2012 Corn Ethanol: Emerging Plant Energy and Environmental Technologies

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Executive Summary

The present study explores the adoption of technologies that reduce the energy and environmental footprint of the corn ethanol production pathway, both at the corn production stage and during corn conversion to ethanol at the dry grind biorefinery. The study is representative of the industry's state in 2012. This is a follow-up effort to a similar study which benchmarked the industry's performance in 2008.

The study shows that at the biorefinery level modern energy and processing technologies such as sophisticated heat integration, combined heat and power technologies, variable frequency drives, advanced grinding technologies, various combinations of front and back end oil separation, and innovative ethanol and DDG recovery have further reduced the energy footprint of the corn ethanol production process.

Our work includes an assessment of over 50% of operating dry grind corn ethanol plants. On average, 2012 dry grind plants produce ethanol at higher yields with lower energy inputs than 2008 corn ethanol. Furthermore, significantly more corn oil is separated at the plants now which combined with the higher ethanol yields results in a slight reduction in DDG production and a negligible increase in electricity consumption. Note that this assessment is a snapshot across all ethanol plant technologies, co-product drying practices, and geographic locations. The table below summarizes the results.

	2012 Corn Ethanol	**2008 Corn Ethanol**
Yield (anhydrous/undenatured, gallon/bushel)	2.82	2.78
Thermal Energy (Btu/gallon, LHV)	23,862	26,206
Electricity Use (kWh/gallon)	0.75	0.73
DDG Yield (dry basis) including corn oil (lbs/bu)	15.73	15.81
Corn Oil Separated (lbs/bushel)	0.53	0.11
Water Use (gallon/gallon)	2.70	2.72

The energy use and product yields of corn ethanol plants depend on a multitude of variables that cannot be statistically controlled for in an analysis. For example, while plants that sell wet distillers grains exhibit lower energy consumption than comparable plants that dry their co-products the energy reduction cannot be statistically quantified since differences in other plant variables cannot be controlled for in the analysis. Therefore, the present study developed energy and co-product balances for four different plant configurations that model the adoption of currently available advanced technologies.

The modeled configurations show that depending on the adopted technology and desired co-product energy consumption of modern corn ethanol plants range between 19,500 and 26,500 Btu/gallon of natural gas with yields as high as 2.89 gallon/bushel.

		Configuration 1 Traditional Corn Dry Milling, DDGS, incorporating corn oil extraction post distillation	Configuration 2 Traditional Corn Dry Milling, DDGS+WDGS, incorporating corn oil extraction post distillation	Configuration 3 Multiple Co-Products – DDGS, High Protein Meal, Grinding of Mash in Liquefaction, Front End Oil and oil post distillation	Configuration 4 Traditional Corn Dry Milling, DDGS, incorporating corn oil extraction post distillation and superheated drying technology
Ethanol Yield	gal/bu	2.85	2.85	2.89	2.85
Front End Oil	lb/bu			0.48	
Back End Oil	lb/bu	0.8	0.8	0.8	0.8
DDGS dry	lb/bu db	13.7	6.85	9.47	13.7
DDGS wet	lb/bu db		6.85		
High Protein	lb/bu db			3.25	
Thermal Energy Use	Btu/gal	25,000	21,000	26,500	19,500
Electrical Energy Use	kWh/gal	0.58	0.58	0.7	0.75

Note: db=dry basis

The study also looks at new technologies that have recently been adopted and further increase the efficiency during the corn production phase of the corn ethanol pathway. For example, over the last several years higher corn yields have also increased the amount of corn stover and additional plant material produced by modern hybrids. As a result growers have started to remove corn stover for use as animal feed in nearby feedlot operations. Consequently, acres producing corn for ethanol and DDG animal feed now also produce a second animal feed at the front end of the process in the form of stover feed. Other efficiency improvements during the corn production phase include more accurate and targeted delivery of chemicals and agricultural inputs, as well as corn hybrids that contain enzymes resulting in reduced processing energy and increased ethanol yields at the biorefinery level.

Introduction

Energy consumption and advanced production technologies of corn ethanol are a topic of considerable interest since these factors constitute important inputs into environmental models that compare different fuel alternatives. The last comprehensive assessment of ethanol plant energy technologies and their adoption rates dates back to 2008.[1] Since then ethanol plants have continued to improve their processes in an effort to reduce energy costs, target specific co-product markets, and improve their environmental performance. Furthermore, emerging agronomic technologies are being rapidly adopted that reduce the environmental footprint of the ethanol production pathway. The recent adoption of energy saving technologies as well as advanced processing technologies has also been supported by new funding sources including ARRA grant money, State Renewable Portfolio Standards, and other state and federal energy efficiency grants.

This technology assessment will provide a comprehensive review of new and emerging energy efficiency technologies adopted by ethanol plants and then quantify their energy savings and the associated environmental impact. Since many plants have recently adopted these new technologies, this report will also provide an assessment and a statistical quantification of the current state of the ethanol industry's energy and water use. A survey commissioned in 2001 by the US Department of Agriculture showed that US dry grind corn ethanol plants used 36,000 Btu per gallon of thermal energy and 1.09 kWh per gallon electricity.[2] By 2008 the thermal energy consumption had dropped by 28% and electricity consumption had dropped significantly and natural gas plants required 26,202 Btu/gal (LHV) and used 0.73 kWh/gal of electricity. It should be noted that these values are reflective of a representative sample of average US corn ethanol and therefore include plants that produce dry and wet co-products at various levels. In addition to energy use water consumption has also been declining. The 2008 survey documented an average water use of 2.72 gallons of water per gallon of ethanol produced which is a 50% reduction compared to a 2005 study conducted by the Minnesota Department of Natural Resources.

The adoption of new technologies at the ethanol plant level is mirrored by emerging technologies at the corn production stage. Reduction in the cost of satellite and remotely sensed technologies as well as new corn hybrids have significantly advanced feedstock production. 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. Besides ethanol a typical plant also processes the non-fermentable nutrients (protein, fat, and fiber) left over after the

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[1] Mueller, S. "2008 National dry mill corn ethanol survey"; Biotechnol Lett DOI 10.1007/s10529-010-0296-7, May 15, 2010. Mueller, S. and Ken Copenhaver "An Analysis of Modern Corn Ethanol Plant Technologies", February 2009.

[2] Shapouri H, Duffield J, Wang M (2002); The energy balance of corn ethanol: an update. Agricultural economic report 813. United States Department of Agriculture

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. Derivatives of the DDGS and WDGS of different forms are also being produced in order to meet more targeted animal feed markets. Finally, most ethanol plants also separate corn oil from the non-fermentable product stream for resale into the biodiesel and/or animal feed markets.

Emerging Dry Grind Ethanol Technologies

The following is a summary of the emerging technologies currently offered to the Dry Grind Ethanol facilities and their effect on production and energy balance of the facilities.

CHP – Combined Heat and Power

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. Ethanol plants are an excellent application for CHP systems since the plants operate year-round on a 24/7 schedule. Furthermore, the thermal and electricity demands at ethanol plants coincide which means that CHP systems can be operated very efficiently. Finally, ethanol plants are oftentimes connecting to weaker, rural electricity feeders. In this case installation of a CHP system can increase the reliability of electricity supply.

CHP systems save energy at ethanol plants due the efficient utilization of otherwise wasted heat. Ethanol plants generally utilize natural gas fired packaged boilers and purchase electricity from the incumbent grid. Central station grid generated electricity, however, is delivered to the plant at relatively low efficiencies of around 30%. In contrast, if sized correctly CHP systems can achieve a combined thermal and electric efficiency of 70% to 90%.

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 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. As a variation ethanol plant CHP systems can be 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.

Financially, the payback of a CHP system depends on various factors including the electricity rate charged by the local utility, the ability to optimize the integration of both thermal and electricity generated CHP energy with the plant process needs, as well as access to financing. Some CHP configurations may incur higher natural gas cost (if the boiler is fired at a higher temperature or a combustion turbine is utilized) in exchange for lower utility costs. Since our last corn ethanol industry assessment several CHP systems have been financed utilizing ARRA funds.

CHP Steam Turbine Configuration – 200 psig steam

Steam generation from the existing boilers can be increased to maximum operating pressure of the current boilers which will vary from 150 psig to 200 psig. This high pressure steam can then be sent to a steam generator which uses the steam to drive a turbine. The exhaust pressure of the turbine would be determined based on the low pressure steam requirements at the facility. The lower the exhaust pressure the greater the electrical generation.

