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Biofuels in the US: Today and in the Future

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Corn-grain-based ethanol has the real and viable potential of producing 15 billion gallons of ethanol by 2015, leaving a net of 12.3 billion bushels of corn available for feed, food, and export markets. This is up 3.0 billion bushels from 2006 and 0.9 billion bushels from 2007. With the incorporation of near-term technologies and increased corn production, corn-grain-based ethanol is also well poised to remain the lowest-cost ethanol production per gallon of any significant volume. Continued support and investment in corn-based ethanol technologies will assure that this is possible. These technologies, despite decades of research and investment, remain at early stages of economic viability and, near term, will likely carry significantly higher production costs.

Key words: ethanol, corn grain, corn stover, production costs.

By 2015 the US corn market can be expected to support 15B gallons of ethanol from corn grain, utilizing less than a quarter of overall US corn production and leaving a net of 12.3 billion bushels (B bu) of corn available for feed, food, and export markets—up 3.0B bu from 2006 and 0.9B bu from 2007. Unlike the speculation that exists in quantifying what is commercially viable with cellulosic ethanol, this projection is near term and based on a progression of technical results that have already been commercially demonstrated and thus have a high degree of certainty—a 2015 "expected base case" (Table 1). Additional potential exists to demonstrate the ability to economically produce more than 20B gallons of ethanol from corn grain by 2020 with an incremental 3.5B bu of corn available for food, feed, and export use relative to 2006 production—a 2020 "potential case." This potential depends upon, *and should only be allowed if*, (a) the continued improvement in annual corn production yields witnessed since the introduction of corn transgenics, (b) the increased optimization of corn hybrids for ethanol production, (c) the integration into existing ethanol plants of the conversion capabilities for corn kernel fiber to ethanol, (d) other near-term technology advancements that increase product diversification and reduce input costs are incorporated, and (e) increased corn substitution value of the animal feed co-produced with ethanol are achieved. A return to a more balanced year-over-year increase in ethanol production capacity, matched with technology adoption and paralleling corn-grain yield increases, is critical to achieve these goals and to eliminate the 2008 supply/demand imbalance.

Additional, albeit limited, upsides exist for ethanol production from corn if a commercially viable means of processing corn stover to ethanol can be demonstrated (Table 2). The ethanol production upside from corn stover, utilizing one third of the stover from the top 50% of the 90M anticipated harvested corn acres in 2015, only approaches 4.4B gallons (Hoskinson, Karlen, Birrell, Radtke, & Wilhelm, 2006; Nelson, 2002; Wilhelm, Johnson, Hatfield, Voorhees, & Linden, 2004). While corn stover is the most readily available and studied source of biomass to-date, this volume remains only an upside possibility (not included in the base case), as data for the potential harvestable acres and ethanol production at or beyond the laboratory scale do not yet justify the economics for commercialization. Aspects of which corn stover acres can be harvested and what percentage of the corn stalk can be taken while retaining critical soil nutrients, moisture, and erosion protection have yet to be rigorously field tested. Elements of the harvest, collection, transport, and storage (including the necessary equipment) that work for the grower, are logistically feasible, and result in an economically viable feedstock cost have also not been developed or field tested for this limited use in a narrow harvest window. Finally, the ability to convert the cellulosic stover biomass to ethanol presents technical challenges that cannot be assumed solved. These challenges have been the focus of academic and Department-of-Energy-sponsored research for decades without commercial success.

Corn Grain Yield per Acre: Agronomic Productivity

Agronomic productivity reflects the combination of optimized planting rates and nutrient and pesticide applications, in conjunction with the use of hybrids that have been performance optimized. These hybrids reflect

Table 1. Corn grain to ethanol: Base case.

	2006 actual	2007 actual	2015 expected	2020 potential
Grain ethanol produced (B gal)[1]	4.9	6.5	15.0	20.0
Harvested corn grain (MA)[2, 3]	71	87	90	90
Grain yield per acre (bu)[2, 4]	149	151	180	200
Total corn grain produced (Mbu)	10,579	13,062	16,200	18,000
Ethanol yield per grain acre (gal)[5]	398	405	582	650
Net corn grain used for ethanol (Mbu)[6]	1,257	1,670	3,866	5,158
Net corn available for other uses (Mbu)	9,322	11,391	12,334	12,842
Net corn used for ethanol	12%	13%	24%	29%

Note. [1] *Historic production data can be found at the Renewable Fuels Assocition website (www.ethanolrfa.org/industry.statistics). Projected production (15B gal/year) has been established under the Renewables Fuels Standard established in the 2007 Energy Bill.*

[2] *Historic crop production yields can be found via a search tool at the United States Department of Agriculture National Agricultural Statistics Service (USDA NASS) website (www.nass.usda.gov/index.asp).*

