fired boiler and a direct fired dryer system for DDGS production. Corn ethanol plants that utilize biomass sourced in the vicinity of the plant or biomass co-produced with ethanol as an energy source can further reduce their natural gas/fossil fuel consumption.

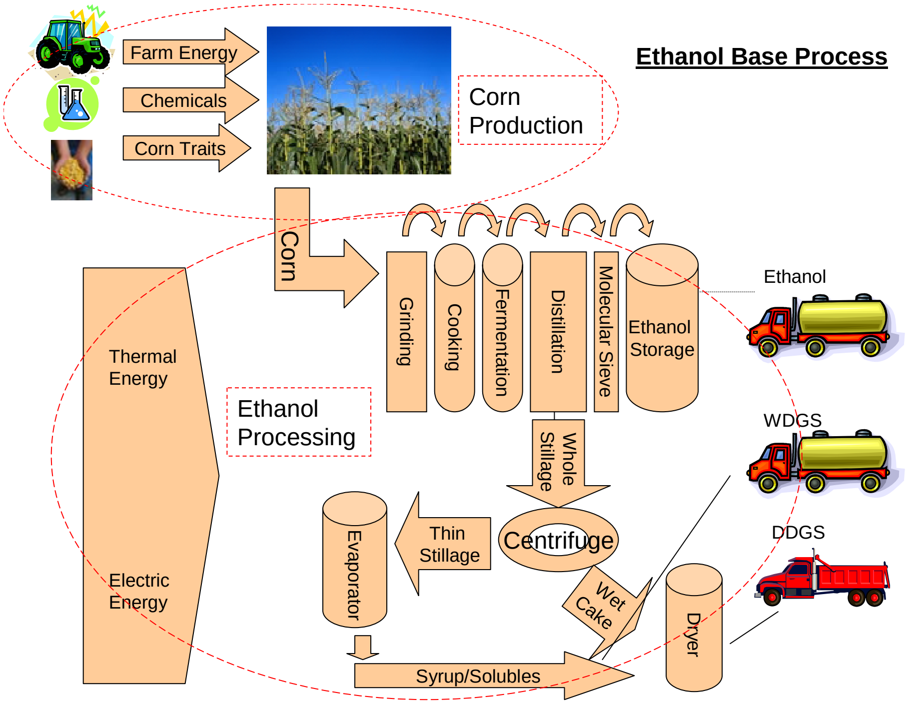

Figure 1: Block Diagram of the Ethanol Base Process

In addition to energy reductions at the ethanol plant level, farm-energy use has also been steadily decreasing. This is largely due to modern farming equipment (including GPS guided equipment with auto-steer) and the use of genetically enhanced corn, which increases yield and thus reduces the energy requirements per acre. As a result of these developments, the on farm energy consumption per bushel of corn in Argonne's GREET model was revised in 2008 down from 22,500 Btu/bu to 12,600 Btu/bu.[5] A recent case

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[3] The Illinois River Energy Center is located in Rochelle, Illinois. The plant recently expanded production from 58 million gallons per year to 100 million gallons per year.

[4] Mueller Steffen and Ken Copenhaver, Michelle Wander; "The Global Warming and Land Use Impact of Corn Ethanol Produced at the Illinois River Energy Center"; Revised 10/22/08.

[5] The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model was developed by Argonne National Laboratory. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.

study of farm energy use around the Illinois River Energy Center showed even lower on-farm energy use of 7,800 Btu/bu.[6]

Reduced ethanol plant and on-farm energy consumption result also in lower greenhouse gas emissions. Figure 2 shows the life cycle greenhouse gas reduction of the Illinois River Energy Center relative to gasoline. At 28.7 gCOe/MJ the ethanol plant energy system is the biggest contributor to the overall GWI of 54.8 gCOe/MJ.

Nitrous oxide emissions from nitrogen fertilizer inputs to corn production are the second largest contributor to the GWI of corn ethanol (14.2 gCO2e/MJ). The remainder includes on-farm energy use, corn and ethanol distribution, and denaturant (11.6 gCO2e/MJ combined). With the main contributors to GWI identified, the present study focuses on technology improvements to plant energy systems, improvements to on-farm energy, as well as nitrogen fertilizer inputs.

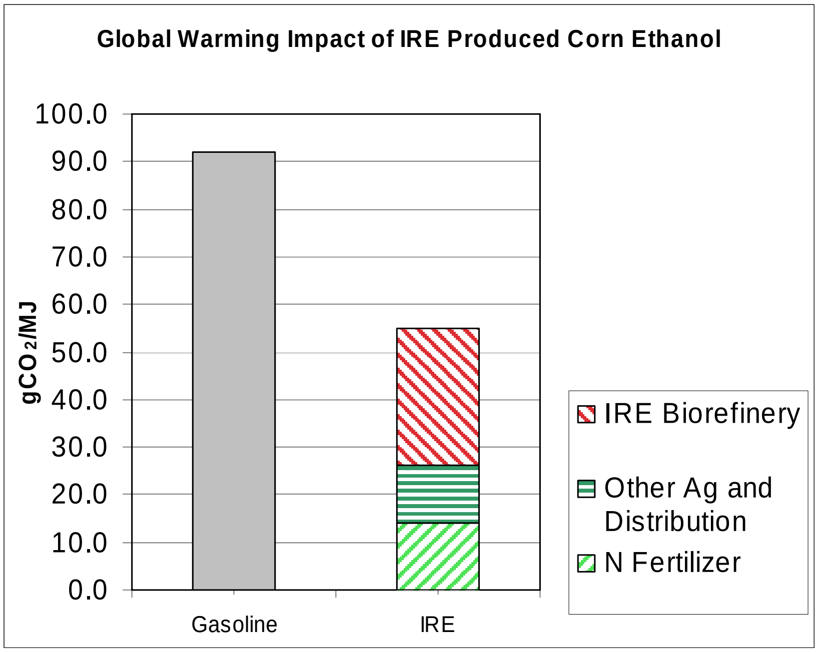

Figure 2: GWI of Corn Ethanol Produced at Illinois River

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[6] These values are stated in Lower Heating Value as used in GREET. Otherwise, unless noted, all values are stated in Higher Heating Value (HHV).

2) Ethanol Processing Technologies

2.1) Corn Oil Extraction

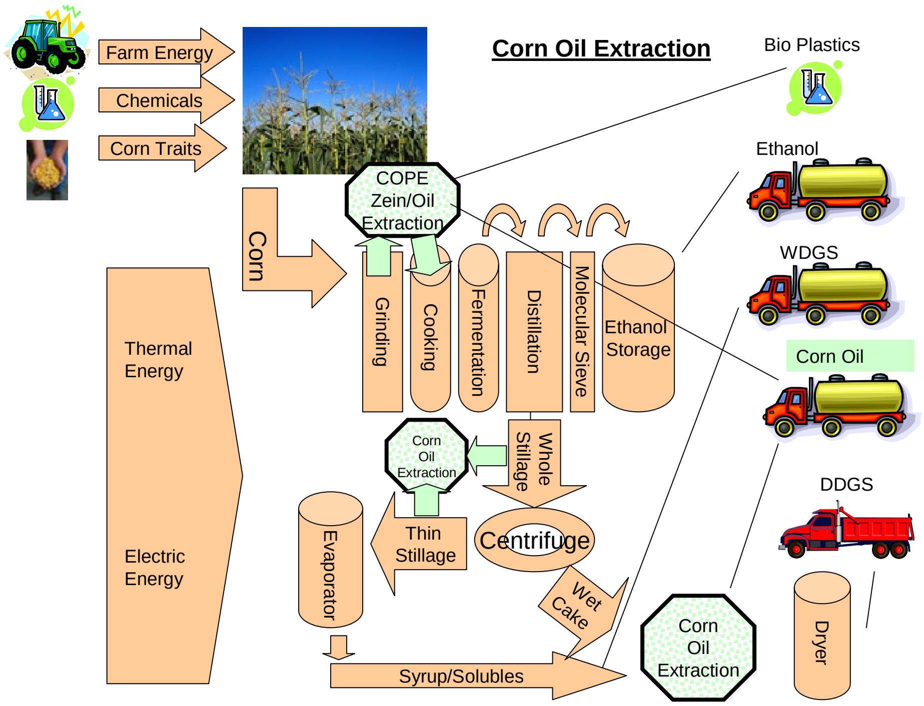

Figure 3: Corn Oil Extraction and the Ethanol Process

In addition to removing corn oil during a fractionation process (discussed later) it can also be removed from the ground kernel using centrifuges. As shown in Figure 3 this type of extraction is possible before or after the ethanol distillation process. Corn oil removed before distillation results in a food grade product, whereas corn oil removed after distillation often enters the fuel product market where it is refined to a diesel (substitute) product.