Typical ICM plants would run exhaust pressures between Atm to 5 psig or as required for evaporation. Typical Delta T plants would run exhaust pressures between 20-30 psig or as required for distillation. Currently facilities that have not implemented the CHP systems are reducing the steam pressure by a pressure reducing valve where the energy loss is inefficiently dissipated in the form of heat.

Energy generation:
Typical plant (50 MM gpy) – 40,000 lb/hr steam load
Electricity Generation: Gen – Several MW

CHP Stream Turbine Configuration – 400-600 psig steam

If the existing boiler can be modified to a higher pressure or a new boiler retrofit is being considered the operating pressure can be elevated to 400-600 psig. In general, the higher the pressure of the motive steam the greater is electricity generation potential. This high pressure steam can then be sent to a steam generator which uses the steam to drive a turbine. The exhaust pressure of the turbine is determined based on the low pressure steam requirements at the facility. The lower the exhaust pressure the greater the steam generation.

Typical plant – 70,000 lb/hr steam load at 600 psig

CHP Combustion Turbine Configuration

In general, steam turbine installations and steam turbine retrofits are less capital intensive than the installation of a natural gas fired combustion turbine integrated with a heat recovery steam generator (HRSG). However, the latter system provides different operational flexibility since supplemental firing in the HRSG can be used to follow steam demand at the plant.

Front End Slurry Grinding

This process is designed to grind the wet slurry prior to or during liquefaction to release starch that is encapsulated in a protein matrix and is not accessible to the alpha amylase in the liquefaction system. There are currently two technologies available for front end slurry grinding. The two technologies differ in that one grinds the entire slurry stream in a colloidal mill, the second technology referred to as "Selective Grind Technology" and/or "Selective Milling Technology" dewaters the slurry and only grinds the selected solids in a grind mill to concentrate milling on starch containing particles. The following paragraphs describe the differences between the two technologies;

Colloidal Mill

In this technology the slurry is pumped through a colloidal mill where water and solids are ground to reduce the particle size. Mill is located in the feed stream to liquefaction.

Selective Grind Technology and/or Selective Milling Technology

This process can be broken down into two steps as follows; slurry dewatering and grinding and are described below.

Slurry Dewatering

Slurry from the cook tank pump will be sent to paddle (dewatering) screens. Screen size is selected depending on the starch/particle size relationship in the mash and only starch containing solids are ground. The slurry enters the feed end where the smaller particles and the liquid portions are passed through the screen surface resulting in a dewatered cake. As the slurry continues down the screen length additional liquid and small particles pass through the screen and the solid content increases until the desired cake moisture is reached at the discharge. The dewatered cake from each screen is then sent via a gravity chute to the feed inlet of the grind mill. Centrate from the paddle screens will bypass the grind mill and will be combined with the grind mill discharge cake in the collection tank.

Grinding

The dewatered cake from the paddle screens is fed to the grind mill. The grind mill is a 36” shear/impact mill that utilizes a unique grinding plate to reduce only the larger starch containing particles. Milled cake from the grind mill and centrate from the paddle screen will be combined in the collection tank which is then transferred to the liquefaction system.

Yield increase – Average 2%-2.5% *
Best Yielding Plant – 2.89 gal/bu undenatured
DDGS reduction – up to 1.0 lb/bu
Oil Yield Increase – 15-20%
Thermal Reduction – up to 1,000 Btu/gal
Electrical Increase – 0.05 Kw/gal
DDGS Starch Reduction – 25% to 50% depending on starting starch yield

*Note: Yield increase in dependent on current yield and available starch in DDGS to be reclaimed, yield increases as high at 5.5% have been achieved.

Front End Oil Recovery – BOS (Brix Oil Separation)

The process consists of system that recovers oil from the slurry/liquefaction stream. The feed stream is taken to a dedicated paddle screen, three-phase disc/nozzle centrifuge, and polishing centrifuge to produce a low-FFA crude corn oil product.

Feed Stream Screening

The feed to the BOS system will be pumped from the desired process point to the feed paddle screen. The paddle screen will remove oversized particles prior to the 3-phase separation step in the Triton centrifuge. The slurry enters the feed end where the smaller particles and the liquid portions (centrate) are passed through the screen surface resulting in desired solids sizing passing forward to the centrifuge. Centrate from the paddle screen will be collected in the triton feed tank. Oversized solids from the paddle screen are carried down the length of the screen and discharge as a solids cake. The dewatered cake discharge will be combined with heavy phases from the Triton and polishing centrifuge in a solids collection tank.

Triton 3-Phase Disc/Nozzle Centrifuge

Centrate from the paddle screen that was collected in the Triton feed tank is pumped to the Triton feed nozzle. The Triton is a 36” disk nozzle centrifuge that can provide 3 phase separation. Heavy sugar and solids will discharge out the underflow nozzles, lighter solids such as germ and some starch and sugar will discharge out the Heavy liquid phase, oil and emulsion will discharge in the light phase. Both the underflow and heavy phases will combine and be sent to the solids collection tank. The overflow will be sent to the polisher feed tank.

Polishing Centrifuge
The Tritons light phase will be sent to the 3-Phase polishing decanter centrifuge for oil clarification. The heavy phases will include any emulsion and residual sugars or solids will discharge in the underflow or cake discharges and will be sent to the underflow collection tank. The polished oil will be discharged from the light phase and will be ready for commercial sale.

Oil Yield Increase – 0.4 to 0.48 lb/bu
Ethanol Increase – 0 gal/bu
Thermal Reduction – 100 Btu/gal (heat need to heat oil through process)
Electricity Increase – 0.02 kw/gal

Protein Recovery – MSC – Maximum Stillage Co-Products

This process involves washing a high value protein from the whole stillage stream post distillation. The protein is then concentrated, dewatered and dried resulting in a 50% purity high value protein meal. A description of the process is described below;

Distillation bottoms (whole stillage) are fed to a set of dewatering screens which provide the first separation step in the process. The centrate from the dewatering screens which contains protein, solubles, and oil is sent to a disc/nozzle centrifuge for concentration. The solids stream from the dewatering screens is sent to the Fiber Filtration Centrifuge. In the Fiber Filtration Centrifuge, the fiber moves through the first dewatering stage where additional protein is removed. As the fiber moves through the second and third stages, washing water is added as needed. The fourth stage completes a final dewatering of the fiber. The fiber discharge is fed to the existing fiber dryer system. The dewatering screens and Fiber Filtration Centrifuge centrate streams are combined and sent to a disc/nozzle centrifuge for protein concentration and soluble solids washing. The disc/nozzle centrifuge concentrates the protein in the underflow stream which is then sent to the existing facility decanter centrifuges to dewater the protein stream. With slight modifications, a distill bottoms dewatering centrifuges can be used for this dewatering step. The overflow stream of the clarifier which contains oil and solubles is fed to the traditional evaporator process.

The decanter protein cake is fed to a adiabatic flash dryer (ring dryer) to dry the protein. The decanter centrate is used as back set. Oil can be recovered in the evaporation banks using traditional oil recovery centrifuges. The stream has decreased protein content compared with traditional streams, so oil recovery is significantly improved when recovering oil while using the MSC process. The oil is recovered and the syrup discharge is sprayed on the fiber stream from the Filtration Centrifuge as in a traditional DDGS process.

Yield Increase – 1% (cleaner backset, fermentable sugars in backset at concentrated)
Protein Yield – 3.5 – 4.5 lb/bu
Oil Yield – 1.0 lb/bu (backend, when combined with front end oil 1.4 lb/bu)
DDGS Yield – 10.0 lb/bu – dry basis
Thermal Energy – No change
Electricity Energy – Additional 0.2 Kw/gal
Facility Throughput – Increase by 10% due to removal or protein solids, increase fermentation and drying capacity.

Fiber Bypassing/Separation – Pre and Post-Fermentation – to be used in conjunction with SGT/Front End Oil and MSC

Fiber Bypassing/Separation

Once we have the ability to remove the protein and additional oil we can know focus on the fiber. The fiber can be removed under the following scenarios and utilized as follows:

- Removal of fiber pre-fermentation – This process bypasses the fiber around the liquefaction heat exchangers, fermentation and distillation and put right to the dryers. The advantage would be the 12% volume that could be freed up in the fermenters for starch and the reduction of fouling and viscosity by removing the fiber. Although this system is not running full scale it will be tested shortly. This process still produces DDGS and ethanol; it would just take fiber out of the process.
- Removal of fiber pre-fermentation – This process washes the fiber so it can be sold as a product or used as a feed source for 2nd generation cellulose ethanol. The fiber can be washed down with low sugar levels and low protein levels. There would be no drying of fiber if you are feeding a cellulose plant. The amount of fiber that could be converted in a cellulose plant would be approximately 10-15% of the plants current capacity – i.e., a 100 MM gpy plant could increase throughput by 10-15 MM gpy.
- Removal of fiber post-distillation – This process removes the fiber after distillation. This fiber would again be used for cellulose ethanol production.

