MINNESOTA TECHNICAL ASSISTANCE PROGRAM

ETHANOL BENCHMARKING AND BEST PRACTICES

THE PRODUCTION PROCESS AND POTENTIAL FOR IMPROVEMENT

TABLE OF CONTENTS

ACRONYM LIST

BACT – Best Achievable Control Technology
BOD – Biological Oxygen Demand
Btu – British thermal unit
CBOD5 – 5-Day Carbonaceous Biological Oxygen Demand
CCX – Chicago Climate Exchange
CO_2 – Carbon Dioxide
CO –Carbon Monoxide
CLS – Cold Lime Softening
CHP – Combined Heat and Power
DDGS – Dried Distillers Grains with Solubles
DNR – Department of Natural Resources
DOE – Department of Energy
EPAct – Energy Policy Act of 1992
EAW – Environmental Assessment worksheet
EPA – Environmental Protection Agency
F – Fahrenheit
gal – gallon
HESC – High Efficiency Stillage Concentration
HP – Horsepower
HRSG – Heat Recovery Steam Generator
IATP – Institute for Agriculture and Trade Policy
kW – Kilowatt
kWh – Kilowatt Hours
lb/hr – Pounds per Hour
LDAR – Leak Detection and Repair
MDA – Minnesota Department of Agriculture
mg/l – milligrams per liter
meq/l – milliequivalents per liter
MTBE – Methyl Tertiary Butyl Ether
MMBtu – Million British Thermal Units
MGD – Million Gallons per Day
MnTAP – Minnesota Technical Assistance Program
MPCA – Minnesota Pollution Control Agency
MGY – Million Gallons per Year
MWWTP – Municipal Wastewater Treatment Plant
NPDES – National Pollutant Discharge Elimination System
NOx – Nitrogen Oxide
PM – Particulate Matter
PM_{10} – Particulate Matter less than 10 microns
RO – Reverse Osmosis
RTO – Regenerative Thermal Oxidizer
SDS – State Disposal System
TO – Thermal Oxidizer
TDS – Total Dissolved Solids
TSS – Total Suspended Solids
µmhos/cm – micromhos per centimeter
VFD – Variable Frequency Drives
VOC – Volatile Organic Compounds
WDGS – Wet Distillers Grains with Solubles

INTRODUCTION

The *Ethanol Benchmarking and Best Practices* study provides an overview of the ethanol production process and some information on potential environmental issues related to the process. This study also introduces some concepts for improvements in the use of resources including energy, water, and reducing environmental impacts. Additionally, it is intended to educate others outside the ethanol industry of the challenges faced by facilities to conserve resources.

Ethanol production in Minnesota is growing at a fast pace. In 1988, ethanol was first used as an oxygenate in gasoline to reduce carbon monoxide emissions. By 2004, many states had banned Methyl Tertiary Butyl Ether (MTBE) as an oxygenate in fuel replacing it with ethanol. In 1980, the United States produced 175 million gallons of ethanol; in 2007, the annual total is expected to be 7.5 billion gallons.[1] First generation ethanol plants in Minnesota were typically producing 20 million gallons per year (MGY), but the current trend is towards larger plants. Plants permitted more recently have capacities in the range of 55-70 MGY and some approved for construction will have capacities greater than 100 MGY.

The benchmarks and best practices presented focus primarily on dry mill facilities, since most of the facilities in Minnesota are dry mill. Due to limited access to facilities, it was difficult to determine exactly how many of these best practices are in place in Minnesota facilities. Even though all best practices have been demonstrated in some facilities, they may not be practical for all facilities. Many practices may also apply to wet mill facilities but their applicability was not reviewed during this process. Excellent resources exist that provide guidance on energy efficiency related to the wet milling industry.[2]

There are three major design firms that have built most of the facilities in Minnesota and each design has features that make them unique. Whether a facility uses a best practice listed in this report can be dependent on the design firm used.

This study focused on the operation of the ethanol plant. There are many important issues related to ethanol production that are not addressed in this report. They include discussions about cellulosic ethanol, climate change, and impacts from increased corn production such as soil erosion, runoff, and water use for crop irrigation.

This report provides a comparison of newer and older facilities in Minnesota by addressing the following questions:

- Does the data show that new facilities use fewer resources than older facilities?
- Can retrofits be made to older facilities to improve performance?
- Do the potential savings justify significant capital investment in facilities?
- Can low cost actions be taken to reduce consumption of energy, water, or reduce environmental impact?
- What areas need support and where can the Minnesota Technical Assistance Program (MnTAP) provide support?

Benchmarks provide a numerical standard for comparison while best practices are techniques or processes that have demonstrated a desired result. For this study, the benchmarks and best practices focused on indicators of reduced resource use or environmental impact. Benchmarks include volatile organic compound (VOC) emissions in tons per million gallons of ethanol, ethanol yield in gallons per bushel of corn, energy use in British Thermal Units (Btu) or kilowatt hours (kWh) per gallon ethanol, and water efficiency in gallons of water per gallon ethanol. Best practices include processes or equipment modifications that achieve reduced water use, energy use, or create less impact on the environment.

The majority of facility information was obtained from 2006 annual data found in publicly available data sources. For one facility, 2005 data was used because 2006 data was incomplete. Site visits were used to validate best practices and to potentially assist facilities with energy efficiency or pollution prevention practices. Information was shared allowing facilities to see what areas they excel at or where performance improvements could be implemented. All private data collected on specific facilities was kept confidential and will not be shared with others outside MnTAP.

MnTAP would like to thank all the companies that took the time to discuss their operations and provide benchmark data. MnTAP would also like to thank Natural Resource Group for their support in promoting this project and providing technical support.

PLANT DESCRIPTIONS

This study included 14 operating dry mill ethanol facilities in Minnesota and one in Wisconsin. The average production rate for a facility in Minnesota for 2006 was 34 MGY. The review included site visits to all facilities willing to participate and phone or email discussions with others. These facilities had original start up dates that ranged from 1991 to 2006, but there was a gap from 2000 to 2004 where no new Minnesota facilities started production. It was expected that some of the older facilities would not have the state of the art technology of the newer facilities. As a starting point, the facilities with start up dates from 1991 to 1999 were considered "old" and the facilities with start up dates of 2005 to 2006 were considered "new".

ETHANOL PROCESS DESCRIPTION

The following provides a basic description of the dry mill ethanol process. Diagram 1, provided at the end of this section, provides a schematic of the typical dry mill process. The diagram provides information on the processes where significant energy, water, or environmental impact occurs.

Figure 1 and Table 1 display the thermal and electrical energy consumption by each process in a typical state of the art 40 MGY facility.[3] These estimates are based on a computer modeling program from the Agricultural Research Service using inputs from ethanol facilities, equipment suppliers, and engineers working in the industry.

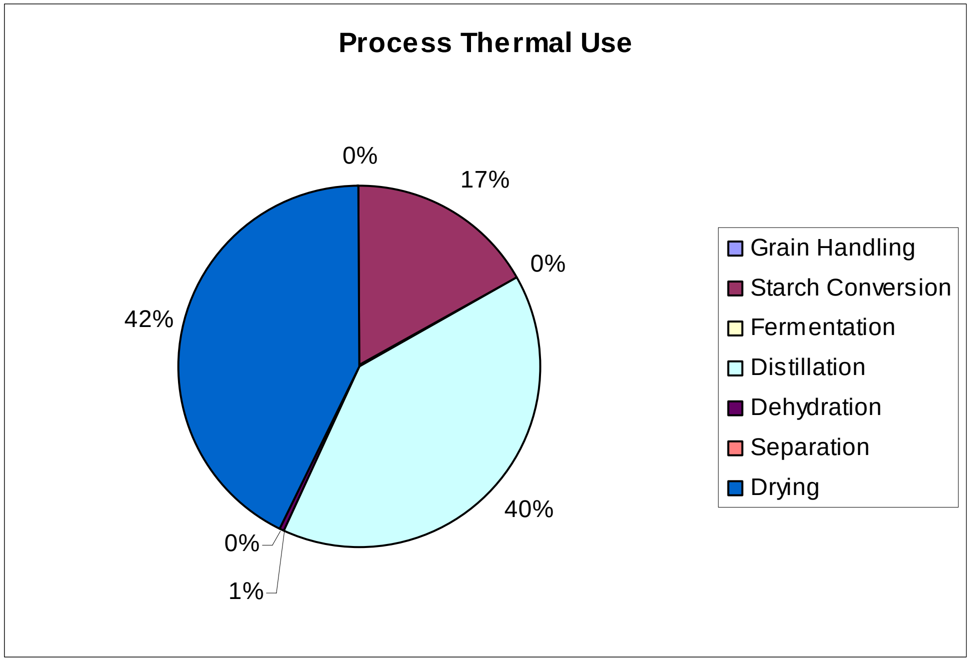
Table 1: Energy Consumption by Process

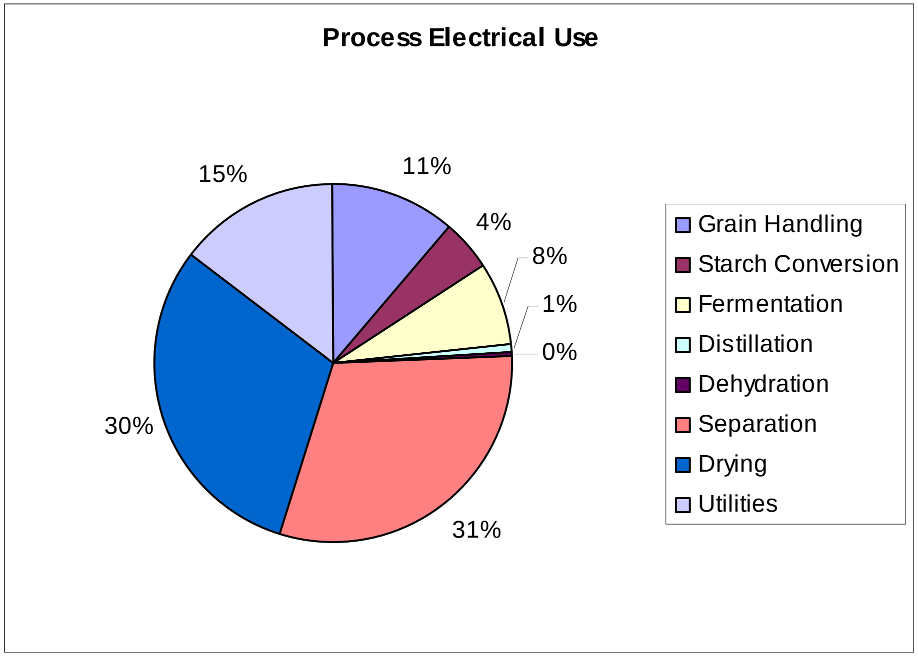
Process	Major Equipment	Elec, kW	Steam, lb/hr	Nat Gas, CF	Elec, Btu/gal	Thermal Btu/gal	Total Btu/gal	% Total Energy
Grain Handling	Hammermills, Conveyors, Dust Collectors, Fans	443	0	0	352	0	352	1%
Starch Conversion	Pumps, Jet Cooker, Agitators	167	23,582	0	133	5,544	5,677	16%
Fermentation	Agitators, Pumps	292	0	0	231	0	231	1%
Distillation	Reboilers, Columns	25	25,172	0	20	12,884	12,904	37%
Dehydration	Mole Sieve, Pumps	16	526	0	13	257	270	1%
Separation (Note 1)	Centrifuge, Evaporators	1,168	0	0	926	0	926	3%
Drying	Dryers	1,176	0	165,000	933	13,914	14,847	42%
Utilities (Note 2)	Thermal Oxidizer, Cooling Tower, Air Compressor, Boiler	570	0	0	0	0	0	0%
	Total	3,858	49,280	165,000	2,608	32,600	35,208	

Notes:

1) Evaporator steam use is allocated to the distillation process because steam is recovered from the rectifier.
2) This process assumes a TO/HRSG combination. Natural gas use for TO is not shown because HRSG uses waste heat from TO exhaust. Electrical energy for utilities is allocated over all processes.