Corn oil removed after distillation can be extracted either from the whole stillage, thin stillage, or the wet distillers grains with solubles. Since the corn oil is removed after the distillation process, the extraction process has no impact on the ethanol yield. Manufacturers quote an extraction rate of about 3-4% by volume, which means a 100 million gallon per year ethanol plant can produce an additional 3-4 million gallons of corn oil. Depending on the fat content the resulting deoiled/debranned DDGS may be of equal or lower value to the feed industry. Thermal energy requirements remain unchanged from the base process. However, VOC emissions during the drying process are reduced. Electricity needs will increase by about 10% to operate the centrifuges for oil extraction.

The COPE process developed by Prairie Gold Inc. uses a different approach and extracts the corn oil prior to the fermentation by percolating ethanol back through the ground corn meal. This extraction process produces food grade corn oil as well as the protein “zein” that can be used for biodegradable products and plastics.[7]

<u>Key Technology Providers:</u>
Greenshift Corporation
Primafuel Solutions
Prairie Gold, Inc.

<u>Installations:</u>
Little Sioux Corn Processors, Marcus, Iowa (Greenshift system)
Utica Energy, LLC, Oshkosh, WI (Greenshift system, corn oil extracted an converted into biodiesel)
Western NY Energy, LLC, Medina, New York (Greenshift system, corn oil extracted and converted into biodiesel)
Amaizing Energy LLC, Denison, Iowa (Primafuel system)

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[7] Personal conversation with Phil Shane, Prairie Gold

2.2) Dry Mill Corn Fractionation

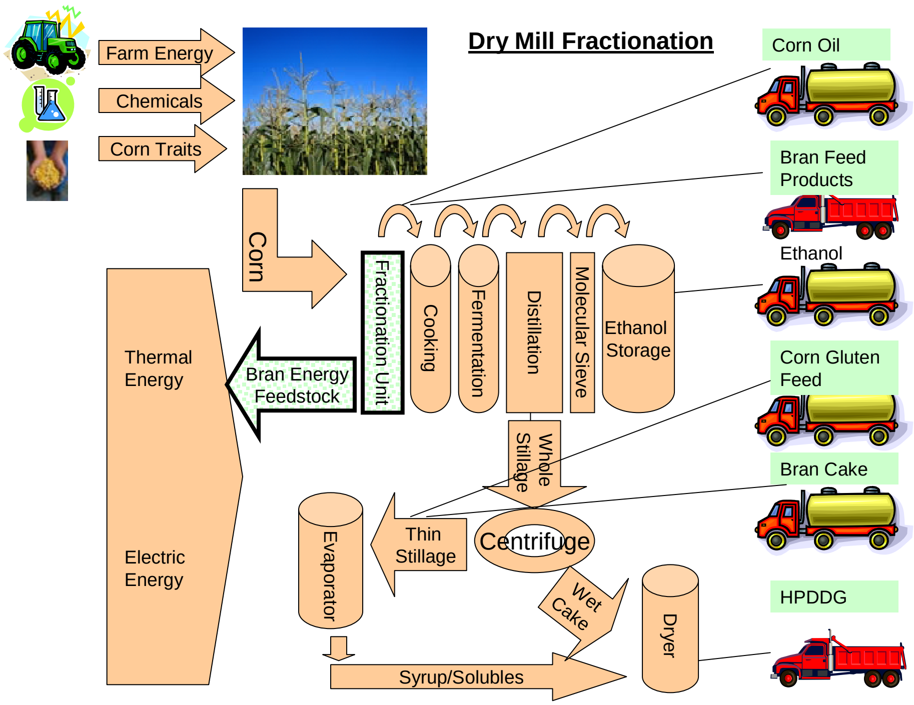

Figure 4: Dry Mill Fractionation and the Ethanol Process

Fractionation separates the corn kernel into its main building blocks: the pericarp, the endosperm, the germ, and the tip cap. The endosperm contains 92 to 96% of the starch, the germ contains close to half of the oil, and the pericarp and the tip cap (collectively called bran) consist primarily of cellulose/fiber. By separating these parts, multiple products are possible: The endosperm is processed into ethanol and a higher protein, higher value animal feed, the germ into food grade corn oil. The bran can be converted into cellulose ethanol, it can be sold as a feed product, or it can be used as a biomass energy feedstock.

Feed Products from Corn Kernel:

The low oil and bran/fiber content in the stillage produces higher protein DDG (HPDDG) that provides greater flexibility in ruminant rations and opens markets in monogastric animals (particularly hogs and poultry). By removing non fermentable components at the front end, the percentage of starch in the slurry is higher, requiring less enzymes. While additional electricity is required for the fractionation system, this is partially offset by the elimination of the requirement for hammermills in the base plant. Also, the removal of non-fermentable compounds reduces the drying load and thus the thermal energy requirements.

A fractionation system can produce the following feed products:

a) High Protein Distillers Dried Grains
The low oil and bran content in the now degermed and debraned corn stream allows production of a high protein animal feed (HPDDG) that is commercially sold as 37-44% protein.

b) Corn Gluten Feed
Mixing the deoiled germ, bran, and syrup results in an animal feed product that is commercially sold as 20% protein.

c) Bran Cake:
Mixing the bran and the syrup results in an animal feed product that is commercially sold as bran cake.

In many instances lifestock markets buy corn gluten feed and bran cake wet. However, if all products are dried to a low moisture content (10%) to increase shelf life, the total thermal energy savings from either producing HPDDG combined with Corn Gluten Feed or from producing HPDDG combined with Bran Cake is 17.6%.

On the electric side, the hammer mills in traditional dry mill processes are replaced by roller mills. Two manufacturers report that their dry mill fractionation process requires about 1 kWh/gal electricity.[8]

Biomass Fuel from Corn Kernel:
Finally, the bran can be used as a biomass fuel via combustion in a solid fuel boiler system. The fractionation process produces approximately 0.5 lbs (between 0.42 to 0.61) of bran for every gallon of ethanol.[9] At an assumed energy content of 7,000 Btu/lb and a bran fractionation yield of 0.5 lbs/gallon combusting the bran in a solid fuel boiler could result in additional energy savings of 3,500 Btu/gallon. Using the bran as a biomass fuel obviously reduces corn gluten feed and bran cake production from fractionation proporationally.

Cellulose Ethanol from Corn Kernel:
Bran conversion to cellulose ethanol utilizes specific enzymes which can convert corn kernel fibers into fermentable sugars. The technology can increase the ethanol yield from a bushel of corn by between 4 to 10 percent.[10] The challenges are to develop affordable enzymes, and create process streams which are concentrated enough for ethanol recovery.[11] According to the National Corn to Ethanol Research Center this technology will likely be adopted with corn fractionation. While the technology increases yield, the energy conversion efficiency is expected to remain constant.

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[8] Email exchanges with CPT technologies and ICM Inc.
[9] Review by Martha Schlicher, GTL Resources USA, Inc.
[10] Per Martha Schlicher, GTL Resources USA, Inc.
[11] Critics argue that fractionation results in a loss of starch and reduced ethanol yields. Source: Ethanol Producer Magazine. “Corn Fractionation for the Ethanol Industry”; November 2005 Issue.

Key Technology Providers:

Buhler Inc.
Ocrim/Delta-T
Cereal Process Technologies
MOR Technologies
Satake USA
Crown Iron Works
Renessen LLC (joint venture between Cargill and Monsanto; process name: Extrax)
ICM via Applied Milling ("Total Kernel Optimization")
FCStone Carbon LLC with Maize Processing Innovators Inc licensing University of Illinois' Quick Germ Quick Fiber technology.