Process - Pre Fermentation

Liquefaction slurry is fed to the counter current washing screens where the germ and sugars are washed off the fiber cake. Cake from the dewatering screen is then sent to a collection tank where the cake is rehydrated with fiber centrifuge centrate. This rehydrated slurry is then sent to the fiber dewatering centrifuges where the remaining sugars are washed off the cake, the dewatering centrifuge produces a 40-45% DS cake. Centrate from the washing screens now containing sugar, starch, fine fiber, protein and germ is sent to fermentation.

Wash water is typically cook water as no additional water is required for the process. The removal of fiber from the liquefaction heat exchangers and the fermentation will allow for an additional 12% of the thin stillage system for protein removal to feed the MSC system. White fiber separation can be accomplished both pre and post fermentation.

White Fiber Yield – 3.5 - 4.5 lb/bu – dry basis
DDGS Yield – 6.5 lb/bu less than starting DDGS yield – dry basis

Protein Yield – 3.5 – 4.5 lb/bu - dry basis
Oil Yield –1.0 lb/bu post distillation(when combined with front end oil 1.4 lb/bu)
Ethanol Yield Increase – 2% (cleaner backset, fermentable sugars in backset at concentrated)
Thermal Energy – approx 5,000 Btu/gal reduction
Electric Energy – Additional 0.2 Kw/gal
Facility Throughput – Increase by 10% due to removal or solids, increase fermentation and drying capacity.

Oil Recovery Summary

The process to recover oil from the dry milling facilities has evolved over the past several years and currently there are several technologies offered for oil removal. The following describes the multiple configurations that are currently installed and also some new emerging technologies are discussed:

- **Back End Oil** – Traditional oil recovery system that either utilizes a disk stack desludger or a 3 stage Decanter. System must be installed in the concentrated thin stillage stream with solids >20-24%. There are no additional heating steps or emulsion breakers added. Yield = 0.4-0.5 lb/bu
- **Back End Oil w/additional heating** - Traditional oil recovery system that either utilizes a disk stack desludger or a 3 stage Decanter. System must be installed in the concentrated thin stillage stream with solids >20-24%. There is an additional heating step(s) where the oil is held at higher temperatures to free the oil from the emulsion phase. No emulsion breakers added. Yield = 0.5-0.65 lb/bu
- **Back End Oil w/additional heating & Emulsion Breaker** - Traditional oil recovery system that either utilizes a disk stack desludger or a 3 stage Decanter. System must be installed in the concentrated thin stillage stream with solids >20-24%. There is an additional heating step(s) where the oil is held at higher temperatures to help free the oil from the emulsion phase and an emulsion breaker is added to either the centrifuge feed tank or directly into the centrifuge feed stream.
  Yield = 0.6-0.85 lb/bu
- **Back End Oil wAOS (advanced oil separation)** - Traditional oil recovery system that either utilizes a disk stack desludger or a 3 stage Decanter. System must be installed in the concentrated thin stillage stream with solids >20-24%. Traditional centrifugation removes an oil/emulsion stream. This targeted emulsion concentrate stream is then further processed through the addition of a polar solvent, ethanol, as the emulsion breaking-agent. This steam is then sent for a secondary centrifugation step. The ethanol liberates oil trapped in the emulsion concentrate that would not be recovered through other conventional methods. Yield = 0.85-1.00 lb/bu
- **Front End Oil + Back End Traditional Oil** – The Front End Oil technology as described earlier is employed with the current traditional backend oil removal systems described above. Additional heating and emulsion breakers area added. Yield = 1.0-1.2 lb/bu
- **Front End Oil + New Back End Oil Removal** – The Front End Oil technology is employed with a new back end oil technology that utilizes a 2 stage disk nozzle centrifuge installed on thin stillage. The overflow from the clarifier is sent to a disk nozzle desludger to concentrate the oil/emulsion stream. This concentrated stream is then sent to the liquefaction system where the heat, residence time and sugar concentrations are used to break the oil emulsion and liberate free oil which is then removed in the front end oil system. Yield = 1.2-1.6 lb/bu

- **Thin Stillage Flotation** – This is the process of installing a flotation cell on the thin stillage and removing the protein and oil emulsion with fine fiber as a float. The floatation cell requires addition of a flocculant agent to remove the oil/emulsion phase called the “float”. The float, once removed from the thin stillage, is sent to a traditional disk stack desludger centrifuge for oil removal. The underflow from the oil separator is send to the dryer. Clarified thin stillage from the flotation vessel is sent to the evaporator as the new thin stillage.

  Oil Yield – 0.7 lb/bu
  Thermal Energy – no change
  Electric Energy – 0.2 kw/gal increase

Super-Heated Steam DDGS Dryers

The Superheated dryer is a closed loop adiabatic flash dryer that uses superheated steam in place of hot air to dry the DDGS. The wet solids from the decanters are fed into a recycle mixer where dry solids from the dryer and mixed with wet cake from the decanters. Syrup is also added to the recycle mixer. Once mixed to a predetermined moistures approximately 25-30% the mixed solids are then introduced into the drying column via a disintegrator. The superheated steam is then used to dry and convey the solids into the separator cyclones.

The transport steam is superheated indirectly via a tubular heat exchanger, by a heating media such as medium pressure steam, flue gases or thermal oil. As the product and steam travel through the drying column moisture is vaporized from the product, forming excess transport steam and lowering its degree of superheat.

The residence time in the drying system is approximately 5-60 seconds. Transport steam and the dry material are separated in a high efficiency cyclone and the material is discharged from the dryer. The dryer exhaust gases are recycled and the evaporated vapor is removed by means of a heat reclaim exchanger. The evaporated vapor is condensed in the reclaim exchanger so the condensate from the reclaim exchanger must be then either recycled to the front end or discharged. Remaining dryer gases are then recycled to the dryer gas heater to be re-superheated and returned to the drying column.

Thermal Savings – 8,000-10,000 Btu/gal
Additional Electricity – 0.3 kw/gal
Water Generated – product of evaporation is condensed so the following water streams are generated
50MMgpy – 60,000-80,000 lb/hr additional water
100 MMgpy – 120,000-160,000 lb/her additional water
Water must either be returned to process or treated in either anaerobic digester or waste treatment facility.

Additional Energy and Yield Projects

Liquefaction Mash Exchanger Plate Expansion

This project involves adding additional plates and passes to the existing heat exchanger bank to reduce the cooling tower loading and increase the beer temperature going to the beer column. Higher beer column feed temperature results in lower steam usage in the distillation system. The project can either increase the number of plates, increase the number of passes or a combination of both.

Current facilities exchange the heat from liquefaction (185F to 100F) to preheat the beer to the distillation column (88F to 140F average). By adding more plates or changing the configuration of the plates the beer feed temp can be increased to 150F +/-. Typically this can be done by just adding plates to the existing frames. Vendors typically recommend a maximum plate count for the exchangers but we have been able to add additional plates above this number. Maximum plate count from vendors is defined to allow room to remove all plates and work between plates, but additional plates can be added well in excess of max plate count recommendation from vendors.

Energy savings
Cooling – 600 Btu/gal
Steam - 600 Btu/gal

Fermentation Exchanger Plate Expansion

This project involves increasing the number of plates and passes to the existing fermentation cooling heat exchangers to provide additional cooling during summer months. The net effect is better fermentation temperature control which increases yield and throughput during summer months. This project will allow facilities to operate during peak summer months a maintain a max beer temp of 96-97F using current cooling systems, although this may not be able to be applied at each facility.
Yield Increase – 0.1-0.3 gal/bu during summer months (June-Aug)

CO_2 Scrubber Ethanol Reclaim

Current facilities use cold water to remove the ethanol from the CO_2 vapors from fermentation. Most of the liquid is returned to the front end of the process which operates at approximately 185° F. When the ethanol is returned to these high operating temperatures the ethanol tends to flash from the liquid and ethanol is lost to the vent system. This ethanol is then either recovered in the thermal oxidizers as a fuel source or is lost. A new condenser is installed ahead of the CO_2 scrubber to remove the entrained ethanol and return this ethanol to either the beerwell or directly into the rectification column for reclaiming.