Figure 1: Process Thermal and Electric Energy Use





The production process is described as follows:

Grain Handling

Corn kernels arrive at the plant by either truck or rail and are stored in silos. Conveyor belts move corn through the area. There are typically two Hammermills, which have motors of approximately 250 horsepower (HP) each, that grind the corn into flour. Baghouse fabric filters are standard particulate control equipment that have a capture efficiency of 99% for particulate matter (PM) and PM less than 10 microns (PM_{10}). This process is driven by electrical power, which is approximately 11% of the electrical energy consumed by the plant. No water or thermal energy is used in this process.

Starch Conversion

The starch conversion process includes liquefaction and saccharification. In the liquefaction process the ground flour is mixed with process water in the slurry tank, the pH is adjusted with ammonia, and alpha-amylase enzyme is added. Steam is injected into the mixture using a steam injection heater called a "jet cooker"; it is then heated to about 185°F to increase viscosity and is held at that temperature for about 45 minutes. The mixture is combined with thin stillage, which is recycled process water from the centrifuge. Steam is injected into the slurry to further raise the temperature to about 220°F and held for about 15 minutes. The mixture is cooled through an atmospheric or vacuum flash condenser. The waste steam recovered from the jet cooker is sent to the distillation system or evaporators for energy recovery.

The final step of the starch conversion process is called saccharification. The pH and temperature are adjusted and another enzyme, glucoamylase, is added. The mixture is held in tanks for about 5 hours at about 140°F to give the enzyme a chance to break down the starch into sugars. At the end of this process the mixture, called "mash", is pumped into the fermentation tanks.

The motors for the pumps in the starch conversion process are relatively small. Electrical energy use is approximately 4% of the total facility's electric use. The steam used in the jet cooker is significant and is estimated at 15% of the total plant process energy. This steam is not recaptured from the process, and is equivalent to water use of approximately 45 gpm or 0.6 gallons of water per gallon of ethanol in a 40 MGY facility.

Fermentation

Once the mash leaves the starch conversion process it is cooled to approximately 90°F and yeast is added to convert the sugars to ethanol and carbon dioxide (CO_2). The fermentation process continuously generates heat and requires cooling to keep the solution at approximately 90° F to avoid killing the yeast. The process takes approximately 50 to 60 hours. There are two types of fermentation: batch and continuous. In batch fermentation, the mash ferments in a single vessel. In a continuous fermentation process the mash will flow through several fermentation tanks until the process is complete. The product leaving the fermentation process is called beer, which is water containing grain solids and about 10% - 15% ethanol.

The other product of the fermentation process is CO_2. Each bushel of corn produces about 18 pounds of CO_2[4], resulting in over 130,000 tons of CO_2 each year for a 40 MGY facility. The CO_2 from the fermentation process is sent through a scrubber that removes ethanol and other water soluble VOCs before the CO_2 is emitted to the atmosphere. Additional CO_2 is removed from the beer by heating the beer with the process streams from the starch conversion process and passing it through a degasser drum to flash off CO_2 vapors, which then go to the CO_2 scrubber.

The motors for the pumps in the fermentation process represent 8% of the electrical load in the facility. The cooling water load is significant for the fermentation process and is approximately 30% of the cooling water flow. The CO_2 scrubber uses water to remove the ethanol and VOCs; the water is recovered and sent to the starch conversion process to mix with the ground corn. The amount of VOCs released during fermentation is approximately 20% of total plant VOC emissions, typically the second highest source.

Distillation

The distillation process removes the majority of the remaining water from the beer based on the different boiling points of water and ethanol. The system is comprised of three columns: the beer mash tower, the rectifier, and a side stripper. Reboilers, which provide non-contact steam for each column, are used to heat the ethanol/water mixture to drive the process. The beer enters the beer mash tower from the fermenter and flows over trays while the reboiler steam heats the liquid in the bottom of the tower. The solids and water, called stillage, are removed from the bottom of the beer column and sent to the centrifuge. The vapor leaving the beer tower is 40 - 50% ethanol and flows to the rectifier column. The rectifier takes the vapor from the beer mash tower and the distillation process continues until it is concentrated to 95% ethanol and 5% water. The rectifier column removes other hydrocarbons, called "fusel", and these are mixed with the final ethanol product. Some of the ethanol leaving the rectifier is condensed and sent back to the rectifier as reflux to draw more water out of the ethanol. The side stripper takes the water out of the bottom of the rectifier and using steam from a reboiler, strips out any remaining ethanol and sends it back to the rectifier.[5]

The energy consumed in the distillation process is primarily from the steam used by the reboilers and represents about 70% of the steam needed by the overall process. This steam is recaptured from the process in a closed loop system with the evaporator system where the condensate is returned to the boiler for reuse. The electricity used in distillation is negligible compared to other processes.

Dehydration

The dehydration process consists of two molecular sieve, "mole sieve", units that are cycled so one unit is regenerating while the other is operating. The 95% ethanol vapor leaving the rectifier is superheated before it enters one of the mole sieves. The vapor passes through a bed of beads where the water is adsorbed on the beads and the ethanol vapor passes through. Just before the bed gets saturated with water, the flow is switched to the other bed and the saturated bed is regenerated. The regeneration of the mole sieve is accomplished by passing some of the anhydrous ethanol vapor back through the bed and applying a vacuum to pull the water out. The recovered water is sent to the stripper column to remove any small amounts of ethanol and then used as process water. The ethanol vapor is cooled in a condenser to convert the vapor to a liquid for storage.

The energy consumed for the dehydration process is mainly related to the steam used to superheat the ethanol entering the mole sieve. This represents just 1% of the total steam used in the facility. Like distillation, this steam is recaptured from the process. The process of condensing the ethanol vapor to a liquid is approximately 20% of the cooling water flow.

Storage and Shipping

To make fuel grade ethanol, denatured ethanol, and 3-5% gasoline is added. The denatured ethanol is stored in large tanks on site until it is loaded into rail cars or trucks for delivery to the customer. A loadout flare, standard control equipment at an ethanol facility, reduces VOC emissions by 95% during the loading process. These emissions represent approximately 10% of total plant VOC emissions. Although emissions are a concern, the flare also protects against the explosion hazard of the fuel loading process.

No significant energy or water is used during the storage and shipping process.

Separation

Stillage from the bottom of the beer column, containing 15% solids, is sent to centrifuges which separate the coarse grains from the solubles. The solubles, called thin stillage, that come out of the centrifuge are sent through evaporators where water is removed resulting in a 35% solids mixture called syrup. Biomethanators are used to treat the removed water so it can be reused within the process. The evaporators are typically multiple-effect and use indirect heat from reboilers. The coarse grains from the centrifuge and syrup from the evaporators are then mixed back together to form wet distiller's grains with solubles (WDGS), which have a moisture content of over 60%. WDGS is sold as a feedstock for cattle.

The motors for the centrifuges and vacuum pumps use approximately 30% of the total plant electrical energy. The steam used in the evaporators is recovered from the distillation process so it does not add to the total steam load.

Drying

The WDGS are sent to dryers to reduce the moisture content to approximately 10%. The product is now called dried distillers grains with solubles (DDGS) and this is sold as a feedstock for cattle. Drying is needed to prevent spoilage, reduce odors, and extend the shelf life of the grain. The typical dryer is a rotary drum dryer which has an air heater, fired by natural gas, mixing hot air with the WDGS to evaporate the water. The VOC emissions from the drying process, typically 30% of the total VOC emissions, are controlled with a thermal oxidizer or regenerative thermal oxidizer (TO/RTO).

The energy used in drying is mainly from natural gas used to fire the dryer and is approximately 42% of all thermal energy consumed in the facility. The electrical energy required is due to the size of the motors needed to power the fans, mixers, and dryers and is approximately 30% of the electrical energy consumed. A significant amount of water in the WDGS is evaporated in the dryer, is not recovered, and amounts to approximately 30% of the incoming plant makeup water supply flow. There is a new technology described in the *Best Practices* section of this report that is focused on trying to recover water evaporated during drying.

Plant Utilities

Plant utilities include the well water pumps, TO/RTO, boiler(s), cooling tower, chillers, air compressors, lighting, water treatment equipment and chemicals. If a TO is used, it is combined with a heat recovery steam generator (HRSG) to recover the waste heat from the TO exhaust to produce steam needed for the process. If a RTO is used, the excess heat from the oxidizer is used to preheat the incoming exhaust gas instead of being ducted to a HRSG. An RTO is combined with a package boiler fired on natural gas to produce steam needed for the production process. Based on the level of process review, at this time, it is unclear whether one configuration is more efficient than the other. Using a TO/HRSG versus a RTO with a package boiler is more dependent on the design firm that built the plant.

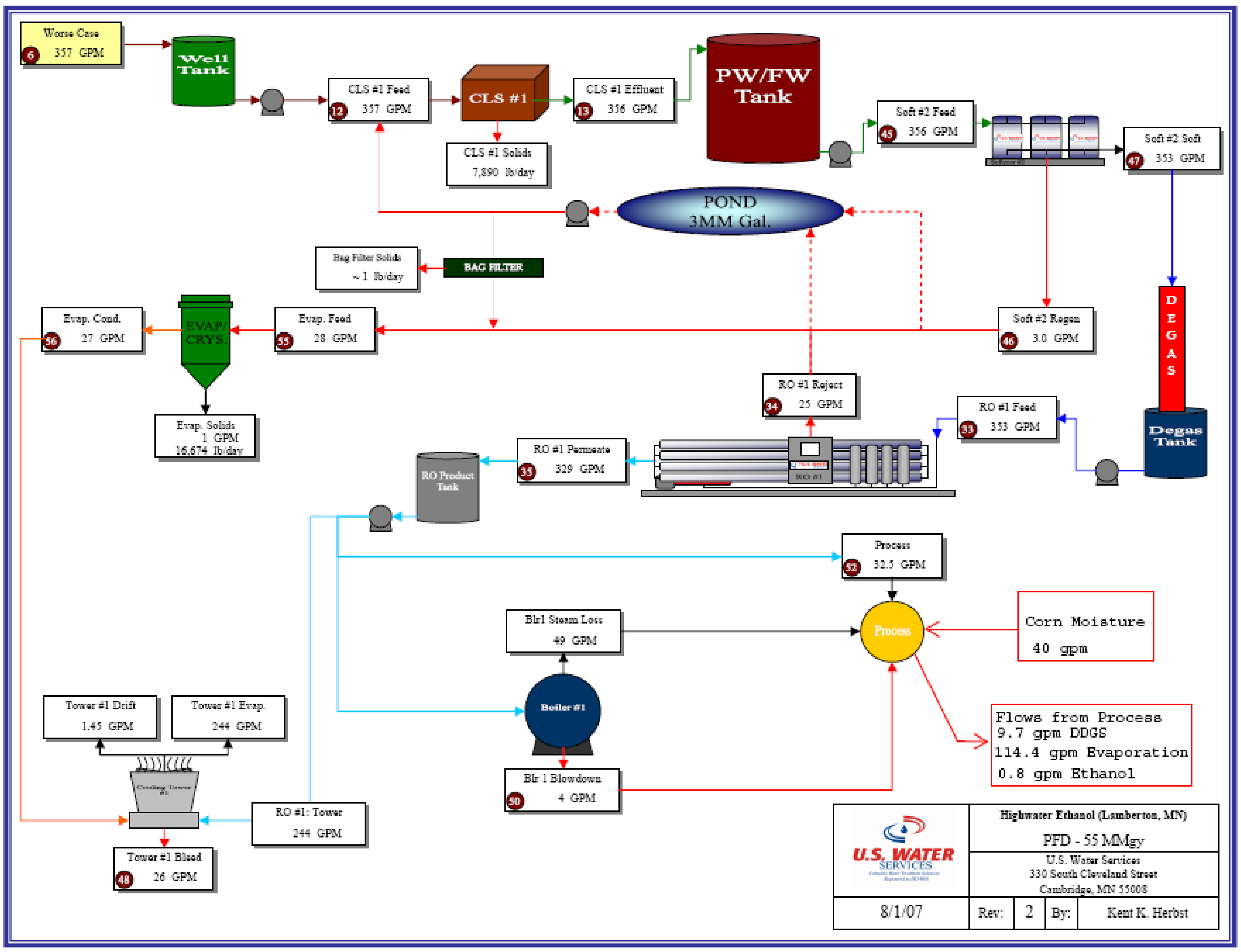
Typical water treatment equipment may include reverse osmosis (RO) units, iron filters, cold lime softening (CLS) units, softeners, or carbon filters. The specific equipment is dependent on the quality of the incoming water; amount of recycling; chemical additives used; and applicable wastewater discharge limits. Chemicals are used to protect the heat exchangers from formation of scale, rust, or microbial growth.