Current Plants Employing Technology:

Illinois River Energy, Rochelle, Illinois
Renew Energy, Jefferson, Wisconsin (using the CPT Process)
Pilot Plant in Eddyville, Iowa (using the Extrax Process)
Didion Milling, Johnson Creek, Wisconsin
Badger State Ethanol, Monroe, Wisconsin

2.3) Cold Cook Process (aka raw starch hydrolysis)

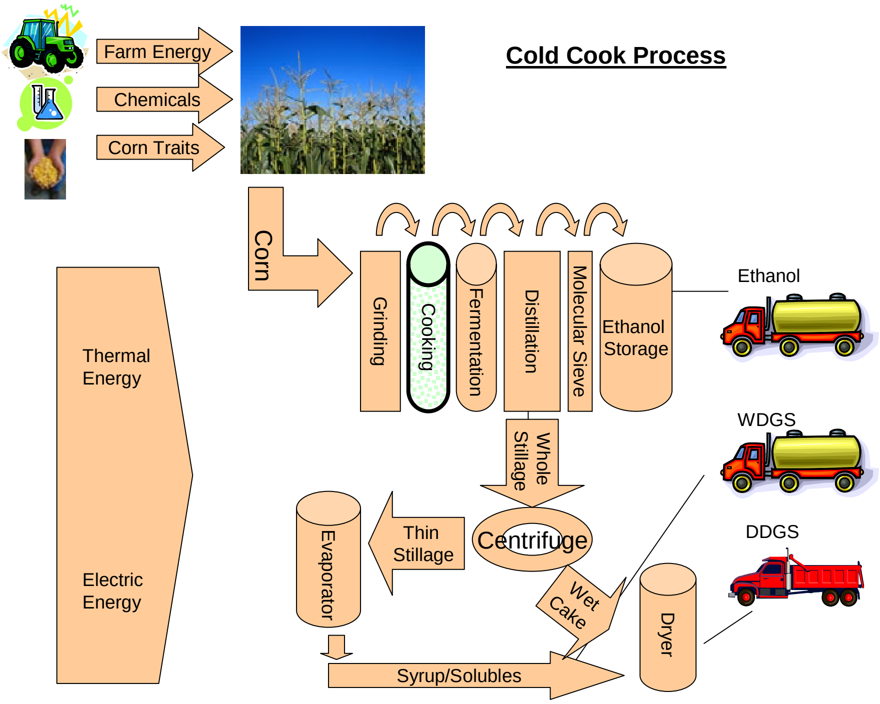

Figure 5: Raw Starch Hydrolysis and the Ethanol Process

Cold cook/raw starch hydrolysis allows producers to eliminate the cooking step. The cold cook process (which occurs at 86 to 104 degrees F) skips the liquefaction and saccharification steps. The ground corn is slurried with water and both gluco amylase and alpha amylase are added, followed directly by fermentation. Skipping the cooking process reduces both water and energy consumption. In an February 2008 Press Release Poet quoted that the cold cook process is "utilized in 20 of POET's 22 ethanol production facilities."[12] Critics argue that the process needs significantly more enzymes (20% more), reduces yield in fermentation, and increases antibiotic use.[13] In a personal conversation with an industry insider, the energy savings from cold cooking were estimated to be about 5,000 btu/gal (5,000/30,000 Btu/gal) or 16.6%. Electricity consumption is likely similar to current dry mill ethanol plants; no increase or decrease in electricity consumption was assumed.

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[12] Dr. Mark Stowers, Vice President of Research & Development at POET ; "POET funds starch to ethanol research collaboration with Iowa State University", http://www.poetenergy.com/news/showRelease.asp?id=108

[13] Ethanol Producer Magazine. "Break it Down", January 2006.

2.4) New Boilers and Motors

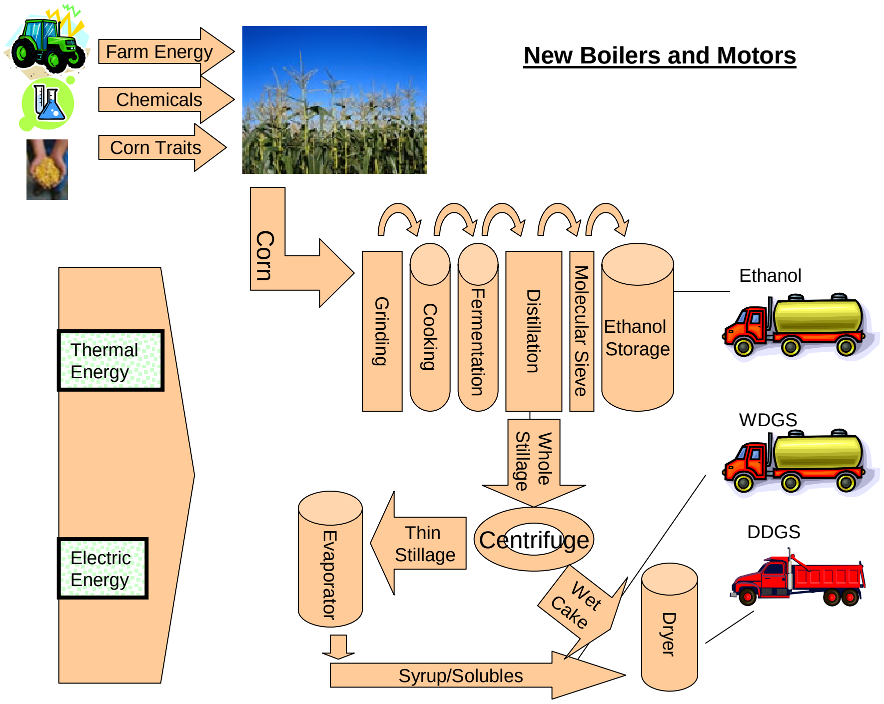

Figure 6: New Boilers and Motors and the Ethanol Process

Technologies that are currently in various stages of the commercialization process will increase the efficiency of currently utilized energy generating and conversion equipment such as natural gas boilers, motors, fans, and pumps.

GTI and Cleaver Brooks are developing the SuperBoiler with DOE funding. The development is on schedule and the efficiency of this technology reportedly reaches 94%. Two units are installed at Specification Rubber in Alabama and at Clement Pappas Company in Ontario.

NEMA Premium efficient motors and the installation of extra inverters decrease both energy consumption and peak demand. Efficiency improvements from premium efficient motors are reportedly in the 5% range.[14]

Additional improvements include the development of advanced process control and automation systems for ethanol plants. Siemens partners with National Corn to Ethanol Research Center for 10 years to develop distributed control and instrumentation systems.

Table 1 provides an efficiency comparison between traditional and advanced boiler and motor technologies.

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[14] Personal conversation with the US DOE Industrial Assessment Center at University of Illinois at Chicago.

Table 1: Efficiency Improvements of New Motors and Boilers

	From	To
Motors	90%	95%
Efficiency Improvement		5.3%
Boilers	80%	94%
Efficiency Improvement		14.9%

Key Technology Providers:

Various

Current Plants Employing Technology:

Pacific Ethanol, Sacramento, California
ADM, Decatur, Illinois

2.5) Combined Heat and Power

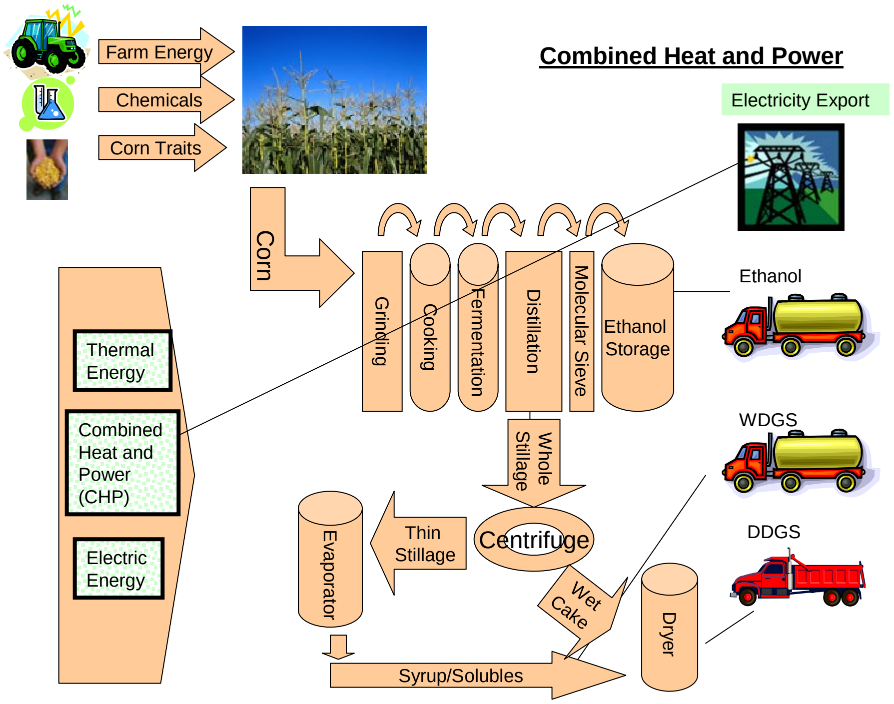

Figure 7: Combined Heat and Power and the Ethanol Process

Combined heat and power systems (CHP, also known as cogeneration) generate electricity and useful thermal energy from the same fuel source in a single integrated system. The primary fuel feed stocks for CHP systems at ethanol plants include natural gas, coal, and biomass. The general equipment configuration for a natural gas fired CHP system consists either of a) a combustion turbine (for electricity production) with a heat recovery steam generator (for thermal energy production), or b) a natural gas fired boiler (for thermal energy production) with a steam turbine (for electricity production). The general equipment configuration for a coal or biomass fired CHP system consists of a solid fuel boiler with a steam turbine.[15] The thermal energy generated from a CHP system can be utilized to meet the cooking, distillation, and the drying needs of the plant. The electricity can be utilized to meet all or a portion of the electric load of the plant with supplemental electricity purchased from the incumbent utility company. Moreover, several ethanol plant CHP systems are sized to meet the thermal energy requirements of the plant, but generate electricity in excess of the ethanol plant load. These systems sell excess electricity back to the grid as a co-product.

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[15] "Research Investigation for the Potential Use of Illinois Coal in Dry Mill Ethanol Plants"; Report to the Illinois Clean Coal Institute, Mueller and Cuttica, October 2006.

Natural Gas CHP systems at ethanol plants[16]

- Adkins Energy, Lena, Illinois (5 MW combustion turbine with heat recovery, sized to meet the electric needs of the plant, supplemental thermal energy provided by additional natural gas fired boilers)
- Northeast Missouri Grain LLC, Macon, Missouri (10 MW natural gas fired combustion turbine, provides excess electricity to the municipal electricity system of the City of Macon)
- US Energy Partners, Russell, KS (15 MW natural gas fired combustion turbine, provides excess electricity to the City of Russel, Kansas)
- East Kansas Agri Ethanol (EKAE) ethanol plant in Garnett, Kansas (1.6 MW natural gas boiler with steam turbine plant)
- POET Biorefining Ashton, Iowa (7 MW natural gas fired combustion turbine system with heat recovery)
- Andersons Albion Ethanol LLC Albion, Michigan (2 MW steam turbine system)
- Little Falls Plant Little Fall, Minnesota (2 MW steam turbine system)
- POET Biorefining Laddonia, Missouri (10.7 MW steam turbine system)
- Prairie Horizon Ethanol Phillipsburg, Kansas (4 MW steam turbine system)

Coal fired CHP Systems

- Heron Lake, MN (Coal-fired fluidized bed boiler)
- Corn LP in Goldfield, IA (Coal-fired fluidized bed boiler)
- Lincolnway Energy, Nevada, IA (Coal-fired fluidized bed boiler)
- Blue Flint Ethanol Plant Underwood, ND (6.5 MW steam turbine co-located next to coal fired power plant)

Biomass Fired CHP Systems

Corn Plus, MN (combusting syrup supplemented by natural gas)

Technology Providers

Various, including:
Solar Combustion Turbines
Dresser Rand Steam Turbines
Energy Products of Idaho (Fluidized Bed Boilers)

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[16] Source: Midwest CHP Application Center. www.chpcentermw.org

2.6) Anaerobic Digesters

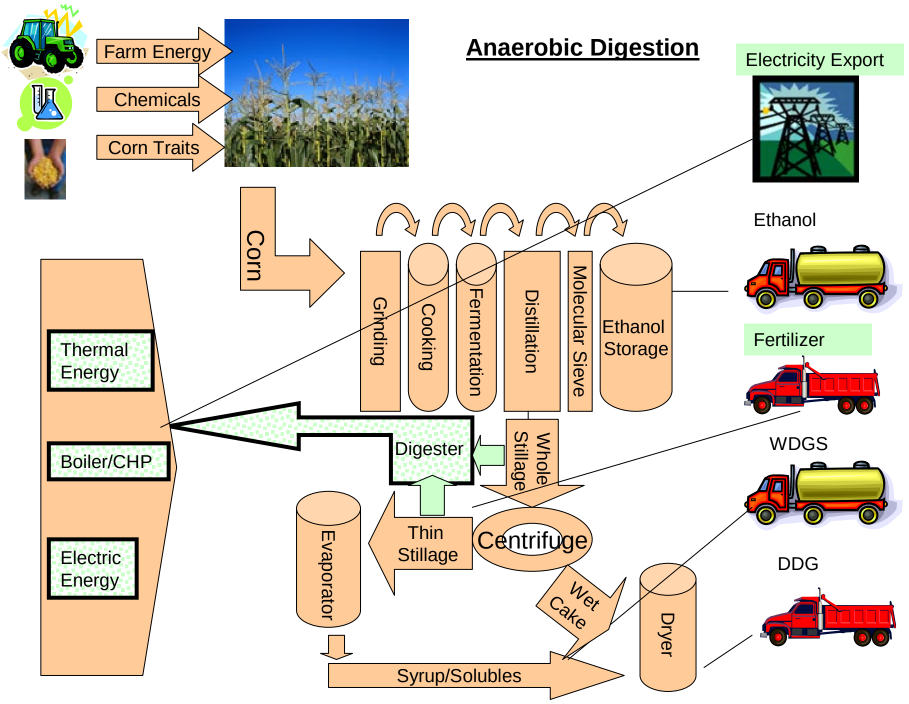

Figure 8: Anaerobic Digestion and the Ethanol Process

A modern ethanol plant produces approximately 5 gallon of thin stillage for each gallon of ethanol. An anaerobic digester can convert the thin stillage into biogas that consists approximately 60% of methane. An energy balance available for this study showed that an efficient anaerobic digester system sized to convert 100% of the thin stillage into biogas would produce approximately 21,000 Btu/gal (HHV) of energy. This approach leaves the wet cake for conversion into DDG (without the solubles). The plant's total energy demand is further reduced by 2,710 Btu/gal from the base plant consumption (from 30,000 Btu/gal to 27,290 Btu/gal) because the solubles are not dried. Therefore the digester will provide approximately 77% of the plant's thermal energy requirements.[17]

Furthermore, for every gallon of stillage one gallon of effluent water is produced containing suspended solids, including nitrogen, phosphorus and potassium which can be recovered and reformed into a fertilizer product. An engineering study showed that an anaerobic digester sized to digest 100% thin stillage would recover approximately 0.25 lbs/gal of NPK product.

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[17] Engineering and Design Proposal provided by NewBio e-Systems for the "Bioconversion of Thin Stillage to Methane" at the Illinois River Energy Center, April 2008.

The electricity requirements of an ethanol plant with an anaerobic digester system would be about 3% higher (0.73 kWh/gal) to operate pumps and motors for thin stillage/effluent movement.

Alternatively, a digester could be sized to convert whole stillage and thereby produce even more energy. However, this approach is less likely from a financial point of view since it would reduce DDG output, a valuable co-product. However, integration of anaerobic digesters from thin stillage with corn-fractionation may provide synergistic benefits.

An ethanol plant integrating anaerobic digestion (from thin stillage) with fractionation would still produce HPDDG. Since the thin stillage would not be dried, the energy requirements of this plant type are reduced from the fractionation base plant requirements of 24,720 Btu/gal to 22,010 Btu/gal (by 2,710 Btu/gal). Digesting the thin stillage would offset 21,000 Btu/gal and thus result in plant energy requirements of 1,010 Btu/gal. Since the plant would also be able to produce 0.5 lbs of bran per gallon produced, this product could be combusted in a small solid fuel boiler system and further offset energy consumption at the plant. In fact, at an energy content of 7,000 Btu per lb and 0.5 lbs per gallon produced, combusting the bran would result in additional energy production of 3,500 Btu/gal producing a net energy surplus of 2,490 Btu/gal for the plant, which could be used to supplement seasonal variations from the digester's biogas production.