Yield Increase – 0.1 gal/bu
Thermal Savings – n/a

200 Proof Denaturing

Plants typically operate their 200 proof purity at approximately 99.5% to 99.0%. The current product specifications call for min 99.0% purity of alcohol. Since process swings are common plants run conservatively at 99.5% purity to account for swings in process conditions.

Fusels or water from the process can be added to the ethanol to control the final product specifications to 99.0% purity. For a 50 MMgpy facility this results in an increase of approximately 250,000 gallons per year or a 0.5% increase in yield for facilities currently operation at 99.5% purity.

Variable Frequency Drive (VFD) Addition

The majority of facilities utilize VFD drives in their current processes. However, there are multiple areas in each plant where existing control valves can be replaced by VFD drives and this replacement results in a significant electrical savings. For example, pumps can be run at slower speeds thereby requiring less amperage. The technology is applicable to the following key motors at the plant:

- Boiler main id fan

- Dryer main id fan
- Cooling tower pumps
- Beer column reboilers
- Liquefaction booster pumps
- Cook tank pumps

Average Energy Savings – 0.05 kWh/gal by implementation of VFD on available motors.

DDGS Cooling

Dryer energy can be reduced by enhancing the DDGS cooling system design. Depending on the current system the DDGS moisture can be increased to 12% and the remaining moisture removal can be accomplished in either a DDGS pneumatic cooling tube or a counter current rotary cooler. Most facilities experience an under designed cooling system which results in a situation where the facility has to over dry the DDGS to 9% moisture to allow for proper conveying of the DDGS to the storage shed.

DDGS Yield Increase – 35% (9% moisture to 12% moisture)
Thermal Energy - 160 Btu/gal (dryer gas savings)

Centrate Vent Condensing

Vents from various process tanks are collected in a common vent header. Tank sources into the vent system are the cook tanks, propagation tanks, regen tank etc, that emit not only water vapors but ethanol vapors. These vapors currently are lost to either the TO or RTO systems. Condensers can be installed on either the main header or each individual tank to condense the ethanol vapors and prevent the vapors from exiting the system.

Ethanol Yield Increase – 0.01 gal/bu

Efficient Ethanol Plant Configurations

The following outlines the yield and energy usages for a well performing corn dry mill ethanol facility based on current available technologies.

Configuration 1 – Traditional Corn Dry Milling, DDGS, incorporating corn oil extraction post distillation

Best Performing Facilities
Attainable Yield – 2.85 gal/bu undenatured
Oil – 0.8 lb/bu
DDGS – 13.7 lb/bu db*
Thermal – 25,000 Btu/gal
Electrical – 0.58 kw/gal

*DDGS yield based on 14.5 lb/bu – lower yield due to higher ethanol yield. Technologies Utilized:

1. Standard dry milling
2. Batch Fermentation
3. High temp or Low temp cook
4. Rotary DDGS drying
5. Back end Oil – Disk Nozzle, Tricanters , Separation Aids – Emulsion Breakers, AOS

These performance characteristics represents the top performing corn dry mill ethanol facilities in operation today in the North American market and define the attainable yields and energy usages that a corn dry milling facility can attain with current technology employed in this sector today. These facilities will utilize traditional hammermills with #6 or #7 screen sizing to reduce the particle sizing and will either incorporate a high temperature or no cook front end.

Furthermore, these facilities will typically utilize 2-3 hrs of continuous liquefaction holding time. The facility will operate between 31.5% to 33% DS through liquefaction. Batch fermentation with ethanol yield of approximately 13.5-14.5wt%, and fermentation must possesses >60hrs to convert sugars with targeted residual sugars of 1 wt%. These higher yielding fermentations also control glycerol generation to 0.7 to 1.0wt% generation through the fermentation cycle therefore maximizing ethanol yield.

Distillation is performed typically in a three (3) column system comprised of a beer, rectification and stripping section. Distillation can be completed either under pressure or vacuum and energy integration into evaporation is required to maintain the thermal energy efficiency of the facility. Dehydration is completed utilizing molecular sieve technology with energy reclaim of the 200 proof vapors also required to maintain thermal energy efficiency.

In order to control fines recycle to maintain fermentable starch in fermenters these facilities have excess decantation capacity and can maintain soluble to insoluble ratios in thin stillage to 2:1 or greater ratios therefore minimizing the fouling and CIP requirements in their evaporator systems and reducing insoluble solids in backset. These facilities also operate with a max backset water ratio of 50%.

All the DDGS is dried in a rotary dryer to 11-12% moisture with remaining 1% moisture removal accomplished in the DDGS cooling system to minimize thermal energy input in dryers. Dryers are also equipped with adequate mixing to prevent balling which results in over drying of the DDGS. Typical hunter color is +55.

Due to low residual sugars at fermentation drop syrup concentration can be maintained at 40-42%DS therefore minimizing syrup addition to dryers. This also allows a shift of overall evaporation from the dryers to the evaporators therefore increasing the overall thermal efficiency of the facility. Traditional back end oil recovery is utilized with yields of 0.8 lb/bu of crude corn oil, typical heat and hold, emulsion breakers and/or AOS oil recovery system are needed to attain this oil yield.

Electrical usage is minimized by utilizing chillers in fermentation to cool only fermenters at peak ethanol generation; entire cooling loop is not passed through chiller therefore reducing the chiller electrical requirements. Typically rotary dryers are utilized due to their lower electrical connected loading when compared to flash drying technologies. Thermal energy is also maintained by utilizing a HRSG integrated dryer/TO/Boiler or RTO technology for VOC reduction with RTO utilizing loadout vent vapors to partially fuel the RTO system.

Facilities typically have addressed cooling limitations during summer months with modifications to liquefaction and fermentation cooling systems and are able to run at near 100% throughput capacity during warmest months without yield or production losses in fermentation. Ethanol recovery in CO2 vent is optimized. These facilities also operate greater than 355 days per year therefore optimizing facility utilization.

Configuration 2 – Traditional Corn Dry Milling, DDGS+WDGS, incorporating corn oil extraction post distillation

Best Performing Facilities
Attainable Yield – 2.85 gal/bu undenatured
Oil – 0.8 lb/bu
DDGS – 6.85 lb/bu db dry*
DDGS – 6.85 lb/bu db wet*
Thermal – 21,000 Btu/gal
Electrical – 0.58 kw/gal

*DDGS yield based on 14.5 lb/bu – lower yield due to higher ethanol yield

Technologies Utilized

1. Standard dry milling
2. Batch Fermentation
3. High temp or Low temp cook
4. Rotary DDGS drying
5. Back end Oil – Disk Nozzle, Tricanters , Separation Aids – Emulsion Breakers, AOS

These performance characteristics represents the top performing corn dry mill ethanol facilities in operation today in the North American market and define the attainable yields and energy usages that a corn dry milling facility can attain with current technology employed in this sector today. This configuration applies to facilities that have the ability to sell 50% of their DDGS to the wet feed market; the remaining 50% is dried.

These facilities will utilize traditional hammermills with #6 or #7 screen sizing to reduce the particle sizing and will either incorporate a high temperature or no cook front end. These facilities will typically utilize 2-3hrs of continuous liquefaction holding time. The facility will operate between 31.5% to 33% DS through liquefaction. Batch fermentation with ethanol yield of approximately 13.5-14.5wt%, and fermentation must possesses >60hrs to convert sugars with targeted residual sugars of 1 wt%. These higher yielding fermentations also control glycerol generation to 0.7 to 1.0wt% generation through the fermentation cycle therefore maximizing ethanol yield.

Distillation is performed typically in a three (3) column system comprised of a beer, rectification and stripping section. Distillation can be completed either under pressure or vacuum and energy integration into evaporation is required to maintain the thermal energy efficiency of the facility. Dehydration is completed utilizing molecular sieve technology with energy reclaim of the 200 proof vapors also required to maintain thermal energy efficiency.

In order to control fines recycle to maintain fermentable starch in fermenters these facilities have excess decantation capacity and can maintain soluble to insoluble ratios in thin stillage to 2:1 or greater ratios therefore minimizing the fouling and CIP requirements in their evaporator systems and reducing insoluble solids in backset. These facilities also operate with a max backset water ratio of 50%.

In order to produce a modified wet feed 50% of the wet feed is removed at 50% moisture. This is typically accomplished by taking a cut between the first and second pass of the rotary dryers. The remaining DDGS is then dried to 11-12% moisture with remaining 1% moisture removal accomplished in the DDGS cooling system to minimize thermal energy input in dryers. Dryers are also equipped with adequate mixing to prevent balling which results in over drying of the DDGS. Typical hunter color is +55.