The electrical energy used to power the motors for plant utilities amounts to approximately 15% of the total electrical load.

As a general approximation, water use at a dry mill ethanol facility can be broken out as 70% non-contact utility water and 30% process water. Process water comes into contact with the corn used in the production of ethanol either by mixing with the corn to make slurry and/or direct injection of steam to cook the mash. This water is typically treated on site and reused in the process.

Diagram 1, the water balance diagram for the proposed Highwater Ethanol facility in Lamberton, Minnesota, is based on a 55 MGY production rate and a maximum water use of 179 MGY which results in a water efficiency of 3.3 gal water/gal ethanol. The diagram shows the significant amount of water evaporated from the cooling tower, the amount of evaporation from the process through the grain drying, and wastewater rejected from the water treatment equipment. The diagram also provides information on the types of water treatment equipment used in the process. The process water is largely consumed through evaporation occurring during the distiller's grain drying process where the moisture is reduced from 60% in the WDGS to 10% in the DDGS. The moisture removed during the drying process is vented to the atmosphere and not recovered. The majority of non-contact utility water is vented to the atmosphere through cooling tower evaporation with a much smaller amount discharged as wastewater from the water treatment equipment.

Diagram 1: Proposed Water Balance for Highwater Ethanol Facility



*THE INTENDED USE IS FOR CAPITAL EQUIPMENT DESIGN AND PERFORMANCE PREDICTION. Highwater Ethanol - USWS WB7D rev2 - 55 MMgy.xls

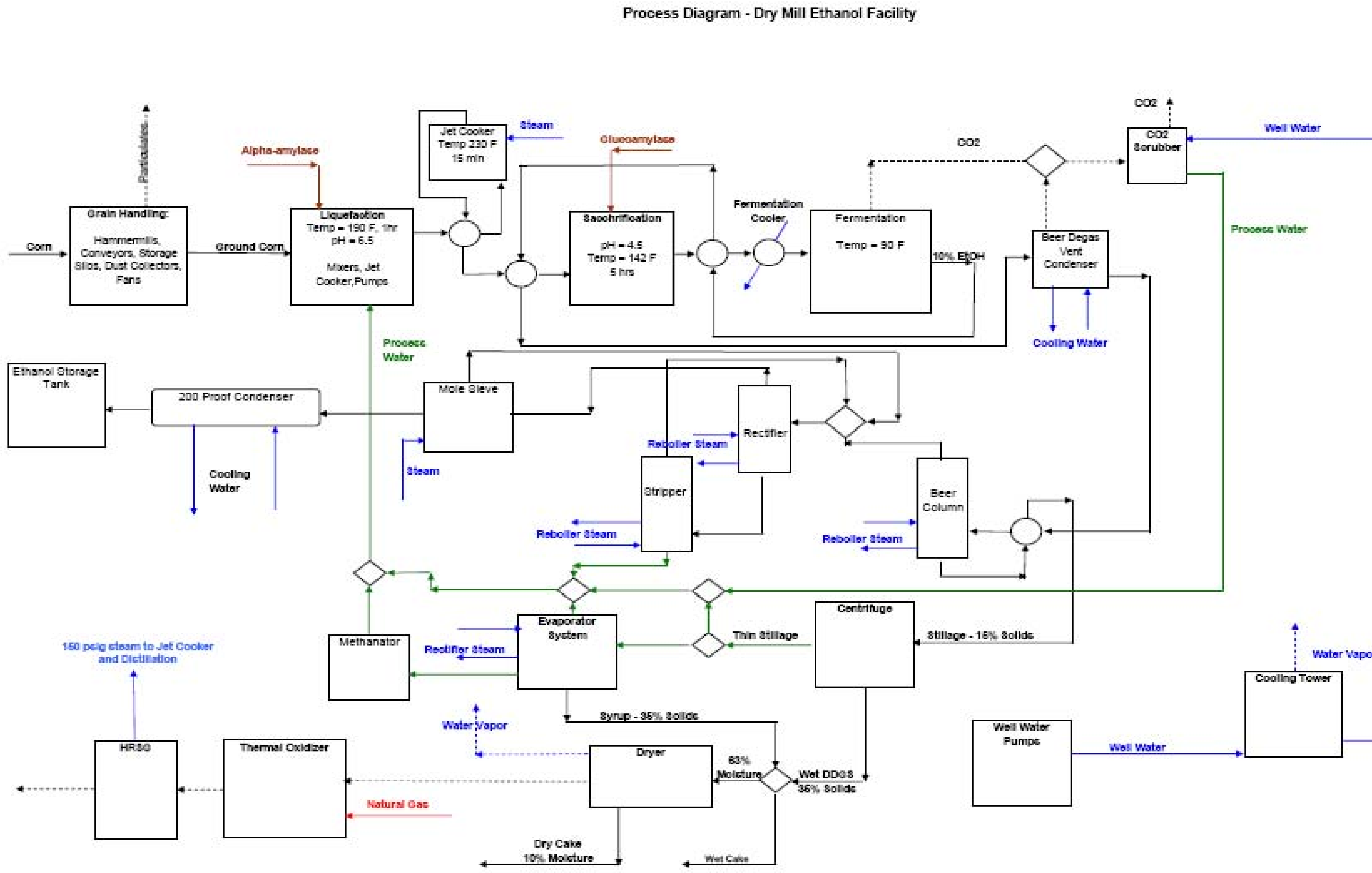


Diagram 2: A Schematic of a Typical Dry Mill

ENVIRONMENTAL IMPACTS ASSOCIATED WITH ETHANOL PRODUCTION

Water Quality

Managing water quality issues for an ethanol facility is a complex task. The level of pollutants in the wastewater is dependent on the quality of supply water, the number of cycles the water is recycled in the process, the chemical additives used, and to the classification of receiving water to which the wastewater is discharged. The supply water is typically ground water from wells located on site or wells from a municipal supply. The wastewater is typically discharged to a ditch or river. Since ethanol facilities are typically located in agricultural areas, most are not connected to municipal wastewater treatment plants (MWWTP) and must have their own treatment processes.

The receiving waters have classifications that are defined by the intended use of the water. The Minnesota water quality rules set standards to protect these uses. For the receiving waters associated with ethanol facilities, this includes fish, plants, crops, wildlife, livestock, and industrial use.

Currently, Minnesota has no dry mill ethanol facilities with process wastewater discharging directly to surface water. Non-contact utility water flows in heating or cooling loops throughout the plant and is used multiple times. Most plants discharge non-contact utility wastewater, from the treatment systems used for the boiler and cooling tower. This is regulated under Minnesota's National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit Program.

Cooling towers are a common example of equipment that discharges non-contact utility water to the environment. Cooling towers with incoming water of poorer quality will have higher blowdown rates, which translates to increased plant makeup water use. Any unwanted constituents such as solids or salts must be removed from the water before it is used. In addition, there are significant losses by evaporation in the cooling tower, which further concentrates the salts in the non-contact utility water. This results in a wastewater stream that has concentrated levels of solids and salts, which may be 3 to 4 times higher than the concentration in the supply water. These concentrations can typically exceed water quality standards for irrigation and crops.

Ethanol plants must also manage stormwater runoff from the site to ensure industrial activities do not impact water quality during storm events. These discharges are usually controlled by maintaining a Stormwater Pollution Prevention Plan and implementing best management practices to control soil erosion.

The following pollutants are typical parameters of concern from an ethanol facility discharging wastewater in Minnesota. They are listed by the relative challenge they present the plant in controlling their discharge.

Total Dissolved Solids (TDS) is a summary parameter that measures various inorganic water contaminants that exist as ions in solution. The major cations typically are calcium, magnesium, sodium, and potassium; the major anions typically are carbonate, bicarbonate, chloride, sulfate, and nitrate. The environmental impact from dissolved salts depends on the specific contaminants in the water, in both absolute and relative amounts. Dissolved salts-related water quality standards, as translated by the MPCA into NPDES/SDS permit requirements, protect Minnesota's waters for drinking water, aquatic life, industrial, irrigation, livestock, wildlife and other uses. TDS is used in this report as an encompassing term to cover issues related to this greater set of various dissolved salts pollutants.

Excessive Phosphorus levels can speed up the aging process of lakes and streams by stimulating algae growth which reduces the amount of dissolved oxygen in the water. The water treatment chemicals used to prevent scale and corrosion formation in the cooling water system are typically organophosphonates and are the primary sources of phosphorus discharges from ethanol facilities. Use of organophosphonates in water treatment chemicals is not unique to ethanol facilities but common in many industrial applications. Managing phosphorus discharges has typically not been a challenge for ethanol facilities and phosphorus monitoring is becoming more common for ethanol plants. Phosphorus trading is a mechanism for an ethanol facility to meet their discharge requirements without installing treatment equipment at their own facility. Presently phosphorus trading appears to be more economical than on-site treatment but the cost for trading will rise as phosphorus discharge limits become more restrictive in order to protect overall watershed quality.

Residual Chlorine is a contaminant that results from the water treatment chemicals that are added at the facility to control bacterial growth. Exceedance of the discharge standard can be toxic to fish in the receiving water. Exceedances appear to be related to the monitoring procedure or controls on the cooling water treatment system. The typical standard requires the daily maximum to remain below 0.04 mg/l.

5-Day Carbonaceous Biological Oxygen Demand (CBOD5) is a minimum discharge standard for most municipal and industrial wastewater discharges to surface water. CBOD5 is an indicator of organic material in the wastewater and higher levels of CBOD5 will reduce available oxygen levels for fish and plant life in the receiving water. Typically, this has not been a wastewater problem for ethanol facilities.

Total Suspended Solids (TSS) is a minimum discharge standard applied to most municipal and industrial wastewater discharges to surface water. The typical standard requires the monthly average to remain below 30 mg/l. Characteristically, this has not been a wastewater problem for ethanol facilities.

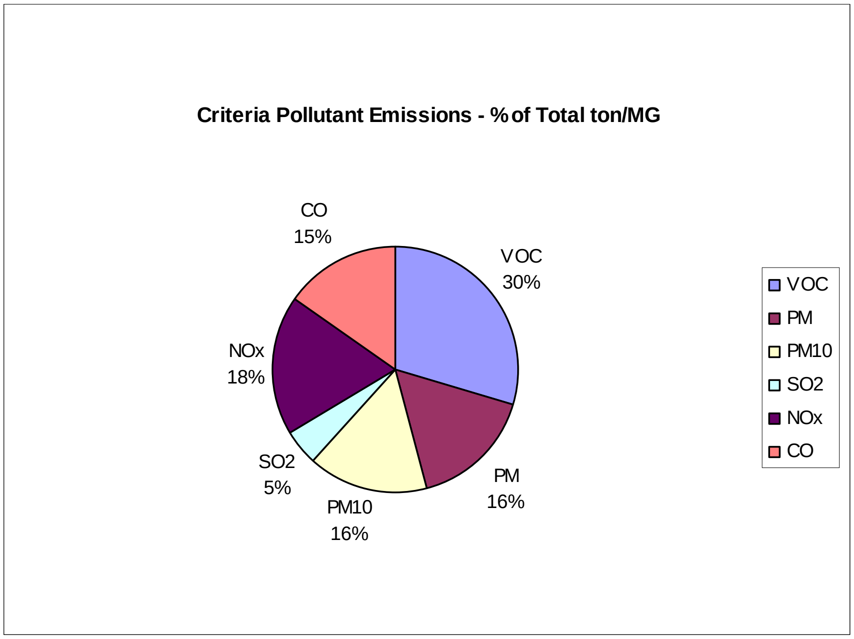
Air Quality

VOC emissions have been the most significant air quality concern for ethanol facilities. Elevated emissions resulted in a 2002 consent decree with the Environmental Protection Agency (EPA) and Minnesota Pollution Control Agency (MPCA) requiring Best Achievable Control Technology (BACT) for control of VOC, nitrogen oxides (NOx), and carbon monoxide (CO) emissions. The 2002 consent decree was focused on controlling the VOC emissions from the dryer because prior to the consent decree the emissions were vented directly to the atmosphere. A TO/RTO was typically determined to be BACT for destroying VOC emissions related to the drying process. Although the TO/RTO was intended to mainly control emissions from the dryers, it can also control the VOC emissions from many other sources in the plant depending on design characteristics. Facilities were allowed some flexibility to use alternative systems instead of the TO/RTO. This flexibility led to more innovation and prompted one facility to design a system that used corn syrup as a fuel source.