Technology Providers:

New BioE
Biothane

Current Plants Employing Technology:

E3 Nebraska[18] (co-digestion of both manure and thin stillage)
Otter Tail Ag Enterprises, Fergus Falls, Minnesota (55-million-gallon corn dry mill interested in stillage digestion)

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[18] The N3 plant is currently in bankruptcy proceedings. However, prior to the bankruptcy filing, the digester system was fully operational (personal conversation with Richard Mattocks, Biothane Corporation).

2.7) Biomass Combustion/Gasification

Several ethanol plants are utilizing biomass as an energy feedstock. Biomass energy feedstocks have the potential to reduce a plant's reliance on fossil fuel and to reduce the emissions and greenhouse gas profile of the operation.

The Chippewa Valley Ethanol Plant in Benson, Minnesota is an example of a biomass gasification retrofit system. An 80% efficient gasifier generates producer gas that is fed to a boiler, dryer, and regenerative thermal oxidizer system (RTO). The boiler, dryer, and RTO are identical to the natural gas fired plant equipment. Due to the efficiency loss in he gasifier, the biomass requirements are derived by dividing the natural gas fired boiler plant requirements by the gasifier efficiency. Therefore, at an assumed natural gas base plant energy consumption of 30,000 Btu/gal a gasification retrofit configuration would require approximately 37,500 Btu/gal.

The Corn Plus ethanol plant in Winnebago, Minnesota is an example of a plant combusting biomass, in this case syrup. Supplemental energy needs are met by a natural gas fired boiler system.

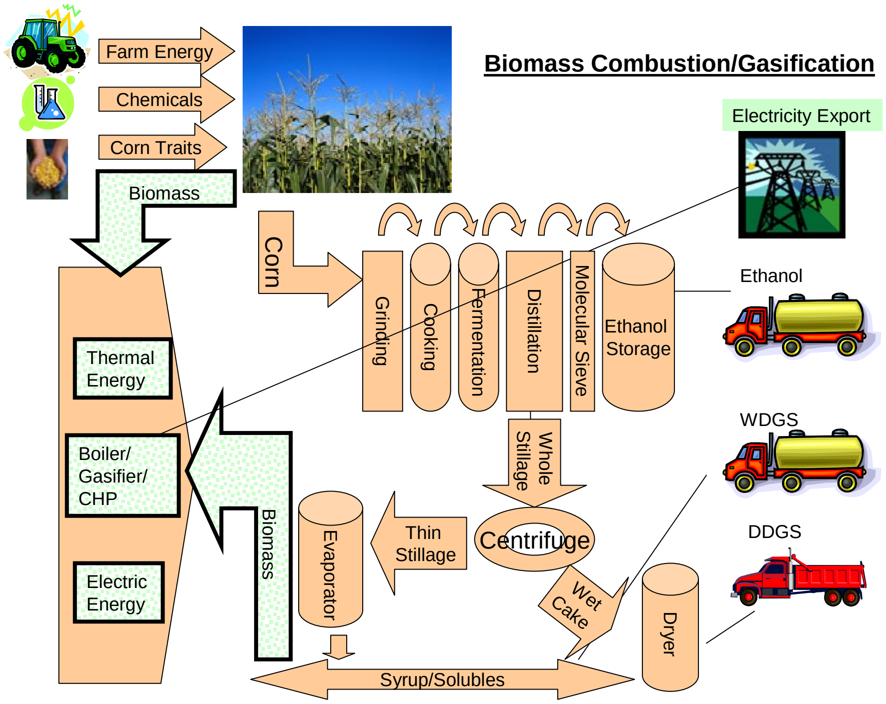

Figure 9: Biomass Combustion and Gasification and the Ethanol Process

Current Plants Employing Technologies:
Corn Plus Ethanol in Winnebago, Minnesota (combusting syrup)
Central Minnesota Ethanol in Little Falls (combusting wood)
Chippewa Valley Ethanol in Benson, Minnesota (gasifying wood waste)

2.8) Other Renewable Energy

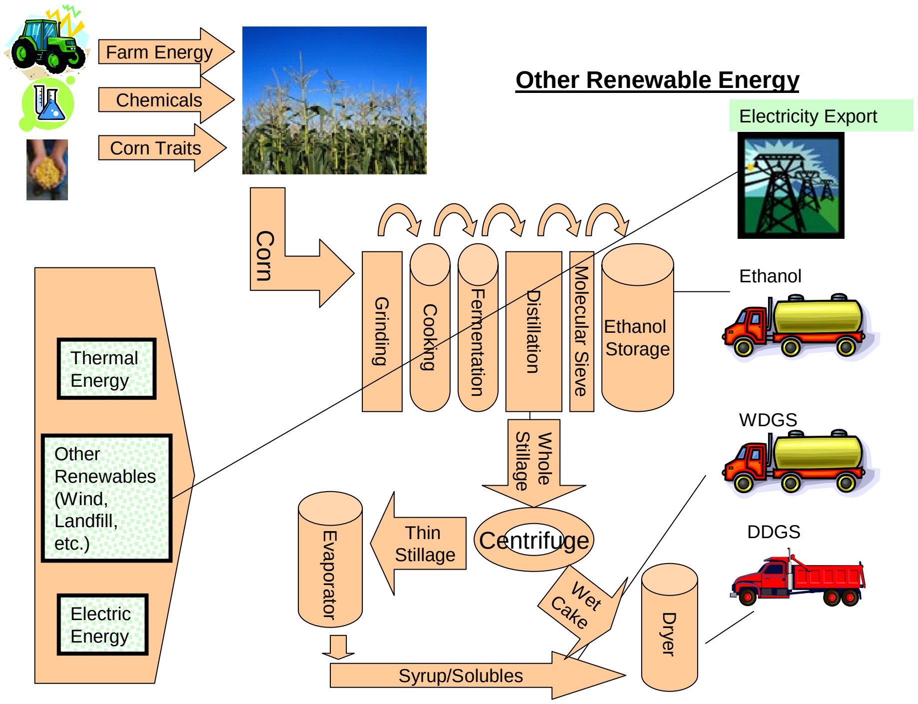

Figure 10: Other Renewable Energy and the Ethanol Process

In order to reduce fossil fuel consumption at the plant, several plants are starting to integrate other renewable technologies.

Key Technology Providers

Abengoa Solar is developing solar thermal systems for integration with ethanol plants.[19]
John Deere (providing wind turbines for Corn Plus)

Current Plants Employing Technology

Siouxland Ethanol, Jackson Nebraska (sourcing biogas from nearby landfill)
Corn Plus in Minnesota is adding wind turbines

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[19] See http://www.abengoasolar.com/sites/solar/en/abengoa_solar_ist/about_us/

