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2008 National dry mill corn ethanol survey

Steffen Mueller

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Abstract Emerging regulations require an examination of corn ethanol's greenhouse gas emissions on a life cycle basis, including emissions from energy consumed at the plant level. However, comprehensive survey data of the industry's average performance dates back to 2001, prior to the industry's expansion phase. Responding to the need for updated data, we conducted a survey to collect energy and processing data for average dry mill ethanol produced during 2008. The study finds that the average liter of anhydrous corn ethanol produced during 2008 requires 28% less thermal energy than 2001 ethanol: 7.18 MJ/l compared to 10 MJ/l. Also, 2008 ethanol requires 32% less electricity: 0.195 kWh/l compared to 0.287 kWh/l, but anhydrous ethanol yields from corn are 5.3% higher and total 0.416 l/kg compared to 0.395 l/kg. Findings also suggest that older plants installed energy efficiency retrofits.

Keywords Corn ethanol yield · Ethanol energy balance · Ethanol life cycle

S. Mueller (✉)
Energy Resources Center, University of Illinois, 1308 South Halsted Street, MC 156, Chicago, IL 60618, USA
e-mail: muellers@uic.edu

Introduction

The recently enacted California Low Carbon Fuel Standard (LCFS) and the Federal Renewable Fuel Standard (RFS) require that the greenhouse gas emissions from corn ethanol have to be assessed on a full life cycle basis, which includes emissions from energy consumed at the ethanol plants (California Environmental Protection Agency 2009; United States Environmental Protection Agency 2010). Effective greenhouse gas regulations require sound data on the industry's current performance, which can be established by means of surveys, engineering models, or case studies.

By the end of 2008, a total of 86% of corn ethanol was commercially produced using the dry mill process. Dry mills have traditionally produced two co-products: distillers dried grain with solubles (DDGS), and wet distillers grains with solubles (WDGS). WDGS is high in moisture and therefore requires less drying energy but it is sold more locally since it has a shorter shelf life and higher transportation costs. Both products enter the animal feed market. Literature suggests that over the last 3 years several plants have started to produce a third co-product and separate corn oil for sale for use in biodiesel production (Nilles 2008; Rendleman 2007).

The last comprehensive survey of energy consumption at corn ethanol plants dates back to 2001. The 2001 survey was conducted by BBI International and it was commissioned by the Office of Energy Policy and New Uses, US Department of Agriculture.

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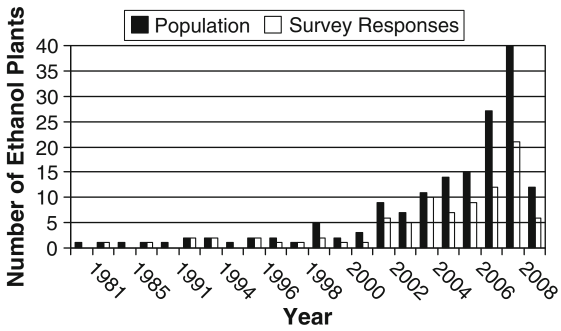

Fig. 1 Plant vintage

The survey results are published in Shapouri (2002) in conjunction with an analysis of the life cycle greenhouse gas emissions of corn ethanol production. The 2001 survey included 17 dry and wet mill plants. Since the 2001 survey there has been a rapid expansion of the dry mill corn ethanol market (see graph of plant population in Fig. 1). As of December 2008, there were 42.2 billion liters of installed ethanol dry mill capacity and 35.2 billion liters of operating dry mill capacity in the US.[1] The present study provides updated industry data in order to inform the emerging regulations.

Methods and materials

Survey sample frame

The survey sample frame was compiled from public sources including the Renewable Fuels Association's database of biorefineries (http://www.ethanolrfa.org/industry/locations/). The survey sample frame consisted of the entire population of dry mill ethanol plants—a total of 150 plants operating during the 2008 calendar year (plus plants starting up in the winter of 2008/2009).

Survey instrument

The survey instrument was developed by the author with input from the ethanol industry (POET, LLC and Renewable Fuels Association) and ethanol life cycle modelers (Michael Wang and May Wu at Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439). The survey instrument was issued to the respondents via a web-based template. The Survey Research Laboratory (SRL) located at the University of Illinois at Urbana-Champaign created the web-based survey template, issued secure survey links to each respondent, and collected the data.

Survey variables

The survey instrument was designed to explore primarily variables pertaining to: (a) energy and processing equipment installed at the ethanol plants; (b) energy consumption, both thermal and electricity; (c) water consumption and water efficiency improvements (not detailed in this publication); as well as (d) products produced by the plants.

Survey response characteristics

In total, 90 dry mill plants responded to the survey representing 23.2 billion liters of operating capacity or 66% of the dry mill survey population of 35.2 billion liters of operating capacity in 2008 (of 150 plants). The missing value rate for questions pertaining to energy consumption was approximately 12%. Two response tests were performed to assess potential bias. The first test determined whether the plant vintage of responses matched the plant vintage of the population since new plant and processing technologies (for example, use of corn oil extraction often increases electricity consumption) may introduce a significant bias.

The histogram of plant start-ups in Fig. 1 confirms that the plant vintage of the responses closely matches the plant vintage of the population indicating that plant vintage does not introduce a significant survey bias. The second test determined whether the geographic location of the responses matched the geographic location of the population. Plant location may influence different technologies and logistics of the production process (vicinity to livestock may increase a plant's WDGS/DDGS co-product ratio). The histogram in Fig. 2 confirms that the plant locations of the responses match the plant location of

[1] Data provided by the Renewable Fuels Association for this study.