In addition to controlling VOCs from all stacks, ethanol facilities are subject to *Subpart VV of Title 40 Code of Federal Regulations Part 60*, which requires implementation of a leak detection and repair (LDAR) program for monitoring leaks associated with pump or compressors seals, valves, and other equipment. The program specifies monthly inspections of pump seals and valves; any leaks must be repaired within 15 days of detection. This can be a time consuming effort as there are 300 to 500 components requiring inspection.

Figure 2 provides an overview of the relative impact of all criteria pollutants emitted from dry mill ethanol plants in Minnesota. This was created by calculating the average emission factor for the 14 dry mill ethanol plants based on their emission inventory report. The emission factor was tons per million gallons of ethanol produced. As stated earlier, this study did not conduct a detailed evaluation of the issues related to greenhouse gas emissions or climate change.

Figure 2: Relative Criteria Pollutant Emissions



Energy Consumption

Thermal Energy

An ethanol facility uses a large amount of thermal energy in the form of steam for starch conversion, distillation, and evaporation, or natural gas for destroying VOCs, and drying the distiller grains. Thermal energy is primarily produced from fossil fuels such as natural gas (and sometimes coal) with propane or diesel providing backup. Given that fossil fuels such as natural gas, oil, and coal are not renewable, there are additional benefits when fossil fuel use is minimized. This study benchmarked fossil and renewable fuel use separately. Total thermal energy use was benchmarked to highlight facilities that have incorporated energy efficient processes to reduce overall energy use.

Electricity Use

Electrical energy represents 10% of the total energy consumed in an ethanol facility. Electricity is used to power pumps, fans, hammermills, agitators, and centrifuges.

As with many energy intensive industries, there are continuing opportunities to reduce the amount of energy consumed through equipment innovations, process operating efficiencies, and recovery of waste energy. Reductions in energy consumption will likely be driven by energy costs. Approximate energy costs for a state of the art 40 MGY plant are approximated in Table 2. These operating costs rank second only to the cost of corn.

Table 2: Approximate Energy Costs for State of the Art 40 MGY Facility

Energy Source	Energy Use Index	Operating Hours	Unit Cost*	Annual Cost
Natural Gas	32,000 Btu/gal	8,550	$8/MMBtu	$10 million
Electricity	0.75 kWh/gal	8,550	$0.05 kWh	$1.5 million

*MMBtu = Million of British Thermal Units, Prices obtained from Energy Information Administration

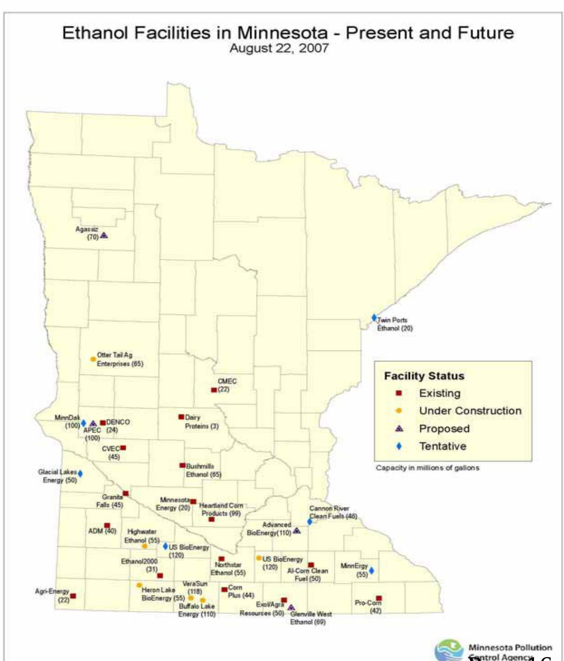
Energy savings are usually related to the amount of time and capital invested in the solution. This report focused on the mid- and long-range energy saving opportunities in ethanol facilities. Short-term savings are not specific to ethanol facilities but are general practices that apply to all industrial facilities. Examples of short-term savings include steam trap maintenance, use of high efficiency motors, minimizing air compressor leaks, lighting upgrades, and proper steam pipe insulation. Unfortunately, there was not adequate access to Minnesota ethanol facilities to benchmark typical opportunities for these short-term savings. MnTAP will continue to try to assess this potential and assist plants in these types of savings.

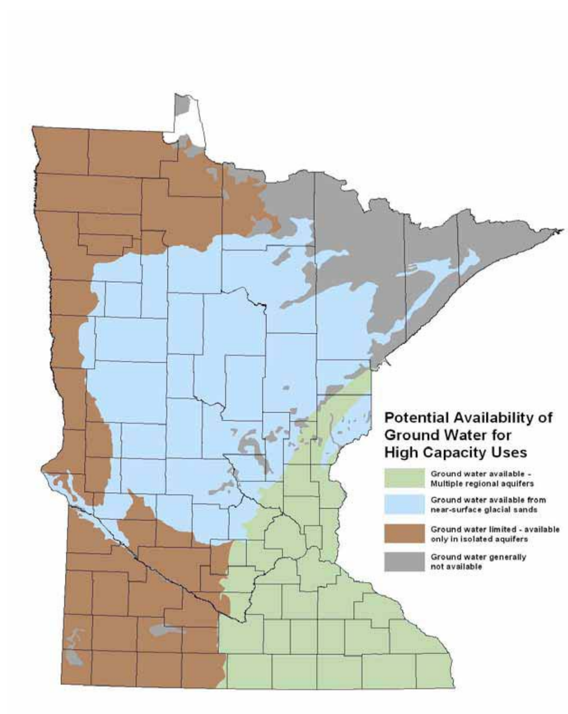
Water Use

Water use is often a limiting factor when existing facility capacity is expanded or new facilities are built. Water availability and use will depend on the plant location, quality of the water supply, and discharge limitations. With only one exception, ethanol facilities in Minnesota use ground water (as opposed to surface water) to supply their water needs. There is concern the water used by ethanol facilities will affect the ground water supplies in certain areas of the state.

Aquifers may not be able to provide sustainable water supplies as more water is withdrawn from them. Many ethanol facilities are located in the southwest part of the state where aquifers are limited in scope or where other water supply challenges exist. One particular aquifer was stressed enough that the ethanol facility drawing water from it switched over to a surface water supply. A proposed 100 MGY facility in southwest Minnesota was cancelled because the aquifer could not meet the water supply needs.

Diagram 3: Locations of Minnesota Ethanol Facilities and Corresponding Areas Where Ground Water Supplies are Limited





As a general approximation, water use at a dry mill ethanol facility can be broken out as 70% non-contact utility water and 30% process water. Most facilities have been able to reuse all of their process water in the production process but still discharge non-contact utility water to the environment when the level of solids and salts is high, resulting in damage to heat exchangers.

Water use is typically benchmarked by measuring the water pumped out of the wells. Water efficiency is calculated by dividing annual reported water use by gallons of ethanol produced. There are no regulatory limits on water efficiency for ethanol facilities. However, the plant has limits on the total amount of water that can be removed from the aquifer on an annual basis. The plant is required to monitor the level of the aquifer and use may be restricted if the aquifer level drops below a certain level. Additionally, plants must make sure their water withdrawal does not interfere with other users of the aquifer.

A 2006 Institute for Agriculture and Trade Policy (IATP) study recommended that if there was a greater economic value placed on water there would be more incentive for ethanol facilities to incorporate water saving practices and make capital improvements to the treatment systems.[6] Currently, water use is limited primarily by the Department of Natural Resources' (DNR) regulatory allocation process because the cost of water and water treatment is not large enough to justify reduced water use based on economics alone.

The concern about water use at ethanol facilities has brought an important water conservation issue forward in Minnesota. Ethanol facilities are just one of the newest users of ground water supplies. Other users in rural areas of Minnesota, including food processing companies, livestock production facilities, farmers for crop irrigation, and municipalities providing potable water, also put a strain on ground water supplies. All Minnesotans must practice good water conservation to ensure sustainable water supplies. For ethanol facilities, conservation cannot rely exclusively on increased rates of recycling non-contact utility water; this practice produces higher levels of TDS which may prevent the plant from meeting their water quality discharge limits.

BENCHMARKS AND BEST PRACTICES

INTRODUCTION

This study evaluated the following benchmarks: yield, water efficiency, thermal energy use, electrical energy use, and VOC emissions. As no definitive and quantitative water quality benchmark could be established, a review of existing permit requirements was completed to determine trends in discharge water quality. Other than electricity use, the benchmarks were determined using data from publicly available sources such as emission inventory reports or water use reports. The benchmarks for old and new plants were compared to determine if a difference could be observed. The intent of this report is to show the status of the ethanol industry in the state as a whole. The intent is not to identify or pass judgment on any specific plant, so the names of facilities have been concealed.

Many benchmarks used in this study are well known in the industry and many plants track these numbers internally. These benchmarks are not only important measurements of resource use or environmental impact but they can be key factors associated with the financial success of a facility. The top five factors associated with financial success include corn price, ethanol price, natural gas price, yield, and plant utilization factor.[7]

Government and utilities are providing significant support to push further development of ethanol production and/or innovation related to energy conservation or renewable resources. It is less clear if incentives or support exist for facilities to implement innovative process improvements if they are strictly related to water conservation. It is the intent of this study to show the potential for process improvement at dry mill facilities within Minnesota by highlighting best practices implemented within the state, in locations outside the state, or as pilot projects.

Best practices are widely discussed at industry conferences and in trade publications. Best practices include practices that leverage opportunities within the local market, such as selling WDGS instead of DDGS. Some best practices that were once considered innovative are now considered standard practice in facilities. For example, the mole sieve used in the dehydration process was introduced in the 1990's and significantly reduced energy use. It is now standard equipment in all dry mill facilities. Many best practices provide multiple benefits but are discussed in the section where they provide the primary benefit. For this study, best practices were verified visually through a site visit, through discussions with plant personnel, or from review of public documents. The public documents included air or water permits, the environmental assessment worksheet (EAW), trade journal articles, or research papers.

Water Quality

Since no definitive and quantitative water quality benchmark could be established, a review of existing permit requirements was completed to determine trends in discharge water quality. The trends provide an overview but do not fully portray the site-specific issues related to the quality of the supply water, receiving water classification, or the amount of recycling of non-contact utility water.

This project did not include a detailed review of supply water quality because the data was not readily available from facilities. Limited data was provided by facilities or from technical articles, which showed the variability in the quality of water supplies. While it is generally expected that ground water supplies will have much higher levels of TDS than surface water supplies, this is not always true. Table 3 shows the variability in TDS levels for the water supply for three facilities using ground water or surface water. The high levels of TDS for Siouxland Ethanol will require more treatment and produce more wastewater than the two other facilities.

