Analysis of the Efficiency of the U.S. Ethanol Industry 2007

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Summary

In 2007, the Renewable Fuels Association (RFA) conducted a survey of US ethanol production plants to provide an assessment of the current US ethanol industry. The survey covers plant operations in both corn dry mills and wet mills. In particular, it includes plant type, ownership structure, capacity, feedstocks, production volumes, co-products, process fuel and electricity usage, water consumption, and products transportation and distribution. The survey response was based on year 2006 data. At the request of RFA, Argonne National Laboratory (ANL) has performed a statistical analysis of the survey data, as an in-kind effort, under a non-disclosure agreement (NDA) between ANL and RFA. During November 2007 and January 2008, ANL processed and analyzed the raw data for statistics. This extended technical memo serves as an official documentation to summarize ANL's analysis.

There were 22 facilities that responded to the survey, representing 1.813 billion gallon of annual fuel ethanol production, which is 37% of the 2006 production (4.9 billion gallons). The results of the statistical analysis from this survey were compared with a Department of Agriculture (USDA) ethanol plant survey conducted in 2001. In comparison to those 2001 findings, the ANL analysis found:

- Ethanol yield per bushel of corn increased 6.4% for dry mills and 2.4% for wet mills.
- Total energy use (fossil and electricity) decreased 21.8% in dry mills and 7.2% in wet mills from 2001 survey.
- Another major change from 2001 survey is 15.7% decrease in grid electricity use in dry mills.
- There is a shift in process fuel use from coal to natural gas in the dry mills.
- More than one third (37%) of the dried distillers grains with solubles (DDGS), the feed co-product of dry mill ethanol production, was sold as wet feed which reduces heat demand in the plant.
- CO_2 collection and production as a co-product is on the rise that a total of 23.5% of the ethanol production capacities responded exported CO_2.
- Finally, water consumption in dry mills decreased 26.6% from 2001 survey.

Results

1. General results

There were 22 facilities that responded to the survey, representing 1.813 billion gallon of annual fuel ethanol production, which is 37% of the 2006 production (4.9 billion gallons). The majority of respondents are Limited Liability Corporations (LLC) - owned dry mills and investor-owned wet mills (Table 1). The data reflects rapid growth of the corn ethanol industry, particularly in dry mills in recent years. Among the respondents, two thirds of dry mill facilities were built after 2001, with a quarter of those undergoing expansion from 2001 to 2007. Corn is still the major feedstock, accounting for 97% of ethanol production. Three percent of ethanol is produced from milo (sorghum).

Table 1. Ethanol plant ownership

Dry mills		**Wet mills**	
LLC	52%	Investor owned	83%
Farmer owned corp.	11%	Public stocks	17%
Investor owned	24%		
Public stocks	13%		

2. Production

There is a considerable variation in production capacity in both dry and wet mills (Table 2). Average scale of dry mills is 52.7 million gallons per year (MMGY) and that for wet mills is 145.9 MMGY (Table 2). A bushel of corn in 2006 generates 2.81 gallons of denatured ethanol in a dry mill and 2.74 gallons in a wet mill. The highest yields from those responding reach 2.96 gallons per bushel (gal/bu) in a dry mill and 2.87 gal/bu in a wet mill. An average dry mill facility processed 17.7 million bushels of corn a year. The amount of corn processed in average wet mill was 52.7 million bushels annually.

Table 2, Ethanol production per plant (MMGY)

	Dry mills	**Wet mills**
Total ethanol production (MMGY)		
Mean ±SD*	52.7 ± 21.6	145.9 ± 92.8
Range	28.7 – 105.5	48.8 – 297.8
Yield (gal denatured ethanol/bushel of corn)		
Mean ±SD*	2.81 ± 0.09	2.74 ± 0.13
Range	2.62 – 2.96	2.51 – 2.87
Corn feed^ (MM Bushel/yr)		
Mean ±SD*	17.7 ± 9.1	52.7 ± 32.7
Range	1.7 – 37.0	16.3 – 106.5

*SD – standard deviation
^Ethanol produced from milo is not included.

3. Co-product

Dried distillers grains with solubles (DDGS) remain a dominant co-product. Increasingly, plants are providing wet DDGS to animal feedlots. Delivery of wet DDGS reduces heating costs for DDGS drying in the ethanol plant. Data shows that more than a third (36.7%) of DDGS is currently sold as wet feed (Table 3). Carbon dioxide (CO_2) as a co-product of ethanol production is on the rise from both dry and wet mills. Dry mills that collect and export CO_2 represent 32% of ethanol production surveyed, which for wet mill is 17%. Together, they represent 23.5% of the ethanol production capacities.