Due to low residual sugars at fermentation drop syrup concentration can be maintained at 40-42%DS therefore minimizing syrup addition to dryers. This also allows a shift of overall evaporation from the dryers to the evaporators therefore increasing the overall thermal efficiency of the facility. Traditional back end oil recovery is utilized with yields of 0.8 lb/bu of crude corn oil, typical heat and hold, emulsion breakers and/or AOS oil recovery system are needed to attain this oil yield.

Electrical usage is minimized by utilizing chillers in fermentation to cool only fermenters at peak ethanol generation; entire cooling loop is not passed through chiller therefore reducing the chiller electrical requirements. Typically rotary dryers are utilized due to their lower electrical connected loading when compared to flash drying technologies. Thermal energy is also maintained by utilizing a HRSG integrated dryer/TO/Boiler or RTO technology for VOC reduction with RTO utilizing loadout vent vapors to partially fuel the RTO system.

Facilities typically have addressed cooling limitations during summer months with modifications to liquefaction and fermentation cooling systems and are able to run at near 100% throughput capacity during warmest months without yield or production losses in fermentation. Ethanol recovery in CO2 vent is optimized. These facilities also operate greater than 355 days per year therefore optimizing facility utilization.

Configuration 3 – Multiple Co-Products – DDGS, High Protein Meal, Grinding of Mash in Liquefaction, Front End Oil and oil post distillation

Best Performing Facilities
Attainable Yield – 2.89 gal/bu undenatured
Protein – 3.25 lb/bu (50% protein purity)
Oil – 0.48 lb/bu – Front End Oil
Oil – 0.8 lb/bu – Back End Oil
DDGS – 9.47 lb/bu db dry, (34-36% Profat)
Thermal – 24,000 Btu/gal
Electrical – 0.7 kw/gal

Technologies Utilized

1. Standard dry milling
2. Batch Fermentation
3. High temp or Low temp cook
4. Mash Grinding – SGT – Selective Grind Technology, SMT – Selective Milling Technology
5. Front End Oil – BOS – Brix Oil Separator
6. Protein Recovery – MSC – Maximized Stillage Co-Products
7. Rotary DDGS drying
8. Back end Oil – Disk Nozzle, Tricanters , Separation Aids – Emulsion Breakers, AOS

These performance characteristics represents the top performing corn dry mill ethanol facilities in operation today in the North American market and define the attainable yields and energy usages that a corn dry milling facility can attain with current technology employed in this sector today. This configuration incorporates the technology of wet milling of mash in the wet phase prior to liquefaction to expose starch for enhanced yield, removal of front end oil in the liquefaction system prior to fermentation and protein removal from whole stillage post distillation.

These facilities will utilize traditional hammermills with #6 or #7 screen sizing to reduce the particle sizing and will either incorporate a high temperature or no cook front end. The facility will utilize wet milling of mash to reduce particle size and expose bound starch prior to mash being sent to liquefaction. This milling technology will also liberate oil at it shears the germ portion of the corn which results in additional oil yield. These facilities will typically utilize 2-3 hrs of continuous liquefaction holding time. The facility will operate between 31.5% to 33% DS through liquefaction. After liquefaction and before mash cooling the mash stream is sent to a dewatering screen to separate solids and liquid streams. The centrate stream is then sent to a centrifuge where the free oil is removed from the centrate in the overflow, remaining sugars and solids are discharged in the underflow stream from the centrifuge. The underflow stream is then recombined with the cake from the dewatering stream and then returned to the mash cooling channel. Since this front end oil has not been exposed to excessive time or temperature of the entire ethanol process this oil is of a much higher quality and contains significant lower Free Fatty Acids levels and much lighter color than traditional back end recovered oils.

Batch fermentation with ethanol yield of approximately 13.5-13.78wt%, and fermentation must possesses >60hrs to convert sugars with targeted residual sugars of 1 wt%. These higher yielding fermentations also control glycerol generation to 0.7 to 1.0wt% generation through the fermentation cycle therefore maximizing ethanol yield. Distillation is performed typically in a three (3) column system comprised of a beer, rectification and stripping section. Distillation can be completed either under pressure or vacuum and energy integration into evaporation is required to maintain the thermal energy efficiency of the facility. Dehydration is completed utilizing molecular sieve technology with energy reclaim of the 200 proof vapors also required to maintain thermal energy efficiency.

Whole stillage is then sent to a fiber separation centrifuge where the protein is washed off the whole stillage resulting in a centrate much higher in protein than a typical decanter. Fiber centrifuges replace existing decanters, existing decanters are then reused for protein dewatering prior to drying. Since protein is removed the fiber the resulting DGS cake can be dewatered to a lower moisture content typically in the 42-45% DS range resulting in reduction in DDGS drying energy due to a dryer feed cake.

Concentrated protein centrate from the fiber centrifuge is then sent to a clarifier where the protein content is concentrated in the underflow stream, the clarified overflow being free of insoluble solids and high in oil is then sent to the evaporator, thus becoming the new evaporator feed. With the reduction of insoluble solids in the evaporator feed stream the resulting syrup can be concentrated to a much higher DS value due to reduction in viscosity, solids as high as 70% DS can be attained, however final syrup concentration is based on amount of condensate that can be recycled back to the cook stream, typical syrup is concentrated to 50% DS based on condensate and water balance.

Evaporator fouling and operating temperature are significantly reduced in the evaporator due to a much cleaner feed stream and significant reduction in evaporator fouling. Evaporator capacity is also increased by 20% due to the reduced fouling coefficient of the syrup stream therefore increasing the overall heat transfer coefficient of the evaporator.

The concentrated protein stream from the clarifier is sent to the existing decanters which now operate in a protein dewatering service versus the original decanting service of whole stillage. The protein is dewatered and the cake is sent to a new flash dryer where it is dried to 10% moisture. Centrate from the protein decanter is sent as backset. Residual sugars that are typically sent to the syrup channel are reclaimed in the decanter centrate and are then sent back with the backset resulting in higher final ethanol yields and reduction or residual sugars in the syrup channel.

Cake from the fiber centrifuges is sent to a typical DDGS drying system where the remaining DDGS is then dried to 11-12% moisture with remaining 1% moisture removal accomplished in the DDGS cooling system to minimize thermal energy input in dryers. Dryers are also equipped with adequate mixing to prevent balling which results in over drying of the DDGS. Typical hunter color is +55. Protein yield and oil yield are maintain to produce a DDGS with a resultant ProFat of 34-36% therefore allowing the DDGS to be sold as typical DDGS with no discounted value.

Lower solubles in the evaporator feed also enhance the traditional back end oil recovery system due to the reduction of the oil/protein emulsion phase. Backend oil yields of 0.8 – 1.0 lb/bu of crude corn oil can be achieved with minimal heat and hold or emulsion breakers requirement. Electrical usage is minimized by utilizing chillers in fermentation to cool only fermenters at peak ethanol generation; entire cooling loop is not passed through chiller therefore reducing the chiller electrical requirements. Typically rotary dryers are utilized due to their lower electrical connected loading when compared to flash drying technologies. Thermal energy is also maintained by utilizing a HRSG integrated dryer/TO/Boiler or RTO technology for VOC reduction with RTO utilizing load-out vent vapors to partially fuel the RTO system. With the reduction of syrup and addition of the new protein dryer facility VOC emissions are significantly reduced.

Facilities typically have addressed cooling limitations during summer months and are able to run at near 100% throughput capacity during warmest months without yield or production losses in fermentation. Ethanol recovery in CO2 vent is optimized. These facilities also operate greater than 355 days per year therefore optimizing facility utilization.

Configuration 4 – Traditional Corn Dry Milling, DDGS, incorporating corn oil extraction post distillation and superheated drying technology

Best Performing Facilities
Attainable Yield – 2.85 gal/bu undenatured
Oil – 0.8 lb/bu
DDGS – 13.7 lb/bu db
Thermal – 19,500 Btu/gal
Electrical – 0.75 kw/gal

Technologies Utilized

1. Standard dry milling
2. Batch Fermentation
3. High temp or Low temp cook
4. Superheated DDGS drying
5. Back end Oil – Disk Nozzle, Tricanters , Separation Aids – Emulsion Breakers, AOS

These performance characteristics represent the top performing corn dry mill ethanol facilities in operation today in the North American market and define the attainable yields and energy usages that a corn dry milling facility can attain with current technology employed in this sector today. These facilities will utilize traditional hammermills with #6 or #7 screen sizing to reduce the particle sizing and will either incorporate a high temperature or no cook front end. These facilities will typically utilize 2-3 hrs of continuous liquefaction holding time. The facility will operate between 31.5% to 33% DS through liquefaction. Batch fermentation with ethanol yield of approximately 13.5-13.78wt%, and fermentation must possesses >60hrs to convert sugars with targeted residual sugars of 1 wt%. These higher yielding fermentations also control glycerol generation to 0.7 to 1.5 wt% generation through the fermentation cycle therefore maximizing ethanol yield.