Table 3: Examples of the Variability in TDS Levels in Water Supply[8]

Facility	TDS, mg/l
Siouxland Ethanol, IA – Ground water	2,113
Little Sioux Ethanol, IA – Surface Water	703
Granite Falls, MN – Ground water	808
Granite Falls, MN – Surface water	648

Table 4 shows the increase of monitoring that is being required at Minnesota facilities as wastewater discharge permits are renewed. It is based on the authorized non-stormwater discharges of non-contact utility wastewater using MPCA permit data as of November 16, 2007. When the wastewater discharge permits were grouped together by the permit expiration date and plant operating status, a clear trend towards more monitoring and limits was shown. The first generation permits, which had expiration dates of 2008 or earlier, have limits on very few parameters. The second generation permits, which had expiration dates of 2009 or later, have many more monitoring requirements. Plants approved for construction have more effluent limits in their discharge permits than operating plants and many of the limits are related to contaminants associated with increased levels of recycling. As the MPCA has become aware of the potentially high pollutant levels in ethanol plant non-contact utility wastewater discharges, limits for these pollutants are being incorporated into the most recent discharge permits

TDS and the various cations and anions that make up TDS were not initially regulated at ethanol facilities. Many permits now have requirements to monitor the discharge and some facilities have a TDS effluent limit. One facility under construction has obtained a temporary variance for this limit but more detailed monitoring is required to ensure the discharge stream does not cause harm to plants or wildlife. This indicates that water quality improvements are being driven by the regulatory process as more monitoring and control is required at facilities.

The only exception to this trend of increased monitoring and effluent limits is for two plants that are approved for construction that do not have utility wastewater discharge monitoring or limits because they have zero liquid discharge systems. This best practice is described later in this report.

Table 4: Trends in Utility Wastewater Discharge Monitoring Requirements based on Permit Expiration Date (5 years after issuance)*

Permit Expiration	**First Generation (2008 or Earlier)**	**Second Generation (2009 or Later)**	**Plants Approved for Construction****
	# of Facilities		
Parameter	4	9	4
$CBOD_5/BOD_5$, mg/l	Limit of 25 at 2 facilities Limit of 15 at 1 facility	Limit of 5 at 2 facilities Limit of 25 at 7 facilities	Limit of 5 at 2 facilities Limit of 15 at 1 facility Limit of 25 at 1 facility
Boron, mg/l	No monitoring or limits	Monitoring at 5 facilities	Limit of 2.86 at 1 facility Monitor at 2 facilities
Chlorides, mg/l	Limit of 100 at 1 facility Limit of 250 at 1 facility	Monitor at 6 facilities Limit of 100 at 2 facility Limit of 280 at 1 facility	Limit of 25 at 1 facility Monitor at 2 facilities
Magnesium, mg/l	No monitoring or limits	Monitor at 2 facilities	Monitor at 4 facilities
Calcium, mg/l	No monitoring or limits	Monitor at 2 facilities	Monitor at 4 facilities
Potassium, mg/l	No monitoring or limits	Monitor at 2 facilities	Monitor at 2 facilities
Phosphorus, mg/l	No monitoring or limits	Monitor at 9 facilities	Monitor at 4 facilities
Phosphorus Trading	None	Done at 2 facilities	Required at 3 facilities
TDS, mg/l	No monitoring or limits	Monitor at 6 facilities Limit of 700 at 1 facility	Limit of 700 at 2 facilities Limit of 3,061 at 1 facility Monitor at 1 facility
TSS, mg/l	Limit of 30 at 3 facilities Limit of 45 at 1 facility	Limit of 30 at 9 facilities	Limit of 30 at 4 facilities
Residual Chlorine/Oxidants, mg/l	Limit of 0.014 at 1 facility	Limit of 0.038 at 7 facilities Limit of 0.014 at 1 facility	Limit of 0.038 at 3 facilities Monitor at 1 facility
Bicarbonates, meq/l	No monitoring or limits	Monitor at 2 facilities Limit of 5 at 1 facility	Limit of 5 at 2 facilities Monitor at 1 facility
Hardness as $CaCO_3$, mg/l	No monitoring or limits	Monitor at 4 facilities Limit of 250 at 1 facility	Limit of 250 at 1 facility Limit of 500 at 1 facility Limit of 520 at 1 facility Monitor at 1 facility
Salinity, mg/l	No monitoring or limits	Monitor at 4 facilities	Limit of 2,290 at 1 facility Monitor at 2 facilities
Sodium,% of total cations in meq/l	No monitoring or limits	Monitor at 6 facilities	Limit of 60% at one facility Limit of 90% at one facility

			Monitor at 1 facility
Sulfate, mg/l	No monitoring or limits	Monitor at 6 facilities	Limit of 1980 at 1 facility Monitor at 3 facilities
Specific Conductance, -µmhos/cm	No monitoring or limits	Monitor at 5 facilities Limit of 1,000 at 1 facility	Limit of 1000 at 2 facilities Limit of 4340 at 1 facility Monitor at 1 facility

*Limits discussed are monthly averages.
** Table does not include facilities that are designed for zero liquid discharge

Table 5 shows actual wastewater discharge data for an unnamed facility in Minnesota excluding stormwater. The primary pollutants of concern include TDS and associated pollutants including chlorides, bicarbonates, hardness, salinity, sodium, sulfate, and conductivity. Whether these levels are a concern will depend on the receiving water for the facility.

Table 5: Wastewater Discharge Data

Parameter	Units	Range
Boron	mg/l	1.6 - 2.5
Chlorides	mg/l	143 - 235
Phosphorus	mg/l	1.25 - 2.03
TDS	mg/l	2320 - 3360
TSS	mg/l	2 - 40
Residual Chlorine	mg/l	0 -0.04
Bicarbonates	mg/l	157 - 298
Hardness	mg/l	1360 - 1900
Salinity	mg/l	2*
Sodium	% in meq/l	71.8*
Sulfate	mg/l	1290 - 2090
Specific Conductance	µmhos/cm	2890 - 4820

*Only one value reported

Best practices related to water quality include the following:

Water Resource Planning Prior to Site Selection

An accurate, well-defined water balance diagram and water treatment design are important first steps in the ethanol project site selection process. Water issues, until recently, have not been a primary concern when choosing a potential site for an ethanol plant. Primary considerations have been access to corn, rail, and natural gas. Water supply and water quality issues are becoming more crucial to the development of new ethanol facilities in Minnesota. Understanding the water quality issues related to supply and discharge are key to determining the types of equipment needed to treat the water. Additionally, the availability of water supply is critical to obtaining approvals for water appropriations.

On-site Retention of Stormwater

A stormwater pond allows the facility some flexibility in controlling stormwater runoff. The pond should keep stormwater discharge levels at least equal to the levels before the site was constructed; allow for sediment removal before the water flows off site; provide a way to treat dissolved organics and nutrients in stormwater runoff such as nitrogen or phosphorus. Stormwater ponds are not intended to provide secondary containment for spills that may occur during the loading process because facilities should provide separate means for spill containment on site.

Segregation of Non-Contact and Process Waters

Non-contact utility water and process water have different characteristics and uses; therefore, it is important to keep them separate. This appears to be a standard practice.

Zero Discharge of Process Water

With zero discharge of process water, the water leaves the production process only through evaporation during the drying process. Although not all facilities were evaluated for this practice during this study, it appears this is a standard practice in Minnesota. Equipment such as biomethanators remove non-fermentable contaminants in the process water allowing many facilities to more easily reuse process water. Biomethanators are used in multiple facilities in Minnesota and are discussed in more detail in the energy section.

Zero Liquid Discharge Technology

Using appropriate equipment, a facility can treat the plant's non-contact utility water so there is no water discharge. The costs range from $5-20 million depending on the water quality at the facility.[9] The first ethanol plant to achieve zero liquid discharge in the United States was Pacific Ethanol in Madera County, California. This facility started operations in November of 2006 and used CLS in combination with RO. Two Minnesota plants plan on using an evaporator/crystallizer system in combination with CLS and RO to achieve zero liquid discharge. VeraSun Energy, a 110 MGY facility in Welcome, Minnesota, will start up in the first quarter of 2008. APEC ethanol facility in Morris, Minnesota will also use this technology with the startup date in 2009. The evaporator/crystallizer system is more complex than CLS. It requires energy in the form of steam to separate the salts from the water and a lined storage pond for temporary storage of the brine solution. Initial analyses of the salts removed indicate these will be disposed of as a solid waste and not a hazardous waste. One significant result of having zero liquid discharge technology is that the facility does not have a utility wastewater discharge with the associated monitoring and limits.

Use of Low or No- Phosphorus Water Treatment Chemicals

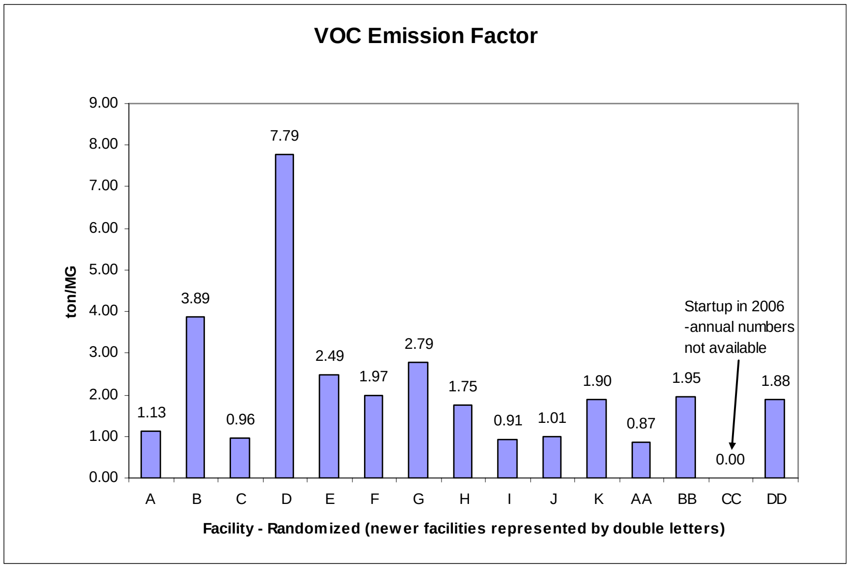
Alternatives such as low or no-phosphorus treatment chemicals are available at this time but they have not been tested in a full scale operating plant. There are concerns that these new chemicals will require more knowledgeable plant operators and tighter controls on the water chemistry system. It appears that no Minnesota facilities have made this transition, but there are efforts to test low phosphorus chemicals in production facilities in other states.

Air Quality

Since the 2002 EPA consent decree, the amount of VOC emissions for ethanol facilities has been substantially reduced. Similar to water quality, there are standards listed in the air permit that limit the amount of VOCs a facility can emit and requirements for reporting annual emissions. A benchmark was created based on tons of VOC divided by millions of undenatured ethanol produced. Figure 3 displays this benchmark. There is not a clear explanation for the significant variation in the emissions data but the facilities with the highest emission factors also have significantly higher fugitive VOC emissions from equipment leaks.

The most significant air quality best practice is related to CO_2 emissions. Each bushel of corn produces about 18 pounds of CO_2[10], resulting in over 130,000 tons of CO_2 each year for a 40 MGY facility. Some facilities will collect this gas, compress it and sell it to other facilities for processing. A typical use for captured CO_2 would be carbonating beverages. The CO_2 is recovered as a co-product in at least five Minnesota facilities.

Figure 3: VOC Emission Factor



Energy

Table 6 presents reference points for benchmarking energy use at dry mill ethanol production facilities. These numbers represent estimates from a national non-profit organization, a corporate consulting firm, and design guarantees from an ethanol plant designer. Averages obtained from this study are also included in Table 6.

These benchmarks only represent the fuel consumed in the production process and do not include fuel related to transportation of the grain to the facility or ethanol and co-products from the facility. There are certainly efficiencies gained in energy consumption as facility size increases and this may have led to the increased capacity of new plants being built. However, there are some concerns that plant size may reach a point where the increased size is not efficient due to higher transportation costs of grain and ethanol.[11] There are also concerns that larger plants will concentrate the environmental impacts related to water use.