Table 3. Co-products produced from ethanol plant

	Dry mills	**Wet mills**
Co-products production (dry lb/gal)	DDGS	CGF/CGM
Mean ±SD*	5.9 ± 0.8	6.5 ± 2.0
Range	4.7 – 8.1	3.3 – 9.5
Fraction sold as wet feed (%)		
Mean ±SD*	36.7% ± 37.0%	41.1% ± 45.9%
Range	0 – 100%	6 – 100%
Share of facilities exports CO_2 (as ethanol production percentage)^	31.6%	16.9%

*SD – standard deviation
^ Ethanol production share of CO_2 producing facilities in total ethanol production

4. Energy

The average dry mill facility requires 31070 British thermal units (Btu), including electricity, to produce a gallon of fuel ethanol (as a denatured gallon) (Table 4). Electricity usage for dry mills averaged 0.70 kilowatt hours per gallon (kwh/gal). A majority of dry mill facilities (86%) generate heat to produce the steam necessary to run the facility using natural gas (NG), on a Btu basis. The remaining 14% are coal fired dry mills that supplement coal use with a range of NG (3-23%) as process fuel.

For wet mills, 47409 Btu are required to produce a gallon of ethanol (as a denatured gallon). Although wet mills require large amount of electricity, most of them are equipped with co-generation capabilities to meet internal electricity needs and thus reduce net grid electricity demand. Average natural gas and coal use per gallon ethanol produced is presented in Table 4. More energy is needed for ethanol production if coal is the choice of process fuel.

Table 4. Ethanol plant process energy use

	Dry mills	**Wet mills**
Total energy including electricity (Btu/gal[1])		
Mean ± SD[2]	31070 ± 7490	47409 ± 14641
Range	17706 – 44034	28795 – 63422
Electricity[3] (kwh/gal)		

Mean ± SD[2]	0.7 ± 0.35	1.96 ± 0.67
Range	0 – 1.57	0.75 – 2.89
Natural gas [4,6](Btu/gal)		
Mean ± SD[2]	27589 ± 6358	14461 ± 9586
Range	16000 – 36883	3397 – 30830
Coal [5,6](Btu/gal)		
Mean ± SD[2]	29174 ± 1708	30448 ± 21158
Range	27966 – 30381	0 – 58553

1. Denatured ethanol
2. SD – standard deviation
3. Grid electricity for dry mills. Grid and cogen electricity use for wet mills.
4. Ethanol plant fueled with natural gas
5. Ethanol plant fueled with coal also use 3-23% (Btu NG in total Btu use) of NG
6. Most wet mills use both coal and NG as process fuel except one facility that uses 100% NG.

Table 5 shows a break down of process fuel type for dry and wet mills. Natural gas holds 79.2% share in dry mills, followed by coal (12.7%) and grid electricity (7.9%). In wet mills, the predominant fuel is coal (71.6%), followed by natural gas (27.1%). Biogas, tire combustion, residual oil, and liquefied petroleum gas (LPG) as process fuels each represent less than 1.2%.

Table 5. Share of process fuels in ethanol production plants

	Dry mills	**Wet mills**
Grid electricity	7.9%	-[1]
NG	79.2%	27.1%
LPG	0.2%	
Coal	12.7%	71.6%
Residue oil	0.02%	0.04%
Biogas		0.1%
Tire		1.15%

1. Shares of fuel type for wet mill do not include grid electricity because some of the plant data did not differentiate between grid and co-gen electricity. Since almost every wet mill has co-gen capability, the grid electricity required is likely small.

5. Water

According to the survey responses, current dry mills use 3.45 gallons of fresh water to produce a gallon of ethanol (as a denatured gallon). Water use in wet mills is 3.92 gallons per gallon (Table 6). The lowest amount of water use from those respondents is 2.65 gal/gal for dry mill and 1.2gal/gal for wet mill. There are significant variations in water use. Newly built plants tend to require less water, possibly due to improved design. On

average, dry mill requires 14.5 pounds (lbs) of steam to producing a gallon of ethanol (denatured). The steam required in wet mills is 29.5 lbs/gallon.

Table 6. Water and steam use

	Dry mills	Wet mills
Water (gal/gal ethanol)[1]		
Mean ± SD[2]	3.45 ± 0.59	3.92 ± 1.76
Range	2.65 – 4.90	1.20 – 6.10
Steam (lb/gal ethanol)[1]		
Mean ± SD[2]	14.47 ±7.63	29.54 ± 14.47
Range	0.60 – 29.60	13.40 – 45.70

1. Denatured ethanol gallon
2. SD – standard deviation

6. Product transportation and distribution

Ethanol and co-products are shipped to destinations via various transportation modes: truck, barge, rail, and pipelines. As indicated in Table 7, ethanol mills rely heavily on rail to deliver ethanol. Rail shipments are responsible for the transportation of three quarters (74%) of dry mill ethanol production and two-thirds (66%) of wet mill ethanol production. Rail and truck split DDGS delivery, while the majority (76%) of corn gluten feed and corn gluten meal, the co-products of wet mill ethanol production, are transported by truck. Most of the CO_2 from dry mills is shipped via trucks (83%) and remaining by pipelines (17%). In wet mills, half of the CO_2 is delivered through pipeline, 37% by rail, and a small portion (13%) by truck.