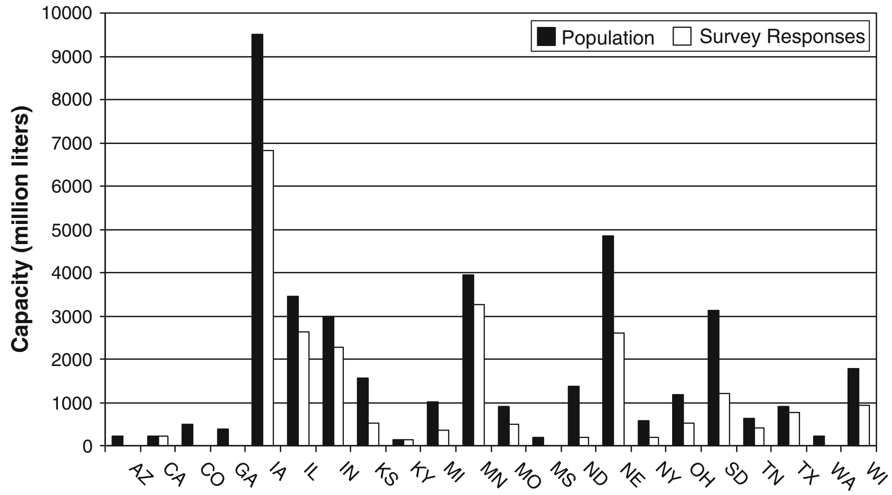

Fig. 2 Plant population by state

the population indicating that geography does not introduce a significant bias.

Results

The survey finds that natural gas-fired energy systems are the predominant thermal energy source for dry mill ethanol plants (used by 73 out of 78 or 94% of valid responses). Five reporting plants use thermal fuel feedstocks other than natural gas (two plants use coal, two use biomass, and one use landfill gas). The average thermal fuel consumption of all responding plants as well as the natural gas consumption of natural gas-fired ethanol plants and the corresponding electricity consumption are shown in Table 1. Numbers shown are weighted by plant capacity as well as simple average by plant count.

The ethanol yield from corn input is summarized in Table 2. The ratio of anhydrous to denatured ethanol reveals that denaturant accounted for 2.5% of denatured ethanol by volume. As usual, numbers shown are weighted by plant capacity as well as simple average by plant count.

Traditionally, dry mill corn ethanol plants produced two co-products: DDGS and WDGS. Over the last few years a third co-product, corn oil, was added. The survey assessed that 30.7% of all ethanol plants have corn oil separation units installed. The average yields of the three co-products for average 2008 corn ethanol are shown in Table 3.

Table 1 Dry mill energy use

	All thermal feedstock plants (MJ/l) anhydrous	Natural gas plants (MJ/l) anhydrous
Weighted average (HHV)[a]	7.97	8.08
Average (HHV)	7.94	8.10
STD (HHV)	1.24	0.95
Weighted average (LHV)[b]	7.18	7.28
N	78	73
	Electricity (kWh/l)	
Weighted average	0.195	0.192
Average	0.200	0.197
STD	0.063	0.061
N	75	70

[a] Higher Heating Value

[b] Lower Heating Value

Discussion

The 2001 survey was representative of 4.9 billion litters or 65% of the industry's capacity during the survey year. The response rate for dry mill only plants was deemed confidential and not stated separately. However, wet milling accounted for 55% of installed capacity in 2001. Therefore, sampling statistics would indicate that the dry mill survey responses were slightly below 65%. Another survey

Table 2 Ethanol yield from corn

	Ethanol yield: anhydrous (l/kg)	Ethanol yield: denatured (l/kg)
Weighted avg.	0.416	0.426
Average	0.419	0.429
STD	0.018	0.019
N	81	78

Table 3 Co-product yields

	DDGS (kg/l)	WDGS (kg/l)	Corn oil (l/l)
Weighted avg.	0.633	0.257	0.006
N	53	53	53

published in Shapouri (2005) included 21 dry mill plants resulting in a much lower response rate of 30% of dry mill capacity. In 2006, Ethanol Producer Magazine conducted a survey, which identified broad technology trends but did not assess energy consumption. That survey's response rate was 44% (43 plants responding out of 97 operating plants). In addition to surveys, data on energy consumption at ethanol plants has been available in the form engineering analyses and case studies (Energy and Environmental Analysis Inc. 2006; Mueller 2006). This type of data was also used for ethanol life cycle assessments (Wang 2007).

Due to the similarly high response rate of our survey we use the 2001 survey as a benchmark. The 2001 survey finds that the average liter of anhydrous corn ethanol produced requires 10.00 MJ/l of thermal energy and 0.287 kWh/l of electricity. In 2001, 1 kg of corn produced 0.395 l of anhydrous ethanol. Ethanol produced in 2008 requires 28.2% less thermal energy and 32.1% less electricity and it requires 5.3% less corn. While the 2001 plant produces two co-products, DDGS and WDGS, which are both sold into the animal feed market, the 2008 plant produces often three co-products (DDGS, WDGS, and corn oil). On average, for each liter ethanol the 2008 plant co-produces at once 0.633 kg DDGS and 0.257 kg WDGS as well as 0.006 l of corn oil.

For further analysis the responses were split into two groups: plants starting operation before 2001, a total of 11 plants (corresponding to the 2001 survey) and plants starting operation after 2001, a total of 67 plants. A One Sample *T*-Test was performed to determine whether or not the mean thermal energy consumption in each sample significantly differ from the mean 2001 thermal energy consumption of 10.00 MJ/l. The significance value for both plant groups is less than 0.05. Therefore, one can conclude that the average reduction of 2.52 MJ/l for the older, pre-2001 plants and 2.89 MJ/l for the post 2001 plants is not due to chance variation, and can be attributed to more efficient technologies. Since the older plant group also shows significant reductions, one must conclude that energy efficiency retrofits were likely installed.

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