Table 6: Energy Benchmarks for Dry Mill Ethanol Facilities

Study	Thermal Energy, Btu/gal	Electrical Energy kWh/gal
1995 study by the Institute for Local Self Reliance – State of the Art Dry Mill[12]	26,500	0.6
1995 study by the Institute for Local Self Reliance – Average Dry Mill[13]	39,000	1.2
2001 BBI International- Average Dry Mill[14]	34,700	1.09
June 2006 – ICM Dry Mill Guarantee[15]	32,000	0.75
2006 Average Minnesota Facility	34,775	0.85
2006 Average for Older Minnesota Facilities	37,000	1.02
2006 Average for Newer Minnesota Facilities	29,000	0.61

Figure 4 shows the thermal energy use index for all facilities. Some older facilities have energy use indexes similar to newer plants, which are likely due to retrofits. It seems reasonable to assume that best practices could be incorporated at older facilities to achieve an average energy use index of 34,000 Btu/gal. For an average sized facility of 32 MGY, this reduction would be worth $750,000 annually based on a natural gas price of $8/MMBtu. Plant size can affect the energy efficiency of a facility. There are some smaller (e.g. 20 MGY) facilities that have been retrofitted and have energy efficiencies equal to larger and newer plants.

Figure 4: Thermal Energy Use Index

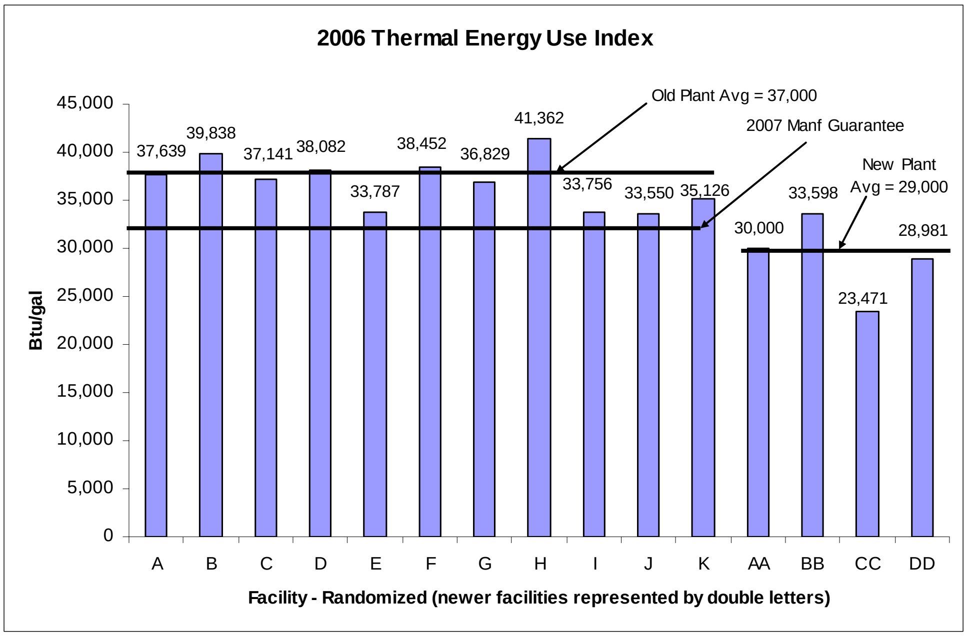


Figure 5: Renewable vs. Fossil Thermal Energy Use Index

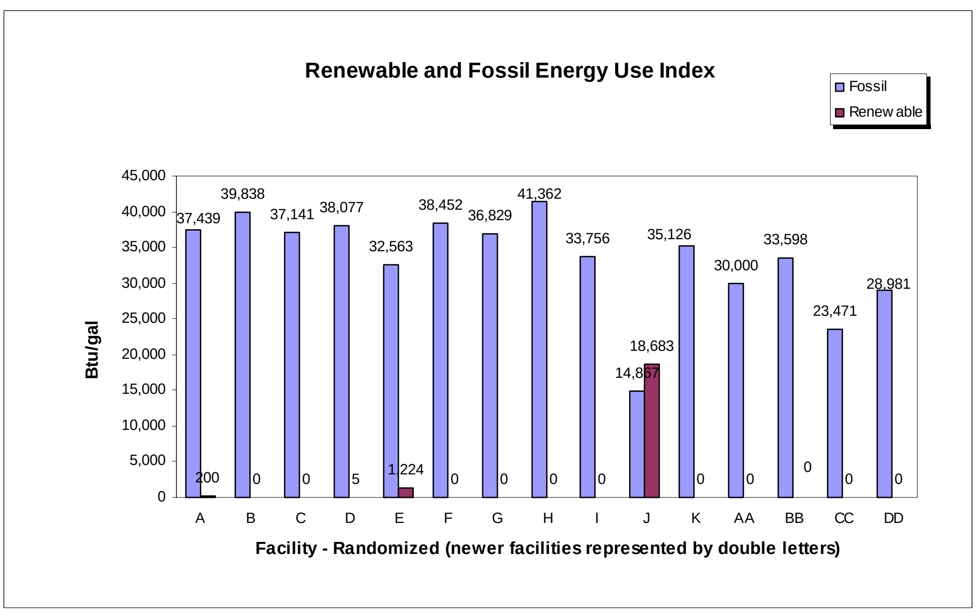
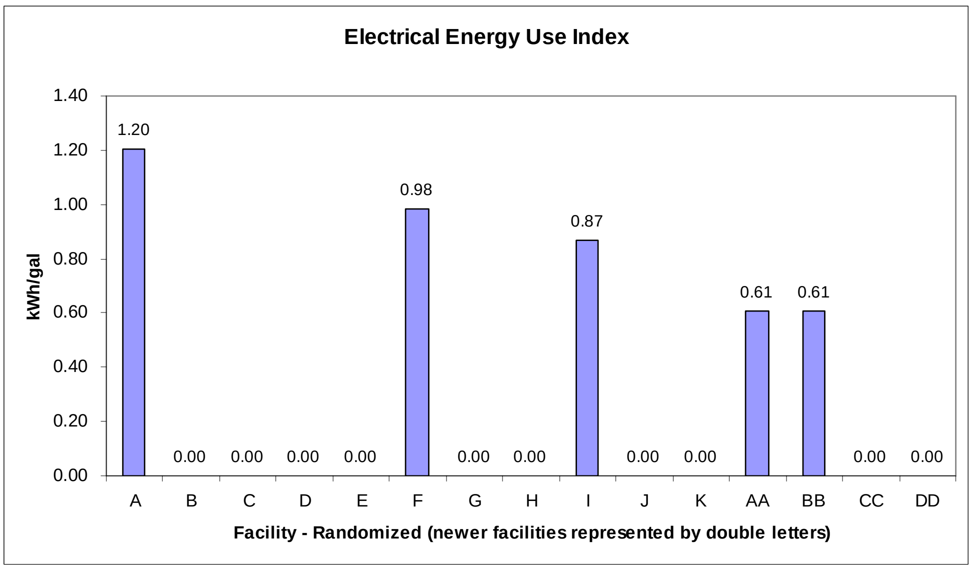


Figure 5 shows the renewable versus fossil energy use index for all the plants. Significant renewable energy use is being demonstrated at one facility but will increase as more facilities implement CHP projects using renewable fuels.

Figure 6 shows the electrical energy use index for all the facilities. There is limited data available on electrical energy use because this data is not available publicly. Data from three older plants and two newer plants were provided by facilities. Even with this limited data there is reasonable indication that electrical efficiency is higher in newer plants. If older facilities could achieve an average energy use index of 0.8 kWh/gal, an average sized facility of 32 MGY with an electrical energy use index of 1.0 kWh/gal improving to 0.8 kWh/gal would be worth $300,000 annually based on electricity prices of $0.05/kWh.

Figure 6: Electrical Energy Use Index



Best practices related to energy include the following:

Heat Recovery from Jet Cooker and Distillation

Waste steam from the jet cookers and evaporators can be used in the evaporator system. This is expected to be standard practice in all facilities but could not be confirmed by this study.

Heat Recovery from TO/RTO

Since TO/RTO were added to facilities fairly recently, there are still opportunities to recover the heat in the exhaust gas. The HRSG is the default application for heat recovery when a TO is installed. Other opportunities include boiler economizers, preheating dryer air, or preheating process water.

Ring Dryers (vs. Rotary Dryers)

Rotary dryer technology has been around since the early 20th century. Although more costly, ring dryers consume less energy than rotary dryers because they have less air leakage. Air leakage results in heating air that is not needed for the drying process. The ring dryer also has a centrifugal classifier to remove lighter dry material while keeping wet material in the dryer longer. It is estimated that a ring dryer consumes 5-10% less energy than a rotary dryer.[16]

Use of Renewable Energy

Ethanol facilities have the potential to supply much of their own energy through the use of renewable fuels. Some facilities may use local sources of biomass such as wood waste, corn stover co-products such as corn syrup, or DDGS. For electrical supply, facilities may use wind turbines. The E3 Biofuels facility in Mead, Nebraska was able to supply thermal energy needs from animal waste biogas from a nearby 28,000-head cattle feedlot.[17] Some Minnesota plants are already using renewable energy sources such as wind, wood waste, and corn syrup. Typically, biomass is combusted in a gasifier or boiler as described in the CHP best practice. More work is needed to develop the emissions factors for biomass combustion and the resulting impact on air quality.[18]

Combined Heat and Power (CHP)

When a CHP process is used to produce energy the overall efficiencies can improve from 49% for a conventional facility to 75% for a CHP facility. CHP processes use a combination of natural gas or steam turbines, HRSG, boilers, gasifiers, thermal oxidizers to convert waste heat or steam into electrical power[19]. As of December 1, 2006, there were six ethanol facilities using CHP and at least 10 others in design or under construction in the U.S. In Minnesota, there are four projects either in construction, being tested, or operational. Two Minnesota projects will use biomass such as wood waste, DDGS, corn stover, or corn syrup. One Minnesota facility has replaced the steam pressure-reducing valve with a steam turbine that generates approximately 1 MW of electricity.

The cost to convert an existing plant to CHP is significant. Cost estimates for a 100 MGY facility in Wisconsin were approximately $58 million and the payback was 4.7 years based on a $6/MMBtu price for natural gas.[20] With the volatility of natural gas prices it can be difficult to assume the risk associated with this significant investment. There are efforts by the University of Minnesota to provide more data on the economics of investment in CHP.[21]

Co-location with Steam Power Plants

The waste steam from a conventional power plant can be used in an ethanol facility eliminating the need for a steam boiler and ground water used for steam supply. The Blue Flint Ethanol facility located in Underwood, North Dakota receives waste steam from the Coal Creek station to provide the thermal energy needed. The facility started operations in February 2007.[22]

Elimination of Grain Drying before Grinding

Most ethanol facilities have the capability to dry the incoming corn if it has too much moisture. Wet grain will limit hammermill capacity. One way facilities avoid drying grain is to store the dry grain separate from the wet grain or by setting standards for moisture content of the incoming grain. Then these two feeds can be mixed appropriately so that drying is not required.

Ship WDGS Instead of DDGS

If a facility has customers close to the facility they will not have to dry the WDGS because it will be consumed before moisture degrades the quality of the co-product. This practice saves energy use in the drying process and is fairly common in Minnesota plants. The cost of shipping wet grains is expensive because they contain approximately 60% water. The typical limit on transporting wet grains is 40 to 50 miles.[23] Odors and stormwater runoff related to storage of WDGS are concerns. Shipping WDGS may be a better opportunity for Minnesota facilities because the size of herds is smaller and the size of a typical truckload of wet cake matches the needs of these facilities.

Biomethanators

Process wastewater in the ethanol production process can be reused by incorporating an anaerobic process which converts non-fermentable contaminants in the process water to methane.[24] The methane will offset a small amount of natural gas use and recycle process water. This is a practice that is fairly common in Minnesota plants.