Table 7. Average transportation mode for products and co-products

	Truck	Rail	Barge	Pipeline
Dry mills				
Ethanol	26.3%	73.7%		
DDGS	43.5%	56.5%		
Wet cake	100.0%			
CO_2	83.3%			16.7%
Wet mills				
Ethanol	25.0%	66.0%	9.0%	
CGF/CGM	76.0%	1.0%	24.0%	
CO_2	13.0%	37.0%		50.0%

Diesel is the major transportation fuel used for feedstock and product delivery (Table 8). A qualitative representation of the dry mill product distribution is shown in Figure 1. Data for dry mill product distribution is incomplete and therefore not presented. Ethanol produced from wet mills is distributed primarily in Petroleum Administration for Defense District (PADD) 1 (43%) and PADD2 (31%). The rest is distributed to PADD 3 (11%), PADD4 (4%), and PADD5 (11%).

Table 8. Transportation fuel use in dry mills*

	Gasoline	Diesel	LPG	E85
% of total transportation fuel use	13.0%	75.2%	9.4%	2.4%

* Data for wet mills are not available.

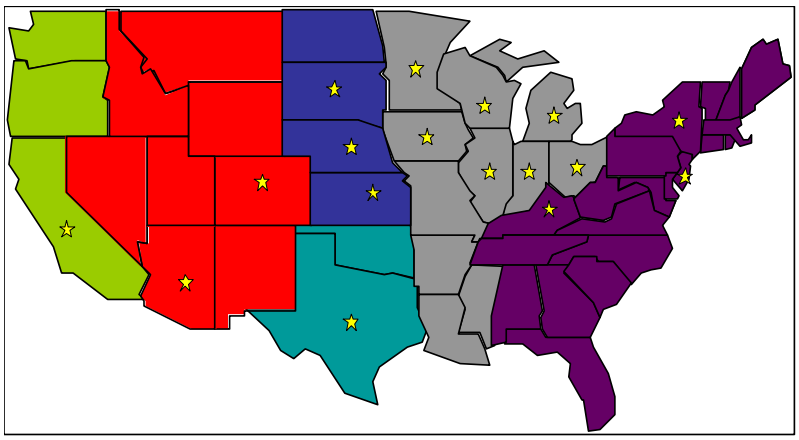

Figure 1. Dry mill ethanol distribution.

7. Comparison to USDA 2001 ethanol plant survey

Based on the survey data and statistics, a comparison was made with USDA 2001 ethanol plant survey for ethanol yield and energy use. Table 9 presents the results of the comparison based on denatured ethanol. Ethanol yield increased 6% for dry mills and 2% for wet mills. Total energy use (fossil and electricity) decreased 21.8% in dry mills and 7.2% in wet mills from 2001 USDA survey. Another major change from 2001 survey is 15.7% decrease in grid electricity use in dry mills. In addition, water consumption in dry mills decreased 26.6% from 2001 survey.

Table 9. Comparison of yield and energy use in ethanol production plant

	Dry mills	Wet mills
RFA 2007 survey		
Yield (gal denatured ethanol /bu)	2.81	2.74
Total energy use (btu/gal denatured ethanol)	31070	47409
Grid Electricity share in total process fuel use	7.9%	NA
Consumptive water use (gal/gal denatured ethanol)	3.45	3.92
2001 USDA survey*		
Yield (gal denatured ethanol /bu)	2.64	2.68

Total energy use (btu/gal denatured ethanol)	39719	51060
Grid Electricity share in total process fuel use	9.4%	0%
Consumptive water use (gal/gal denatured ethanol)**	4.7	NA
Change from 2001 survey		
Yield (gal denatured ethanol /bu)	6.4%	2.4%
Total energy use (btu/gal denatured ethanol)	-21.8%	-7.2%
Grid Electricity share in total process fuel use	-15.7%	
Consumptive water use (gal/gal denatured ethanol)	-26.6%	

* Source: Shapouri, Duffield, and Wang, The energy balance of corn ethanol: An update, USDA AER/814, July 2002.

**Shapouri H., Gallagher, P., July 2005, USDA's 2002 Ethanol Cost-of-Production Survey