Distillation is performed typically in a three (3) column system comprised of a beer, rectification and stripping section. Distillation can be completed either under pressure or vacuum and energy integration into evaporation is required to maintain the thermal energy efficiency of the facility. Dehydration is completed utilizing molecular sieve technology with energy reclaim of the 200 proof vapors also required to maintain thermal energy efficiency.

In order to control fines recycle to maintain fermentable starch in fermenters these facilities have excess decantation capacity and can maintain soluble to insoluble ratios in thin stillage to 2:1 or greater ratios therefore minimizing the fouling and CIP requirements in their evaporator systems and reducing insoluble solids in backset. These facilities also operate with a max backset water ratio of 50%.

All the DDGS is dried in a superheated flash dryer to 11-12% moisture with remaining 1% moisture removal accomplished in the DDGS cooling system to minimize thermal energy input in dryers. The superheated flash dryer allows for approximately 85% recovery of the thermal energy input into the dryer by condensing the evaporated vapors in an external heat exchanger and recovering the latent heat of vaporization back into the process. Condensing vapors from the dryer however requires that the facility be equipped with either an anaerobic digester or waste treatment system to handle the additional condensate that cannot be recycled back to the cook system.

Due to low residual sugars at fermentation drop syrup concentration can be maintained at 38-40%DS therefore minimizing syrup addition to dryers. This also allows a shift of overall evaporation from the dryers to the evaporators therefore increasing the overall thermal efficiency of the facility. Traditional back end oil recovery is utilized with yields of 0.8 lb/bu of crude corn oil, typical heat and hold, emulsion breakers and/or AOS oil recovery system are needed to attain this oil yield.

Electrical usage is minimized by utilizing chillers in fermentation to cool only fermenters at peak ethanol generation; entire cooling loop is not passed through chiller therefore reducing the chiller electrical requirements. Thermal energy is also maintained by utilizing a HRSG integrated dryer/TO/Boiler or RTO technology for VOC reduction with RTO utilizing loadout vent vapors to partially fuel the RTO system.

Facilities typically have addressed cooling limitations during summer months and are able to run at near 100% throughput capacity during warmest months without yield or production losses in fermentation.
Ethanol recovery in CO2 vent is optimized. These facilities also operate greater than 355 days per year therefore optimizing facility utilization.

Technology Adoption

The following is a non-exclusive list of plants that have adopted one or more of the above detailed technologies.

Plant Name	Plant Name
East Kansas Agri Energy	Illinois River Energy
ACE Ethanol – Stanley Wisconsin	Kansas Ethanol, Lyons KS
Aemetis	LDC Grand Junction
Adkins Ethanol	Lifeline Foods, St. Joseph, MO
ADM – Cedar Rapids	Lincolnland Agri-Energy, Palestine, IL
Anderson Albion	NuGen
Andersons Clymers	One Earth
Andersons Greenville	POET Biorefining
Arkalon Energy LLC	ShowMe Ethanol
Badger State Ethanol – Monroe Wisconsin	Sterling Ethanol
Bridgeport Ethanol	Valero, Albert City
Center Ethanol	Valero, Bloomingburg
Central Minnesota Ethanol Co-op	Valero, Charles City
Columbia Pacific Biofuels	Valero, Fort Dodge
Front Range Energy – Ethanol	Valero, Hartley
Great Plains Renewable Energy Shenandoah	Valero, Welcome
Great Plains Renewable, Ord, NE	Western NY Energy
Greenfield Johnstown	Yuma Ethanol
Greenfield Varennes	

Emerging Agricultural Practices and Technologies Relevant to Corn Ethanol Production

Corn Replacement Feed

Over the last several years higher corn yields have also increased the amount of corn stover and additional plant material produced by modern hybrids. As a result, growers have started to remove corn stover for use as animal feed in nearby feedlot operations. Stover, pretreated with lime to improve digestibility, is used at the feedlots to substitute for corn and other feed ingredients, essentially functioning as a corn replacement feed (CRF).[3,4] Many regional and national studies have documented the stover feedstock availability[5,6], the sustainability[7,8], and the financial viability of using stover as CRF.[9] A recent survey conducted with 60 growers delivering to an Iowa-based corn ethanol plant showed that growers, on average, removed 0.77 tons of stove per acre around that plant. The stover was shipped to nearby feedlots where it substituted for corn feed on a 1:1 ratio. Obviously, removal rates and feed substitution rates vary by region and feedlot, respectively.

A simplified way to gain an insight on the co-product impact of stover provides the following example: A corn field with a yield of 160 bu/acre produces 4.5 tons of corn and approximately an equivalent amount of corn stover. If 50% or 2.25 tons of that stover can be sustainably removed for CRF (a very reasonable removal rate for many corn growing areas) this is equivalent to producing an extra 80 bushel of corn on that acre (assuming an equal substitution for stover of corn in animal diets).

Adopters:
Siouxland Energy and Livestock Cooperation (SELC)
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Nitrogen Stabilizers

Nitrogen stabilizers work by retarding the formation of nitrate by nitrifying bacteria. The original use of nitrification as an agronomic practice aimed to conserve nitrogen fertilizer close to the root zone for use by crops. Lately, however, a lot of attention is being paid to the reduction of N leaching and the associated environmental benefits including the potential for significant greenhouse gas emissions reductions.

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[3] Sewell, J. R.; Berger, L. L.; Nash, T. G.; Cecava, M. J.; Doane, P. H.; Dunn, J. L.; Dyer, M. K.; Pyatt, N. A.; Nutrient digestion and performance by lambs and steers fed thermochemically treated crop residues. J. Animal Sci. 2009, (87) pp 1024.

[4] Shreck, A. L., Nuttelman, B. L.,; Griffin, W. A.; Erickson, G. E.; Klopfenstein, T. J.; Cecava. M. J.; Reducing particle size enhances chemical treatment in finishing diets; Nebraska Beef Report. 2012, pp 108.

[5] US Department of Energy; US Billion Ton Update. Biomass Supply for a Bioenergy and Bioproducts Industry; August 2011; prepared by Oak Ridge National Laboratory.

[6] Nelson RG; Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States - rainfall and wind-induced soil erosion methodology. Biomass Bioenerg 2002;22:349.

[7] Wilhelm, W.W., J.R. Hess, D.L. Karlen, J.M.F. Johnson, D.J. Muth, J.M. Baker, et al; Review: Balancing limiting factors & economic drivers for sustainable Midwestern US agricultural residue feedstock supplies. Ind. Biotechnol. 6:271-287, 2010

[8] D. Muth and K. M. Bryden; An Integrated Model for Assessment of Sustainable Agricultural Residue Removal Limits for Bioenergy Systems; accepted with revision, Environmental Modelling and Software, Available online 11 May 2012, ISSN 1364-8152, 10.1016/j.envsoft.2012.04.006.

[9] Shreck, A. L., Nuttelman, B. L.; Griffin, W. A.; Erickson, G. E.; Klopfenstein, T. J.; Cecava. M. J. Chemical treatment of low-quality forages to replace corn in cattle finishing diets. Nebraska Beef Report. 2012, pp 106.

A published meta-analysis across trials in the US found that, on average, the use of nitrogen stabilizers increases crop yields by 7% and soil nitrogen retention increased by 28%, while nitrogen leaching decreased by 16% and greenhouse gas emissions decreased by 51%.[10] Nitrogen stabilizers can be applied with many forms of nitrogen fertilizer products including manure.

Nitrogen stabilizers are manufactured by several companies. Most prominently Dow Agrosciences is producing N-serve and Instinct. According to personal conversations with industry insiders nitrogen stabilizer product lines have experienced approximately 20% growth for each of the 5 previous years.