3) Corn Production Technologies

3.1) Farm Energy

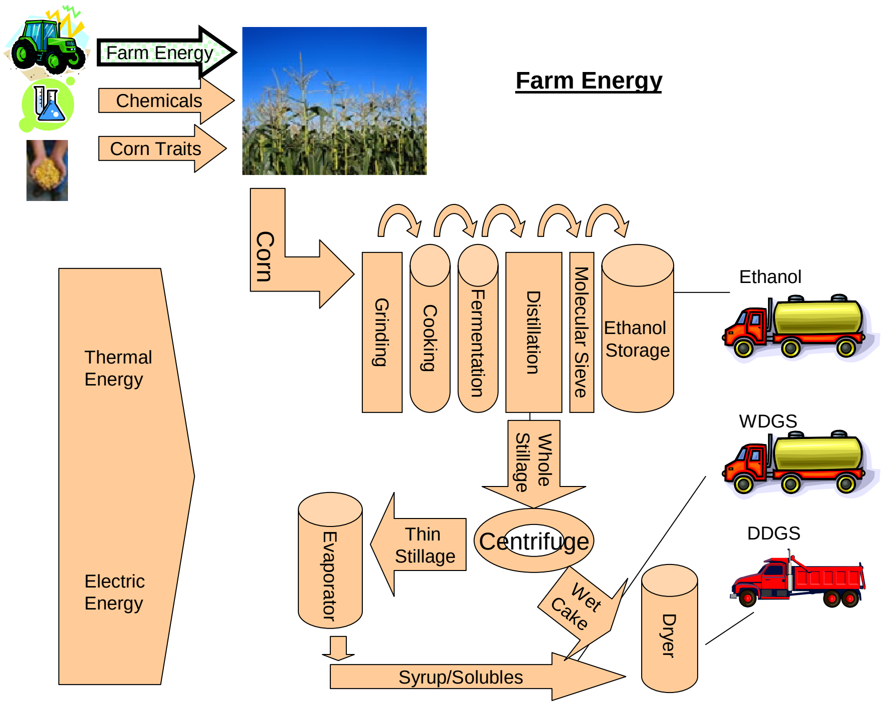

Figure 11: Farm Energy and the Ethanol Process

Several publications by the USDA have documented the farm energy use to produce corn.[20] These publications, adjusted for efficiency improvements form the basis for life cycle energy models such as the GREET model. GREET's current default value for on-farm energy consumptions required for corn production (tractor fuel, custom hauling, irrigation energy, input hauling) totals 12,600 Btu/bu.[21] This value reflects average Midwestern corn producing states. The value reflects a recent update (as of July 2008) where it was revised down from 22,500 Btu/bu. We believe that this value is likely reflective of the actual average. However, a recent survey with 29 corn growers delivering to the IRE ethanol plant indicates that much lower values are possible. The survey shows that the average grower delivering to this particular plant only utilizes 7,800 Btu/bu during corn production. At IRE's yield of 2.73 gal/bu the surveyed 7,800 Btu/bu results in an energy contribution of 2,857 Btu/gal. At GREET's assumed average

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[20] Shapouri, H., J. A. Duffield, et al. (2004). The 2001 Net Energy Balance of Corn-Ethanol. Proceedings Of The Conference On Agriculture As A Producer And Consumer Of Energy, June 24-25. Arlington, VA. Shapouri, H., J. A. Duffield, et al. (2002). The Energy Balance of Corn Ethanol: An Update. Washington, DC, US Department of Agriculture.

[21] GREET Version 1.8b

yield of 2.72 gal/bu the 12,600 Btu/bu results in an energy contribution of 4,632 Btu/gal.[22]

Several reasons can contribute to lower on farm energy consumption: the use of no-till practices and advanced farm equipment technologies including tractors equipped with geographic positioning system (GPS) and auto-steer.

No-till Practices:
The results from the growers' survey around IRE shown in Table 2 indicate that farmers practicing no-till reported markedly less tractor trips (4.7) across their fields than other growers (6.1).[23] By reducing tractor trips and by inference tractor fuel consumption, no-till practices also reduce global warming emissions. Furthermore, no-till practices can, under certain circumstances, reduce GHG emissions by increasing carbon sequestration.[24]

Table 2: Tractor Trips and Tillage Practices

	Conventional Till Tractor Trips	No-Till Tractor Trips
Mean	6.1	4.7
STD	1.9	1.2
N=	8	19

Farm Machinery Technologies Using GPS Tracking Technology with Auto-Steer:
Purdue University in cooperation with CropLife Magazine conducts an annual "Precision Agricultural Services Dealership Survey." The 2008 report states that "the biggest growth seen from 2007 to 2008 was in the use of GPS guidance systems with autocontrol/autosteer, growing from 27 percent of the dealerships in 2007 to 37% in 2008."[25] The technology is predominantly used with tractors, combines, and self-propelled sprayers. GPS systems and auto steer reduce the overlap along each pass across the field. Overlap improvements have shown to range around 4 percent.[26] The resulting savings depend on the type of field pass. Not overlapping on tillage, for example, reduces fuel consumption whereas not overlapping on spraying operations reduces fuel and chemical product consumption.[27] The newest technologies turn individual planter and sprayer components on and off based on their specific position in the field. According to John Deere, farmers are seeing an additional reduction of 5-10% in seed, fertilizer, and

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[22] These values are stated in LHV.

[23] Mueller Steffen and Ken Copenhaver, Michelle Wander; "The Global Warming and Land Use Impact of Corn Ethanol Produced at the Illinois River Energy Center"; Revised 10/22/08.

[24] A recent study by the University of Illinois at Chicago showed that applying a set of published sequestration rates to the amount of no-till acres supplying corn to IRE (13% no-till) would reduce the life cycle of IRE corn ethanol from 54.8 gCO2e/MJ to 52.2 gCO2e/MJ. Subtracting the average sequestration numbers for encouraging 100% no-till on IRE supply acres from the life cycle of IRE corn ethanol reduces it to 35.9 gCO2e/MJ.

[25] Whipker, Linda and Jay Akridge:"2008 Precision Agricultural Services Dealership Survey Results"; Working Paper #08-09. Crop Life Magazine and Purdue University, September 2008.

[26] Prairie Agricultural Machinery Institute; "Determining Options to Lower Mechanical Overlap in Sinuous Riparian Areas"; by Nathan Gregg and Patricia Lung, 2007.

[27] Farm Industry News;"Autosteer Is Here"; by Wayne Wenzel, February 15, 2004.

pesticides from this input control technology.[28] In summary, auto-steer will likely result in about 4% reduction in fuel and chemical use, whereas GPS based input control will result in additional 5% to 10% savings.

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[28] Email exchange with Larry Hendrickson, John Deere.

3.2) Corn Traits

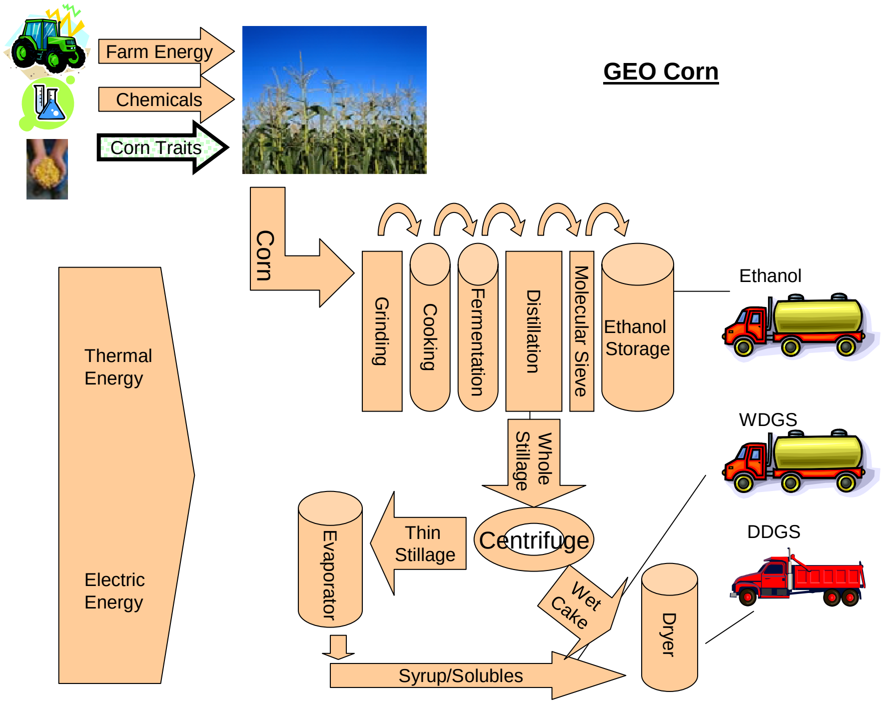

Figure 12: Corn Traits and the Ethanol Process

We are not aware of a statistical assessment that summarizes how much transgenic/GEO corn is used for US average corn ethanol production. However, the above mentioned survey of growers that supply corn to the IRE ethanol plant indicates that these growers do utilize predominately GEO corn. The graph below shows the breakdown of technologies. Respondents indicated that the vast majority of delivered bushels have genetically enhanced organisms (GEO) traits (89%) and the vast majority of GEO corn is triple stack type. Figure 13 below indicates the make up of the corn trait by bushel.