Raw Starch Hydrolysis

Raw starch hydrolysis, or "cold cook enzymes", eliminates the alpha-amylase and glucoamylase enzymes and uses a new enzyme in the starch conversion process eliminating the need for heat required for liquefaction. Since this steam is typically injected into the mash, this practice also reduces water use. This process increases the alcohol content coming out of the fermentation process from the typical value of 10% to values as high as 20%. Additional benefits include less time to complete the fermentation process, less cooling water use during fermentation, and less energy in the distillation process. The process has been incorporated in approximately 17 plants across the U.S. and since the enzymes are produced by two separate companies the costs are more competitive.[25]

Fractionation

Fractionation involves separating the parts of the corn kernel so only the fermentable parts are sent to the starch conversion process. Based on air permit data there is one Minnesota facility that is using this technology. There is a high capital cost associated with fractionation technology. The benefits include the following:

- Increased capacity and yield due to the removal of the non-fermentables from the front end of the process before the starch conversion process[26]
- Reduced fermentation times which results in less cooling water use
- Increased value of the co-products if local markets are available
- Reduced energy for drying DDGS and lower VOC emissions from drying since more solids are removed from the process at the front end[27]
- Reduced VOC emissions and cleaner, more efficient heat exchangers from removing the germ on the front end resulting in fewer oils produced[28]

High Efficiency Stillage Concentration (HESC) System

A typical evaporator system will produce syrup concentrations of 35% solids; the HESC will produce solids concentrations up to 50%. This system is designed to be a retrofit to an existing evaporator system. Mechanical vapor recompression is used to evaporate the water from the syrup. The system will require additional electrical energy for the pumps and compressors but this is offset by the energy savings in the dryer. The system requires a significant capital investment but the return is equally significant. Based on energy savings from the reduced dryer duty alone, the system could save 20% in overall energy consumption. An added benefit is water that normally would be evaporated in the dryer is recovered for reuse in the process. Energy savings result from reduced dryer duty and reduced amounts of steam needed for the evaporation system. This process is relatively new, and more specific information on plant locations was not available.

Use of Variable Frequency Drives (VFD) and High Efficiency Motors

Using VFD for operations that require varying motor speeds will reduce electrical consumption. Use of high efficiency motors will reduce electrical consumption. The Energy Policy Act of 1992 (EPAct) required that motors meet a higher minimum standard of efficiency by October of 1999. Any facility built earlier than 1999 may have an opportunity for energy savings when they replace motors. There are also opportunities for facilities to install premium efficiency motors that are 1-2% more efficient than the EPAct standards.

Advanced Process Control

If the control system can be optimized to reduce bottlenecks in the process more ethanol can be produced for essentially the same energy input. Advanced process control is typically not installed when a facility is initially built but added as a retrofit once facilities are up and running and the location of the bottleneck is determined. This type of retrofit will typically result in a 5% energy savings but requires significant investment. An added benefit is improvement in yield.

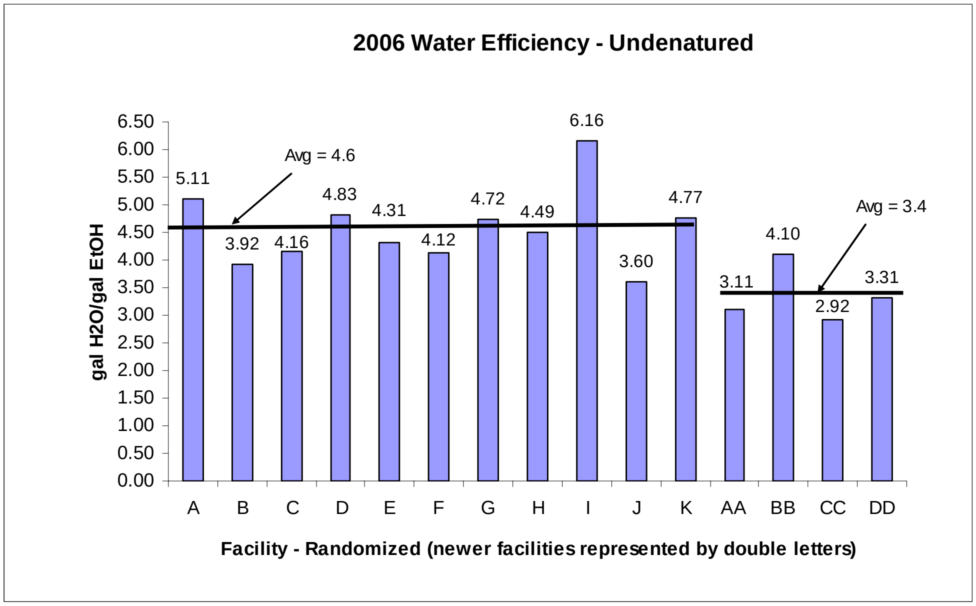
Water Efficiency

Water efficiency is measured as gallons water used per gallon of ethanol produced (gal/gal). All Minnesota facilities withdrawing surface or ground water have a requirement in their water appropriations permit to report annual water withdrawals to the DNR. For this report, the amount of undenatured ethanol produced was estimated from the annual emissions inventory report which required a detailed evaluation of the data. In the past water efficiency was based on ethanol production data from the Minnesota Department of Agriculture (MDA) and based on denatured ethanol production numbers. However, since ethanol facilities add denaturant in amounts ranging from 3-5%, water efficiency was compared using the amount of undenatured ethanol produced.

There have been significant gains in water efficiency in the ethanol industry. Based on publicly reported data the water efficiency of Minnesota dry mills has improved 30% from 1998 to 2006. The average for 1998 was 5.8 gal/gal and in 2006 it was 4.1 gal/gal. There is discussion that 1.5 gal/gal is achievable but no demonstration of this was found in an operating plant.[29] The gains may be due to reductions in the amount of steam use, reductions in cooling water use, reuse of wastewater streams in the process, or higher recycle rates on the cooling tower or RO system. There are limits to the amount of recycling that can be done with the cooling tower or RO system because salts get concentrated in the wastewater streams and may cause harm to the receiving water.

Figure 7 shows the water efficiency for all the facilities in the study. Water efficiency is data for calendar year 2006 except for one facility where the number was estimated because it did not operate the entire year. The overall average was 4.2 gal/gal and the standard deviation was 0.5 gal/gal. The average for the older plants was 4.6 gal/gal and the average for newer plants was 3.4 gal/gal. Since some plants did not participate, it was difficult to determine which best practices had the most impact on lowering water use. The ones observed included raw starch hydrolysis, biomethanators, and no-contact steam systems. Since MnTAP did not have access to incoming water quality at each facility, it is unclear how much the water supply quality affected water efficiency.

Figure 7: Water Efficiency



Best practices related to water use include the following:

Public Records of Water Use

The 2006 IATP study recommended that states maintain publicly available records of water use by ethanol facilities.[30] This practice is already in place in Minnesota through the DNR, but is unique because it appears facilities in other states do not have to report their water use. This study also recommended that water use issues must be discussed openly during the siting process for new facilities. This practice is part of the permitting process in Minnesota.

No-Contact Steam Systems[31] vs. Direct Injection

With these systems the condensed steam is returned to the boiler and reused versus being injected into the process and then later evaporated in the grain drying process. The best example is in the starch conversion process where the jet cooker typically uses direct steam injection to heat the mash, but some facilities will heat the mash using heating coils where the condensate is returned to the boiler. It is expected that this could reduce water use by approximately 45 gpm or 0.6 gal/gal in a 40 MGY facility.

Municipal Wastewater Reuse

An ethanol plant may be able to use the discharge from a MWWTP for non-contact cooling water use. They may not be able to use this water for process water supply because of concerns about DDGS quality degradation. A study by the Metropolitan Council Environmental Services determined that there were enough MWWTP within 10 miles of ethanol facilities to provide a potential supply of 52 million gallons per day (MGD), and the current demand is approximately 6 MGD.[32] This practice has been demonstrated at other industrial sites in Minnesota. In Mankato a new power plant was built near an existing wastewater plant. By recycling 6 MGD of wastewater from the plant, no additional water was needed for cooling, and the power plant needed to obtain fewer permits.[33] Tharaldson Ethanol LLC, in Casselton, N.D., will implement this technology in their 100 MGY facility which is scheduled to start up in December 2008.[34] The water will be piped a distance of 27 miles each way.

High Efficiency Dryer Technology

Dryers that use superheated steam as the heat source can be sealed better to prevent unwanted air leakage that occurs in rotary drum dryers. These dryers send the exhaust vapor to the evaporator system to recover the water removed from the WDGS. The water is then treated so that it can be used as cooling tower makeup water. This system has been in operation since April, 2007 in an ethanol facility in China but without the water treatment component. This system will be installed at the 130 MGY Renew Energy facility in Jefferson, Wisconsin and is scheduled to start up in mid-October, 2007.[35]

Chemical Treatment of Cooling Tower Water

HiCycler is a patented system that is being used in other industrial facilities with cooling towers to remove hardness and silica from the water to greatly increase the recycle rate of water. The closest operation to Minnesota is the Creston Bean Plant in Iowa, which produces biodiesel. There are ethanol facilities where this is being installed in Nebraska and Kansas, but water savings have not been confirmed.

Membrane Technology

Liquid and gaseous phase membranes can replace existing rectifiers, strippers, and mole sieves to reduce water and energy costs. The membrane system can accept ethanol from the beer column, which is only 40% to 50% ethanol, and complete the dehydration process like the mole sieve. This is compared to the mole sieve which can only accept 95% ethanol. This membrane system replaces the rectifier, stripper, and mole sieve to produce significant energy savings. This process has been demonstrated on a pilot scale in an ethanol plant in Canada, but not in a commercial scale facility.[36]

Recycling Discharge Water with Livestock Facilities

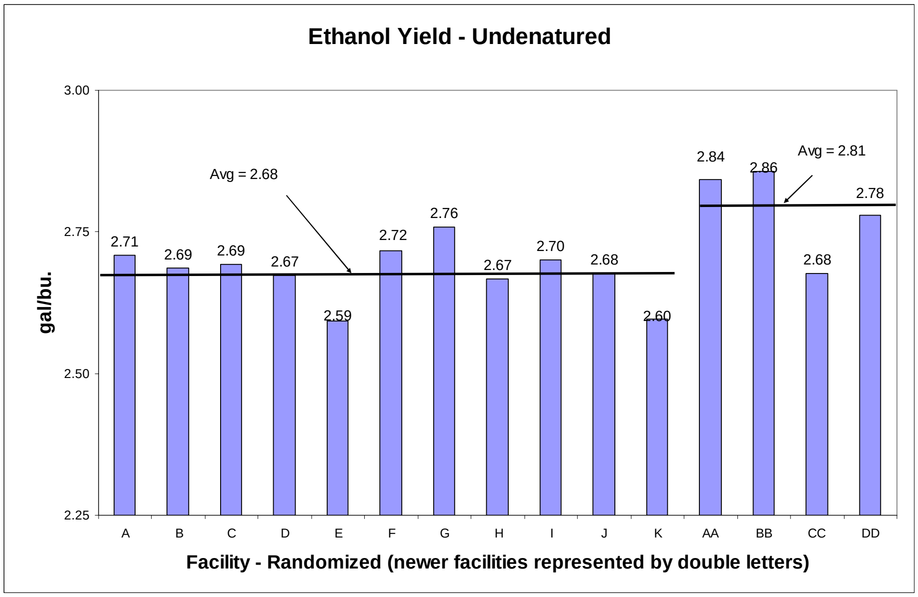
The IATP study recommended ethanol plant wastewater be recycled with livestock facilities that could displace another high use of ground water. This practice will depend on large livestock facilities that are close to the plant. It is not likely that this will happen in Minnesota because typically livestock facilities are relatively small compared to those in other states like Texas or Nebraska.

Yield

Yield is defined as the number of gallons of ethanol that can be produced from a bushel of corn. Yield was calculated by taking the amount of undenatured ethanol produced and dividing by the throughput of corn, as reported on the annual emission inventory report. Twenty years ago the average ethanol plant produced only 2.5 gallons of ethanol per bushel of corn and today a plant using state-of-the-art technology can achieve yields as high as 2.85.[37] The ICM website provides a yield guarantee of 2.67 (2.80 for 5% denaturant) for new facilities.[38] An increase in yield from 2.60 to 2.70 for a 40 MGY facility results in using 600,000 less bushels of corn. This savings is approximately $2 million if corn is $3.25 per bushel.