Control Release Nitrogen

Control release nitrogen generally comes in two forms: sulfur or polymer coated urea. Recently, prices of polymer coated urea have become more competitive which increases adoption of this technology. The new polymer coatings are refined to match the uptake curve of the target crop. Agrium, Inc. and Helena Chemical Company, for example, produce the technology.[11]

Soil Testing and Remote Sensing

Soil testing and remote sensing allow a more targeted application of nitrogen fertilizer at variable and thereby reduced rates. The process starts out by mapping the fields based on topography, soil types, and field history to derive zones of homogenous growing conditions. Satellite derived field imagery is also an important tool to select fields with homogenous zones. Then soil samples are taken from each zone and sent to labs (for example Brookside Laboratory in New Bremen, Ohio) where the soil is tested for 20+ variables. Based on this testing procedure the additional application of macronutrients (calcium magnesium, phosphorus, sulfur) or micronutrients (boron, iron, manganese, copper, zinc, aluminum) is evaluated.

Separately, additional field samples are being taken during the growing season after emergence and sent to the soil lab to test for ammonium and nitrate. With that it can be determined where more or less nitrogen inputs to soil are needed. Soil-Right Consulting Services, for example, offers this service.[12]

Farm Machinery Technologies Using GPS Tracking Technology

Recent research has documented that rising corn prices increase investment in precision farming equipment and seed technologies.[13] Precision farming technology is predominantly used with tractors, combines, and self-propelled sprayers. These technologies reduce the overlap along each pass across the field and spatially vary the application of agricultural inputs (seeds and chemicals) which in turn reduces fuel, chemical and seed use.

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[10] Wolt, Jeffrey D; 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.

[11] Nitrogen Transformation Inhibitors and Controlled Release Urea; G.J. Schwab and L.W. Murdock, Department of Plant and Soil Sciences; UNIVERSITY OF KENTUCKY COLLEGE OF AGRICULTURE, Issued 4-2010; http://www.ca.uky.edu/agc/pubs/agr/agr185/agr185.pdf

[12] http://www.soilright.com/

[13] Is Yield Endogenous to Price? An Empirical Evaluation of Inter- and Intra-Seasonal Corn Yield Response; Barry K. Goodwin*, Michelle Marra*, Nicholas Piggot* and Steffen Mueller**; *North Carolina State University **University of Illinois at Chicago, June 3, 2012, http://www.erc.uic.edu/PDF/mueller/Goodwin_Marra_Piggott_Mueller.pdf

Since we last issued our technology assessment in 2008, CropLife magazine and Purdue University's Center for Food and Agricultural Business have conducted another survey on the adoption of precision agriculture technology with agricultural dealerships across the U.S. Highlights from the 15th survey indicate the following:

- Between 2009 and 2011 use of automatic control/autosteer for fertilizer/chemical application increased from 53% of the respondents in 2009 to 64% in 2011.
- The introduction of new GPS-enabled sprayers has seen rapid adoption and is used by 39% in 2011.
- Variable seeding applications are a rapidly emerging new technology with large growth potential in the immediate future.

A recent study conducted in 2012 by North Dakota State University quantifies the energy savings from the adoption of precision agriculture.[14] The study, based on a survey with growers in North Dakota finds that GPS guidance systems reduce fuel use by 6.3% and the use of autosteering systems accounted for additional 5.3 % of fuel savings.

Enzymes Contained in Corn Endosperm

Recently, Syngenta released a genetically engineered corn hybrid with an alpha-amylase enzyme contained within the corn endosperm. The technology is sold under the trade name Enogen. Alpha-amylase is used in the liquefaction step of the ethanol dry grind milling process when starch is converted to fermentable sugars. When corn containing Enogen Technology is metered at prescribed levels into the commodity corn (or other starch-based feedstock, e.g. sorghum, wheat, etc.) stream, no additional liquid alpha-amylase needs to be added to the ethanol production process.

Syngenta states that the use of Enogen Technology in a dry grind ethanol plant will impact the sustainability of the final ethanol product as follows: Enogen grain will produce a lower viscosity slurry and mash than what is typically observed following liquefaction. A lower slurry and mash viscosity means the process can be run with a higher solids content than usual with existing pumps and motors. Transitioning to a higher solids content in the slurry and mash can save process energy at the facility in a number of ways.

First, per gallon produced, there is less material being moved through the process, which will reduce electrical power usage. Electricity savings are expected to be small in existing plants because the plants' drive motors will be oversized after switching to Enogen Technology. Although there is less demand for mechanical power, the now oversized drives will not be operating at their optimum design point. In new plant applications, however, plant designers and process engineers will be able to specify drives optimized for use with Enogen Technology either with variable frequency drives (VFD) or by sizing the drives to the load expected with Enogen Technology. Syngenta expects that Enogen Technology will be implemented at new plants with VFDs and that some retrofitting will take place to incorporate VFDs at existing plants as well. For plants that incorporate VFDs, we project an electrical energy savings of 0.1 kWh/gal from typical modern dry grind ethanol plants, for a total facility- wide consumption of 0.68 kWh/gal (2,319 BTU/gal) after the savings are applied. This would represent a reduction of 13% from the average 2,660 BTU/gal electricity consumption per gallon assumed by EPA in 2012.

Next, the reduced volume of water being carried through the process can result in thermal energy savings related to a reduction in heat loads when mash and beer heating is required. Syngenta process

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[14] Bora et al. Energy, Sustainability and Society 2012, 2:22 Page 3 of 5, http://www.energsustainsoc.com/content/2/1/22

engineers have identified eight unit operations in a standard dry grind ethanol plant that may experience thermal energy use reductions as a result of running at higher solids contents enabled by use of Enogen Technology. The table below summarizes these unit operations by process category and presents savings estimated using mass and energy balance approach for two levels of increased solids content. Ethanol plants today typically operate near 32% solids content throughout the process. Enogen Technology trials to date have been conducted at solids contents up to 34%. It is expected that a solids content of 36.5% will be feasible once the Enogen Technology has been optimized at commercial scale.

The table below shows a projected natural gas savings of 3,522 BTU per gallon. These savings are expected to be realized both for plants producing 100% dry DGS and 100% wet DGS.

Projected natural gas savings with Enogen Technology, showing savings in BTU (LHV) per gallon of anhydrous ethanol compared with operation at 32% solids.

Process Section	**Unit Operation**	**Natural Gas Savings with Enogen Technology at 35.5% Solids**	**Natural Gas Savings with Enogen Technology at 36.5% Solids**
Slurry	Cook Water Pre-Heat	221	247
Slurry	NH3 Motive Steam	53	53
Slurry	Slurry Tank Steam	435	471
Fermentation	CIP Heater Steam	2	2
Distillation	Beer Feed Warm-Up	734	779
Evaporation	Reduced Evap. Feed	1,576	1,970
Total		3,020	3,522

Finally, Syngenta states that inclusion of Enogen Grain in the dry grind milling process has also been shown to enhance ethanol yields from fermentation by increasing residence time in the fermenters enabled by lower overall throughput. Syngenta has observed ethanol yield increases of 3.2% while running at 33.25% solids and 3.4% increase while running at 34% solids. Syngenta expects to observe yield increases of at least 3.6% while operating the 36.5% solids targeted for Enogen Technology.

Industry Assessment of 2012 Corn Ethanol Energy and Water Use

Assessment Setup and Execution

Ethanol is produced along the different technology pathways detailed above. Yet, despite the different production methods, the final ethanol product is sold as a fungible commodity. For policy purposes the ethanol commodity is compared to other transportation fuels such as gasoline. Therefore, any assessment of the ethanol commodity product must ensure that the individual technology pathways sampled provide a representation of all technologies employed across the industry.

In the following we detail the results from our industry assessment, which constitutes a representation of 2012 corn ethanol production. This means that the value provided include an average blend of all production technologies weighted by the respective gallons produced with these technologies. The assessment is, however, limited to the natural gas dry grind corn ethanol process.

In a first step an assessment form was compiled by UIC and reviewed by the US Department of Energy Clean Energy Application Center, the Renewable Fuels Association, and the Illinois Corn Growers Association. The plant variables assessed were consistent with those from the 2008 assessment. The key units were also held consistent (all units reported on an anhydrous basis, lower heating value, and where possible on a per unit of ethanol output reported). The assessment form was pre-tested with two ethanol plants.

The assessment was conducted with support from the Renewable Fuels Association (RFA), POET, the Nebraska Ethanol Board, as well as the ICM and Fagan plant user groups. The RFA sent an assessment form to their members with a separate cover letter and UIC collected the results. The data was combined with the assessments submitted by POET and the ICM/Fagan user group plants. In total, the assessment was sent out to close to 90% of the population of operating plants.