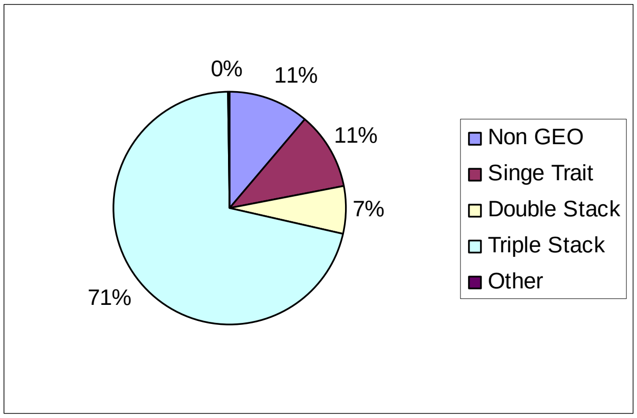

Figure 13: Corn Trait Selection of Farmers Supplying to IRE

Use of GEO corn may reduce use of pesticides, herbicides thus reducing the amount of tractor trips across the field. Furthermore, GEO corn increases yield thus reducing the energy per bushel spent.

3.3) Chemicals

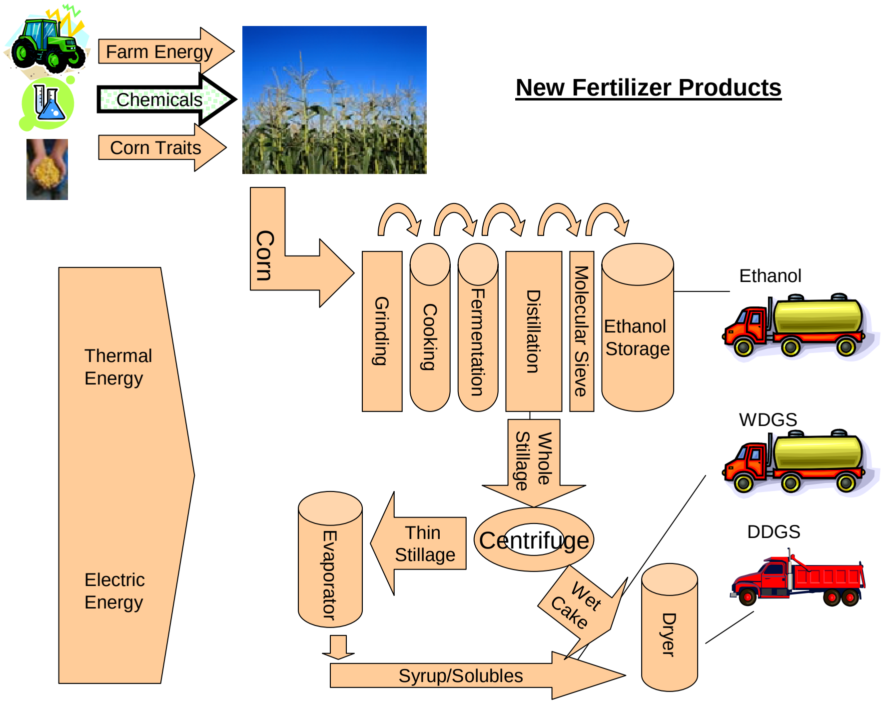

Figure 14: Chemicals and the Ethanol Process

Nitrogen fertilizer and other chemicals contribute to the energy use (during application as well as during the manufacturing process of the chemicals) of corn agriculture. Moreover, nitrogen application and the resulting dinitrification and nitrous oxide production contribute significantly to the GWI of corn ethanol. Technologies exist that allow for the application of nitrogen fertilizer only where and when it is required. These technologies include GPS and Auto-Steer systems in farm equipment (detailed above), but also slow release fertilizers and nitrification inhibitors (like N-Serve produced by Dow Agrosciences), N-application based on soil testing and remotely sensed imagery, and N-side dressing.[29] In the following a brief summary of several technologies will be provided.

Nitrification Inhibitors:

Nitrification inhibitors work by retarding the formation of nitrate by nitrifying bacteria. A publication by Dow researchers in the Journal of Nutrient Cycling in Agroecosystems

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[29] R. Nider, D.K. Bembi; “Carbon and Nitrogen in the Terrestrial Environment”; Springer, 2008.

asserts that “greenhouse gas emissions decreased by 51%” with the application of nitrification inhibitors.[30]

Soil Testing and Remote Sensing:
Other methods which allow a more precise application of nitrogen fertilizer include soil testing to determine nitrogen availability in different parts of the field and remotely sensed imagery which can be used in-season to apply N only where needed based on plant vigor. Figure 15 demonstrates a project in which near infrared (NIR) imagery was used to estimate nitrogen requirements for a field in east central Illinois. Corn reflectance from the imagery was regressed to chlorophyll meter readings (SPAD readings) taken throughout the field that were then converted to nitrogen requirements.[31,32] This led to reduced nitrogen use in the field compared to a traditional application rate.

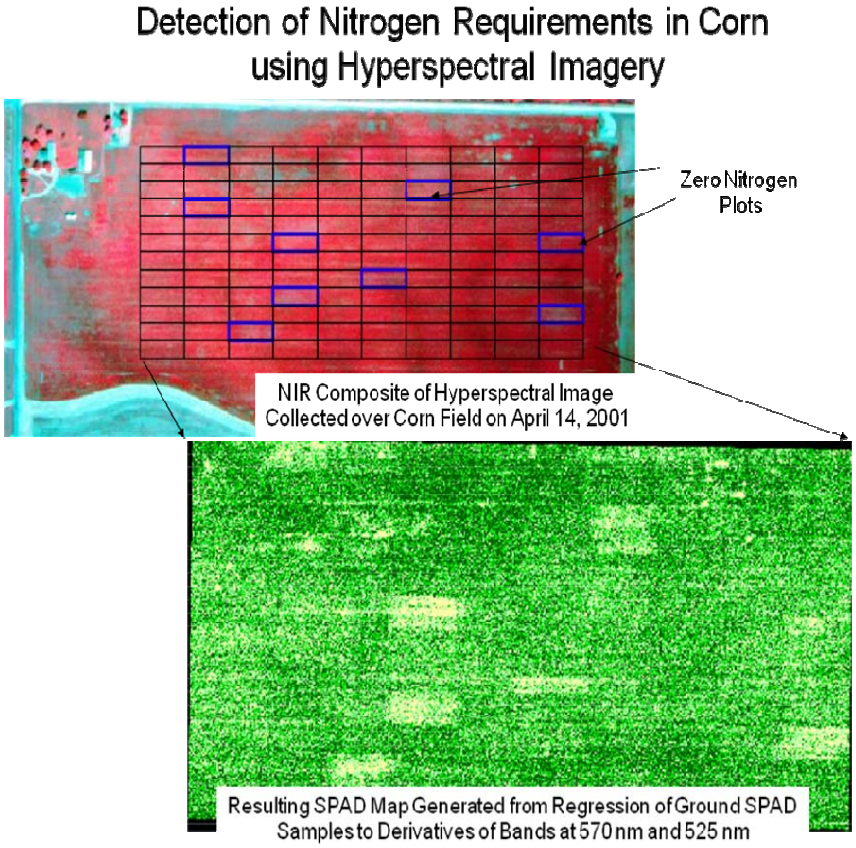

Figure 15: Determining N-Requirements Using Remote Sensing

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[30] Wolt, Jeffrey; “A meta-evaluation of nitrapyrin agronomic and environmental effectiveness with emphasis on corn production in the Midwestern USA”; Nutrient Cycling in Agroecosystems, 69:23-41,2004.

[31] Spectrum Technologies, Inc.;”Using a Chlorophyll Meter to Improve N Management”; www.specmeters.com

[32] Image produced by Institute for Technology Development

N-Side Dressing:

This process involves direct injection of nitrogen into the soil after emergence of the plant. The advantage of this method is that the application is timed to coincide with the plant's peak N-demand. The application system consists of a toolbar and injection coulters. Recent key advancements allow for applications at higher speeds (up to 12-14 mph on fields), which is important since there is only a short time window after plant emergence to apply the product before the plant gets too high.[33] Key manufacturers include John Deere, Case, and Hagie.

Various methods exist to quantify the nitrous oxide emissions from fertilizer inputs. GREET employs an emissions factor model based on the Intergovernmental Panel on Climate Change (IPCC). Using the GREET methodology and the above referenced data collected for the IRE ethanol plant, the influence of precision agriculture and slow release fertilizers/nitrification inhibitors will be demonstrated.

The current GREET Version 1.8b uses the following equation for N_2O emissions estimates from fertilizer application.