Figure 8 shows the yield for all facilities. The average yield was 2.71 gallons per bushel of corn (gal/bu) and the standard deviation was 0.08. The average for the older plants was 2.68 gal/bu and the average for newer plants was 2.81 gal/bu. The data shows that all facilities are significantly above the average of 2.50 from the 1980's. Improvements in yield have been primarily due to improved enzymes and better process control.

Figure 8: Yield



Yield is affected by enzymes, process controls, and yeast strains. This project did not include any specific best practices related to yield. Some best practices that reduce energy or water use also improve yields. For example, fractionation provides increased yield while also reducing energy and water use.

Summary

Table 7 provides a summary of the best practices reviewed for this report. Best practices were classified as standard if they were expected to be seen in all plants. The table shows whether they were observed in operating Minnesota operating facilities or in facilities outside Minnesota or if they have only been demonstrated on a pilot scale. Some best practices may not have been documented in an operating plant during this study or the facility using this best practice considered the information confidential. Finally, best practices were identified if they were considered a possible retrofit for older plants or if they required low or high capital cost expenditures.

Table 7 Summary of Best Practices

Description	Standard	Minnesota	Outside Minnesota	Pilot	No Info / Not Demonstrated	Retrofit	Low Capital	High Capital
Water Quality								
On-Site Retention of Storm Water	√							
Segregate Non-Contact and Process Water	√							
Zero Discharge of Process Water	√							
Zero Liquid Discharge Technology			√					√
Low Phosphorus Water Treatment Chemicals					√			
Energy								
Heat Recovery from Jet Cooker and Evaporators	√							
Heat Recovery from TO/RTO	√							
Ring Dryers (vs. Rotary Dryers)		√				√		√
Use of Renewable Fuels		√				√		√
Combined Heat and Power		√				√		√
Co-location with Steam Power Plants			√					
Ship Wet Cake Instead of Dry Cake		√					√	
Biomethanators		√				√		√
Raw Starch Hydrolysis		√				√		
High Efficiency Stillage Concentration (HESC) System					√	√		√
Fractionation		√	√			√		√
Use of Variable Frequency Drives (VFD) and *High Efficiency Motors*		√	√			√	√	
Advanced Process Control		√				√		√
Water Use								
Public Records of Water Use		√					√	
No-Contact Steam Systems		√						
Municipal Wastewater Reuse			√					√
High Efficiency Dryer Technology			√					√
Membrane Technology				√		√		
Recycling Discharge Water with Livestock Facilities					√			

CONCLUSIONS

Fuel ethanol production is a complex energy intensive process, going through a significant growth period throughout the United States. Within the study's constraints of limited time and access, the following conclusions were made about the ethanol industry in Minnesota:

1. Numerical benchmarks indicate that the newer facilities are using fewer resources than older facilities. Table 8 provides a summary of results from this study. The variability in VOC emissions was high and the data had a standard deviation of 1 ton/MG. Therefore the VOC difference for old plants and new plants did not clearly demonstrate improvement.

Table 8: New Plants (2005/2006 startup) vs. Old Plants (1991 – 1999 startup)

Benchmark	Have New Plants Achieved Improvements?	Old Plant Avg	New Plant Avg
Electrical Energy	Clearly demonstrated improvement	1.02 kWh/gal	0.61 kWh/gal
Thermal Energy	Demonstrated improvement	37,000 Btu/gal	29,000 Btu/gal
Yield (undenatured)	Demonstrated improvement	2.68 gal/bu	2.81 gal/bu
Water Efficiency (undenatured)	Demonstrated improvement	4.6 gal/gal	3.4 gal/gal
Water Quality	Demonstrated improvement	*	*
VOC	Not clearly demonstrated	2.4 ton/MG	1.2 ton/MG

* There was no single numerical benchmark for water quality but data trends indicate improvements

2. It is possible to retrofit existing plants to achieve reductions in resource use. This is indicated by the numerical benchmarks achieved by existing plants.
   a. It seems reasonable to assume that best practices could be incorporated at older facilities to achieve an average energy use index of 34,000 Btu/gal. For an average sized facility of 32 MGY this reduction would be worth $750,000 annually based on a natural gas price of $8/MMBtu.
   b. If older facilities could achieve an average energy use index of 0.8 kWh/gal, an average sized facility of 32 MGY with an electrical energy use index of 1.0 kWh/gal improving to 0.8 kWh/gal would be worth $300,000 annually based on electricity prices of $0.05/kWh.
   c. An increase in yield from 2.60 to 2.70 for a 40 MGY facility results in using 600,000 less bushels of corn. This savings is approximately $2 million if corn is $3.25 per bushel, and even higher if corn sustains a price over $4.00 per bushel, as it has in early 2008
3. Low cost actions that will achieve reductions in resource use are possible. Short-term savings are not specific to ethanol facilities but are general practices that apply to all industrial facilities. Examples of short-term savings include steam trap maintenance, use of high efficiency motors, minimizing air compressor leaks, lighting upgrades, and proper steam pipe insulation.
4. Natural gas prices will drive innovation towards further reductions energy consumption. Even though some best practices require a high capital investment, if savings of 20-40% can be achieved, the payback in fuel savings makes these investments attractive. An indirect benefit of many energy conservation measures will be reduced water use (e.g. fractionation or raw starch hydrolysis).

5. Improvements in water quality are being driven by the MPCA's regulatory process. Regulatory oversight has increased as permits get renewed, which should reduce water quality impacts from facilities. Although ground water used in ethanol plants is often of poor quality due to high concentration of TDS, increasing TDS impacts were not foreseen during the initial permitting of ethanol facilities and may be related to increased rates of recycling. Facilities are being required to improve the capabilities of their water treatment processes. Modifying ethanol plants to include treatment for wastewater will be considered the cost of doing business.
6. Reductions in water use cannot be significantly improved by increasing water recycling, but must be dependent on reduced use or recovery of water evaporated in the process. If recycle rates are increased from current levels the concentrations of salts in the discharge water will increase above acceptable discharge levels for many receiving waters. Current TDS levels may already be above acceptable levels.
7. Generally newer and larger facilities should be more efficient, but some older or smaller facilities have been retrofitted and have efficiencies similar to new facilities. There are two older and smaller facilities that have thermal energy use indexes less than 34,000 Btu/gal. , only slightly above the level being guaranteed by new plant designers in 2007.

RECOMMENDATIONS

The following recommendations are specific activities that MnTAP could take to assist the ethanol industry in Minnesota:

1. Support general energy or water efficiency programs related to operations and maintenance. These types of efforts should provide smaller efficiency gains, less than 5%. This could include utilizing existing tools provided by the agricultural research service to conduct process efficiency analysis or department of energy tools to optimize fan or pump operation. This could be supported by a MnTAP intern.
2. Pilot emerging technologies in plants that are willing to try them. This might include advances in leak detection instrumentation that could assist with LDAR programs. This might include water chemistry testing to pilot low phosphate water treatment chemicals or testing to treat discharge waters to remove salt concentrations and increase water recycling rates. This could be supported by a MnTAP intern.
3. Track best practices being demonstrated in single facilities to see if they can be retrofitted to existing plants or incorporated in new plants. Provide case studies on best practices being implemented in Minnesota facilities.
4. Continue benchmarking efforts and provide this data to the industry and public to increase general knowledge about the technical aspects of ethanol plant operation. Detailed benchmarking of the plant process may provide additional indications of specific opportunities for improvements.
5. Provide resources on the MnTAP web page to promote energy conservation or pollution prevention efforts at ethanol facilities.

Reference

[1] Fuel Ethanol Production in the United States, Renewable Fuels Association, http://www.ethanolrfa.org/industry/statistics/#A
[2] Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry, U.S. EPA, July 2003
[3] Modeling the process and costs of fuel ethanol production by the corn dry-grind process, J. R. Kwiatkowski, A.J. McAloon, F. Taylor, D.B. Johnston, August 2005
[4] Feeding Coproducts of the Ethanol Industry to Beef Cattle, North Dakota State University, http://www.ag.ndsu.edu/pubs/ansci/beef/as1242w.htm
[5] Advances in Distillation Equipment and Applications, Daniel R. Summers, P.E., Paper 264b, November 14, 2006
[6] Water Use by Ethanol Plants Potential Challenges, Institute for Agriculture and Trade Policy, October 2006
[7] Factors Associated with Success of Fuel Ethanol Producers, Douglas G. Tiffany and Vernon R. Eidman, August 2003
[8] Granite Falls ground water data reprinted with permission from Granite Falls Energy, LLC. Iowa facility ground water data from Water Implications of Biofuels Production in the United States, 2007, http://www.nap.edu/catalog.php?record_id=12039
[9] Making Water Work, Ethanol Producer Magazine, July 2007
[10] Feeding Coproducts of the Ethanol Industry to Beef Cattle, North Dakota State University, http://www.ag.ndsu.edu/pubs/ansci/beef/as1242w.htm
[11] Wind and Ethanol: Economies and Diseconomies of Scale, John Farrel, Institute for Local Self-Reliance, July 2007
[12] How Much Energy Does it Take to Make a Gallon of Ethanol?, David Lorenz and David Morris, Institute for Local-Self Reliance, August 1995
[13] How Much Energy Does it Take to Make a Gallon of Ethanol?, David Lorenz and David Morris, Institute for Local-Self Reliance, August 1995
[14] The 2001 Net Energy Balance of Corn-Ethanol, Hosein, Shapouri, et. al., U.S. Department of Agriculture.
[15] ICM Performance Guarantees, http://www.icminc.com/pdf/PerformanceGuarantees.pdf, June 2006
[16] From Operating Ease to Operating Costs: Weighing Differences in DDGS Dryers; Ethanol Producer Magazine, June 2007
[17] Cow Power, Ethanol Producer Magazine, July 2007
[18] Emission Factors for Priority Biofuels in Minnesota, Eastern Research Group, Inc., June 30, 2007
[19] Combined Heat and Power, An Energy-Efficient Choice for the Ethanol Industry, http://www.epa.gov/chp/markets/ethanol_fs.html
[20] Replacing Natural Gas with Biofuels in Ethanol Production: Analysis of Options for Western Wisconsin Energy, LLC, Cooperative Development Services and Sebesta Blomberg, April 2007
[21] Biomass for Electricity and Process Heat at Ethanol Plants, http://www.biomasschpethanol.umn.edu/
[22] August a Big Month for Plant Openings, Ethanol Producer Magazine, October 2007
[23] More Producers Choosing to Sell WDG, Ethanol Producer Magazine, October 2002
[24] Diversifying Energy Options, Ethanol Producer Magazine, December 2006
[25] Ethanol Production, A presentation by V. Singh on October 17, 2007, UI Dept of Ag. And Biological Engineering
[26] Corn Fractionation for the Ethanol Industry, Ethanol Producer Magazine, November 2005
[27] Panel Discussion: Innovations in Ethanol, ACE Ethanol Conference and Trade Show, Jeff Lautt, POET, August 7–9, 2007
[28] Corn Fractionation for the Ethanol Industry, Ethanol Producer Magazine, November 2005
[29] Producing Greener Ethanol, Ethanol Producer Magazine, September 2007
[30] Water Use by Ethanol Plants Potential Challenges, Institute for Agriculture and Trade Policy, October 2006
[31] Opportunities to Conserve Water, Ethanol Producer Magazine, February 2007
[32] Minnesota Ethanol Facilities and Wastewater Reuse, Presentation to Stakeholders by Deborah Manning, July 20, 2006
[33] Recycled Wastewater Could Provide Water For Industry, http://www.metrocouncil.org/directions/water/water2007/wastewaterRptAug07.htm
[34] Ethanol Activity picks up in North Dakota, Ethanol Producer Magazine, August 2007
[35] Producing Greener Ethanol, Ethanol Producer Magazine, September, 2007
[36] Industrial Applications Vaperma website, http://www.vaperma.com/industrial_applications/ethanol.php?lang=en
[37] Panel Discussion: Innovations in Ethanol, ACE Ethanol Conference and Trade Show, Jeff Lautt, POET, August 7–9, 2007
[38] ICM Performance Guarantees, http://www.icminc.com/pdf/PerformanceGuarantees.pdf, June 2006