The table below details the assessment response characteristics. The response characteristic shows that 84 dry mill plants out of 162 operating plants during 2012 responded to the assessment.[15] Out of the 1344 assessed variables, the missing value number totaled ~19%. Plant size could introduce a significant bias. Therefore, the number of assessed plants were grouped into five capacity classes and compared to population plants in these capacity classes. Overall, all capacity sizes were well represented in the assessment.

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[15] Plants less than 30 mgpy were excluded from the analysis since most of these plants are generally considered research and development facilities. Also mixed feedstock plants were excluded.

Capacity Range		**Population**[16]		**Sample**	
mgpy	mgpy	# of Plants	% Plants	# of Plants	% Plants
30	40	16	10%	3	4%
41	75	85	52%	52	62%
76	110	36	22%	15	18%
111	145	22	14%	13	16%
146	180	3	2%	0	0%
	Total:	162	100%	84	100%

Assessment Results

The table below shows the results from the assessment. All values are stated on an anhydrous basis and include plants that dry their distillers grains at varying levels. On average, 2012 dry grind plants produce ethanol at higher yields with lower energy inputs than 2008 corn ethanol. Furthermore, significantly more corn oil is separated at the plants now which combined with the higher ethanol yields results in a slight reduction in DDG production and a negligible increase in electricity consumption.

	2012 Corn Ethanol	**2008 Corn Ethanol**
Yield (gallon/bushel)	2.82	2.78
Thermal Energy (Btu/gallon, LHV)	23,862	26,206
Electricity Use (kWh/gallon)	0.75	0.73
DDG Yield (dry basis) including corn oil	15.73	15.81
Corn Oil Separated (lbs/bushel)	0.53	0.11
Water Use (gallon/gallon)	2.70	2.72

An open ended question asked respondents to list one or two technologies that have significantly reduced energy consumption at their plants. The answers, reproduced in the table below, show that a wide variety of technologies has been adopted by plants to reduce energy use.

List of Energy Efficiency Technologies Adopted by Ethanol Plants
High Efficiency Motors
Waste Heat Recovery, Fermentation Efficiency
CHP
Enogen Corn, Updated heat exchangers,
ICM Selective Milling Technology, ICM CO_2 Scrubber, Bottom Ethanol Recovery
Integrated heat recovery throughout thermal oxidizer system, higher yield through mash/cook changes Reduced volume to dryers

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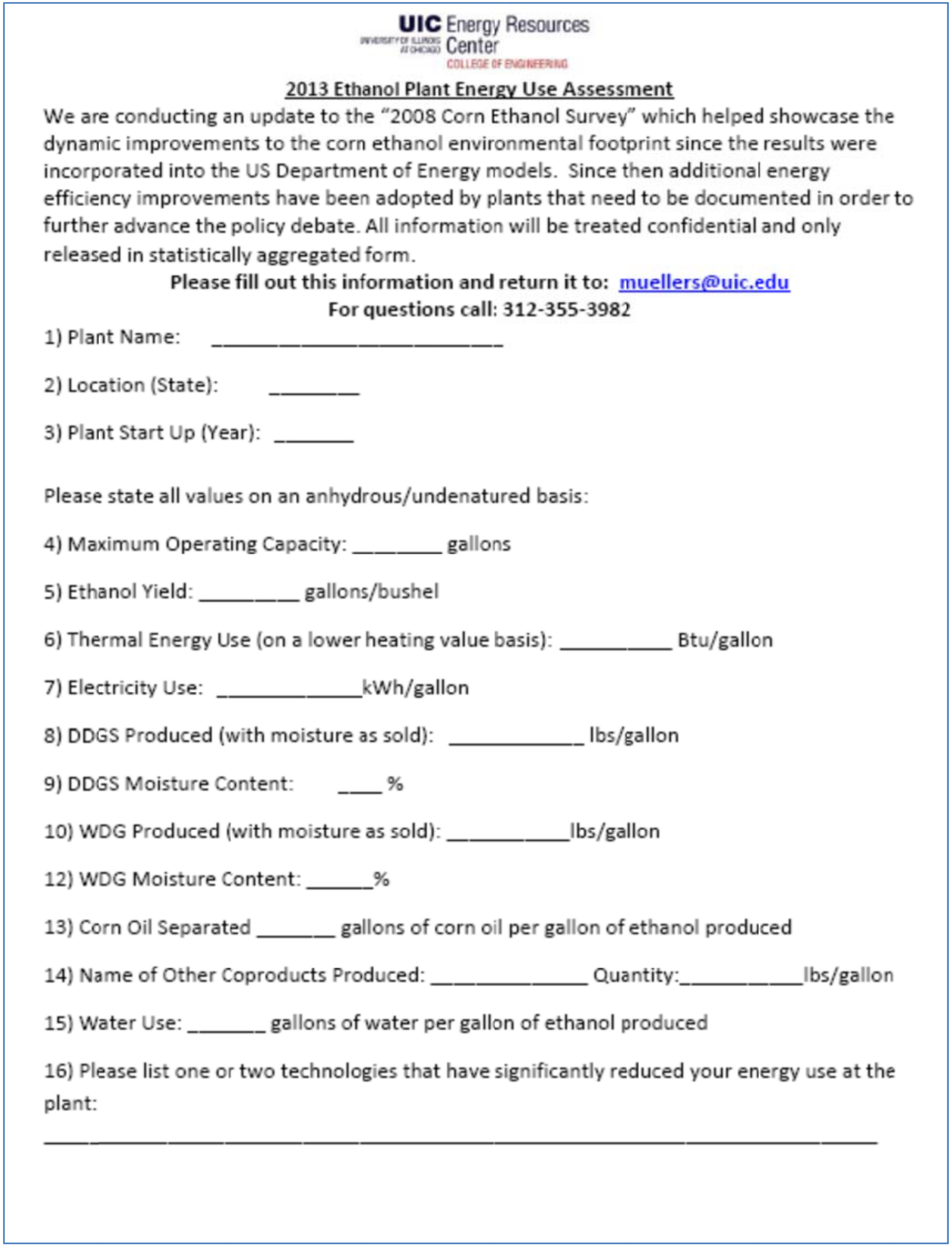
[16] Source: Renewable Fuels Association. Population values by capacity range for 2012 provided by Geoff Cooper for this study.

Increasing ethanol yields continue to decrease per gallon natural gas and electrical usage per gallon
Molecular sieve economizer upgrade: Increased heat recovery resulting in reduced steam needs and lower cooling tower loads.
Cookwater economizer upgrade: Increased energy recovery
Variable frequency drives on a majority of motors
Thermal oxidation combined with HRSG
Stack coil economizers
Avantec CO_2 bottoms to the side stripper
Electrical VFDs
Making 100% MWDGS and numerous heat transfer modifications
Variable Frequency Drive on Motors, Use of Landfill gas
Dryer Differential Temperature Control
Heat Recovery Exchanger at the stack
Variable speed drives
Pavillion Advanced Process Control and Upgraded Beer/Mash Exchanger System

Appendix A: Assessment Form



UIC Energy Resources Center
UNIVERSITY OF ILLINOIS AT CHICAGO
COLLEGE OF ENGINEERING

2013 Ethanol Plant Energy Use Assessment

We are conducting an update to the "2008 Corn Ethanol Survey" which helped showcase the dynamic improvements to the corn ethanol environmental footprint since the results were incorporated into the US Department of Energy models. Since then additional energy efficiency improvements have been adopted by plants that need to be documented in order to further advance the policy debate. All information will be treated confidential and only released in statistically aggregated form.

Please fill out this information and return it to: muellers@uic.edu

For questions call: 312-355-3982

1) Plant Name: ___________________________

2) Location (State): ________

3) Plant Start Up (Year): _______

Please state all values on an anhydrous/undenatured basis:

4) Maximum Operating Capacity: ________ gallons

5) Ethanol Yield: _________ gallons/bushel

6) Thermal Energy Use (on a lower heating value basis): __________ Btu/gallon

7) Electricity Use: _____________kWh/gallon

8) DDGS Produced (with moisture as sold): ____________ lbs/gallon

9) DDGS Moisture Content: ____ %

10) WDG Produced (with moisture as sold): ___________lbs/gallon

12) WDG Moisture Content: ______%

13) Corn Oil Separated _______ gallons of corn oil per gallon of ethanol produced

14) Name of Other Coproducts Produced: ______________ Quantity:__________lbs/gallon

15) Water Use: _______ gallons of water per gallon of ethanol produced

16) Please list one or two technologies that have significantly reduced your energy use at the plant:

____