N_2O from nitrogen fertilizer, and above and below ground biomass =
(420 g/bu of N + 141.6 g/bu of N) * 0.01325 *44/28 = 11.7 g/bu

Where:

420 g/bu of N is the default value for N applied in fertilizer

141.6 g/bu of N is N content of above and below ground biomass (ie corn stover left on the field).

0.01325 is a factor for N in N_2O as fraction of N in N fertilizer and biomass. GREET assumes that 1.3% (including 0.2% from leaching) of the available N is converted to N in N_2O.

44/28 is the mass fraction of N_2O and N_2 in the molecule

At 420 g/bu or 0.93 lbs/bu the GREET default nitrogen input is slightly higher than the IRE surveyed N-input of 368 g/bu or 0.81 lbs/bu. Following the above equation, the difference in N-inputs results in different nitrous oxide production rates and subsequently in different contributions to the corn ethanol lifecycle: Applying 0.93 lbs/bu results in a contribution of 15.2, whereas applying 0.81 lbs/bu results in a contribution of 13.8 gCO2e/MJ (assuming IRE ethanol yield).

The graph below shows the GWI contribution to IRE produced corn ethanol as a function of N-inputs. As can be seen, if growers applied N close to the theoretical minimum of 0.6 lb/bu, these growers would contribute only 11 gCO2/MJ to the corn ethanol life cycle according to the GREET methodology. In contrast, growers that apply 1.6 lbs/bu would

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[33] Allen, Carrie; "Sidedressing Nitrogen in Corn Makes Sense"; Fluid Journal, Spring 2002.

contribute 24 gCO2//MJ. This difference of 13 gCO2//MJ (24 gCO2//MJ -11 gCO2//MJ) may account for 20% to 25% of the total GWI of an ethanol plant.[34] Utilization of the above described advanced N-application technologies will result in a move further towards lower inputs in the graph.

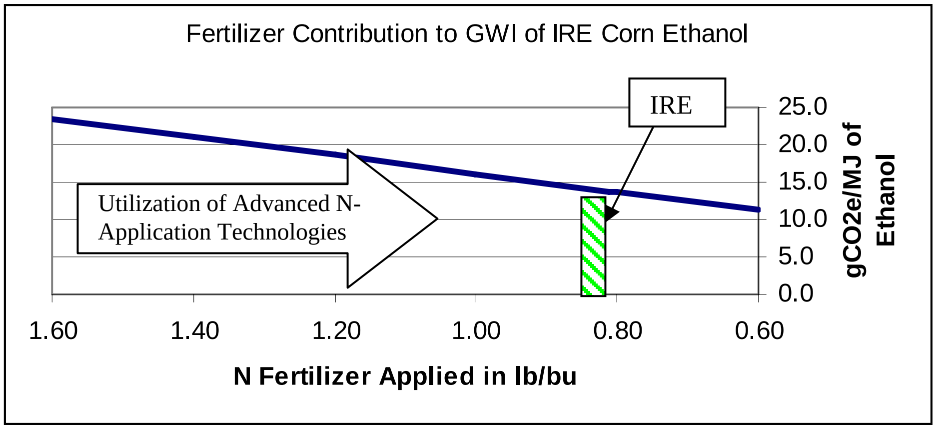

Figure 16: Relationship Between Global Warming Impact and Fertilizer Application

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[34] Remember that the IRE global warming impact totaled 54.8 g/MJ including N fertilizer contributions

4) Energy Summary

Table 3 below summarizes the thermal energy and electricity requirements as well as the co-product balance of modern corn ethanol production systems.

Table 3: Thermal and Electric Energy Consumption by Technology

	Thermal	*Electric*	*Comment*
	HHV per unit anhydrous ethanol (Btu/gallon)		
	Corn Agriculture		
On-Farm Energy[35]	8,851 (GREET, Prior to 7/08) 4,957 (GREET, Adjusted 7/08) 3,057 (IRE, Illinois Case Study)		
	Ethanol Plant		
Base Dry Grind Ethanol Plant	20,000 (boiler fuel) 9,700 (dryer fuel) 300 (thermal oxidizer equipment for emissions control) Total: 30,000	0.71	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS, 100% Drying
Cold Cook	25,000	0.71	Ethanol Yield: 2.73 gal/bu[36] Co-Product: 5.66 lbs/gal DDGS, 100% Drying
Corn Oil Extraction	30,000	0.71*1.1=0.78	Ethanol Yield: 2.73 gal/bu Co-Product: Corn Oil 3-4% by Volume (a 100 mgpy ethanol plant produces an additional 3-4 million gallon of corn oil)
Anaerobic Digesters[37]	27,290-21,000=6,290	0.71*1.03=0.73	Ethanol Yield: 2.73 gal/bu Co-Product: 2.6 lbs/gal DDG 21,000 Btu/gal of energy provided from digester biogas 0.25 lbs/gal of NPK fertilizer

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[35] Energy requirements in Btu/bu converted to Btu/gal and then to Higher Heating Value based on the following equations:
22,500(Btu/bu)/2.72(gal/bu)*1.07 HHVdiesel/LLVdiesel = 8,851 Btu/gal.
12,600/2.72*1.07=4,957 Btu/gal
7,800/2.73*1.07=3,057 Btu/gal
Note that the IRE farm energy value is converted based on the IRE yield, the GREET values are converted based on the GREET yield.
Note that HHV/LLV conversions are based on diesel, recognizing that diesel is the dominant but not exclusive fuel share. Errors from this assumption should be small.

[36] Critics argue that cold cook processing may lead to starch loss. Therefore, yields may be lower, see Ethanol Producer Magazine article “Break it Down”, January 2006.

	Thermal	***Electric***	***Comment***
Fractionation[37]	30,000*(1-.176)=24,720	1.0	Ethanol Yield: 2.64 gal/bu Co-Products (Common fractionation split): Approximately 2.6 lbs/gal HPDDG Approximately 3.7 lbs/gal Corn Gluten Feed Approximately 0.75 lbs/bu of corn oil. This equates to 3.75% corn oil by volume (a 100 mgpy ethanol plant produces 3.75 mgpy corn oil).
Fractionation[37] Combined With Anaerobic Digestion	24,720 [base fractionation]-2,710 [no stillage drying] -21,000 [digester]=1,010	1.03	Ethanol Yield: 2.64 gal/bu Co-Products: 2.6 lbs/gal HPDDG Combining fractionation with anaerobic digestion of thin stillage does not enable production of corn gluten feed, but alternatively 0.5 lbs/gal of bran. Bran may be used as a feed product. 0.25 lbs/gal of NPK fertilizer
Fractionation Combined With Anaerobic Digestion combined with NEMA Motors	24,720 [base fractionation]-2,710 [no stillage drying] -21,000 [digester]-3,500 [bran] = -2,490	1.03*(1-0.053)=0.98	Ethanol Yield: 2.64 gal/bu Co-Products: 2.6 lbs/gal HPDDG Combining fractionation with anaerobic digestion of thin stillage does not enable production of corn gluten feed, but alternatively 0.5 lbs/gal of bran. Bran may be combusted in a solid fuel boiler making the ethanol plant a net producer of energy, which can be used to absorb seasonal variations of digester biogas production.
Natural gas base plant with Superboiler and NEMA Motors	30,000*(1-.149)=25,530	0.71*(1-0.053)=0.67	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS

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[37] The biomass in this case is credited towards reduced energy requirements since it is a co-product from the ethanol production process. The listed value reflects the residual natural gas requirements.

	Thermal	*Electric*	*Comment*
Natural Gas Combined Heat and Power sized to meet electric load	32,352	0.13	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS
Natural Gas Combined Heat and Power sized to export power	46,468	-2.23 kWh/gal	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS Electric Power Export
Biomass Combustion (Fluidized Bed Boiler)[38]	35,897 Natural gas fuel consumption: 0	0.85	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS
Biomass CHP (Fluidized Bed Boiler plus Steam Turbine)[38]	39,515 Natural gas fuel consumption: 0	0.1	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS
Biomass Gasification (Gasifier Retrofit to Natural Gas Boiler)[38]	37,500 Natural gas fuel consumption: 0	0.85	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS
Other Renewable Energy	Solarthermal	Solar, wind	Ethanol Yield: 2.73 gal/bu Co-Product: 5.66 lbs/gal DDGS

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[38] Biomass is assumed to be sourced from outside suppliers. Therefore, the Btus that need to be sourced are stated.