[3] *ProExporter forecasts 85M harvested acres from 92M planted acres based on PRX 2007 planting assumptions of 86M acres. These acres were adjusted upwards to reflect current corn prices and the development of corn hybrids making more acres economically attractive for corn production.*

[4] *Fraley (2006), Korves (2008), and Sanders (2007).*

[5] *Assumes 2.73 gallons of absolute ethanol per bushel of corn for current dry grind production and 2.50 gallons of absolute ethanol per bushel of corn for current wet mill production. Assumes 1.3B gallons of ethanol from wet mill production constant over time. Assumes 3.3 gallons of absolute ethanol per bushel of corn for future dry grind production; incorporating corn kernel fiber conversion and high-starch hybrids.*

[6] *Assumes 16.1 lbs/bu of animal feed from wet mill production and 16.5 lbs/bu of animal feed from dry grind production.*

Table 2. Corn stover to ethanol: Additional upside.

	2006	2007	2015	2020
Stover ethanol produced (B gal)	0	0	2.8[8]	4.4[8]
Total corn acres harvested (MA)	71	87	90	90
Corn acres from which stover harvested (MA)	0	0	45	45
% of available stover used (all corn acres)			(15%)	(15%)
Ethanol yield per stover acre harvested (gal)	0	0	15	24

Note. [8] *Sheehan et al. (2004). Utilized current laboratory results of 95% yield from glucose sugars and 85% yield for 2015. 2020 presumes C5 sugars are incrementally converted at 85% yield. Stover corn composition taken from National Renewable Energy Laboratory [NREL] (2002).*

the benefits of years of conventional breeding development as well as the benefits from the introduction of transgenic pest protection that has increased yield and reduced corn-yield variability by minimizing crop damage. Utilizing historic trends that demonstrate a 1.8% annual increase in yield since 1961, yields of 180 bushels per acre are possible by 2015 (USDA NASS website). This provides a conservative estimate of the yield-per-acre potential as yield increases since 2001 have averaged 2.8% annually (USDA NASS website). Utilizing these more recent yield trends and seed company estimates, more than 200 bushels per acre are possible by 2020. Additional upsides exist beyond these forecasts, owing to the substantial increased investment and, thus, advancements in molecular breeding by the corn seed companies that allow for targeted significant advancement in hybrid production yields and reduced inputs (e.g., fertilizer, water) (Fraley, 2007). Similar investments by machinery providers have advanced closer seed planting and nutrient and pesticide applications tailored to the needs of a specific acre.

Ethanol Yield per Bushel: Optimized Grain Ethanol Production

Combining continued process improvements with improved feedstock selection (hybrids specifically selected based on their ethanol yields) and the conversion of corn kernel fiber cellulose to ethanol provides a certain path to ethanol yields per bushel of more than 3.3 gallons, up from 2.73 gal/bu today. Process improvements in ethanol production have to-date already resulted in increased ethanol yields per bushel from 2.4 gal/bu in the early 1980s to 2.8 gal/bu in the best of plants today (Madson & Monceaux, 2003). Hybrids specifically developed by corn seed companies for dry-

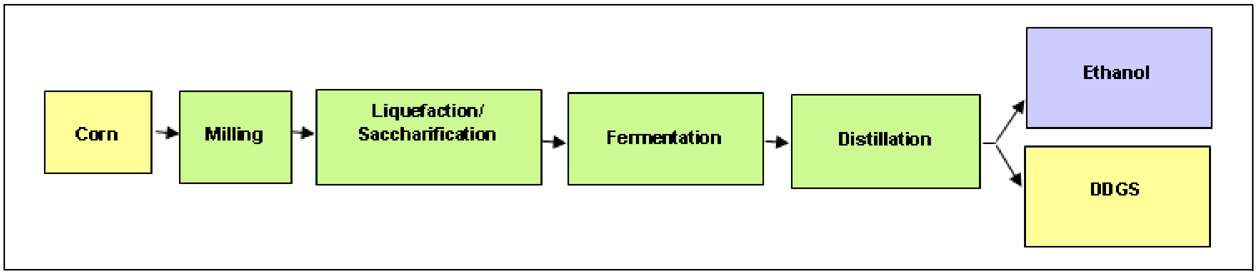

Figure 1. Dry grind fuel ethanol production process.

grind ethanol production have demonstrated commercial ethanol production yield increases of 2.7%.[1] Corn kernel fiber has the potential to increase ethanol yield per bushel by 10-13%.[2] Enzymes are already available that assist in the breakdown and conversion of corn kernel cellulose; corn kernel hemicellulose conversion enzymes and organisms for five-carbon sugar to ethanol are under development as a part of the broader cellulosics research and development effort. With hybrid and plant process optimization, theoretical yields of 3.5 gal/bu are possible with no negative impact on oil or protein content for animal feed uses, and these gallons qualify as cellulosic ethanol. The realization of this cellulosic opportunity is far more certain than other new biomass sources still requiring extensive agronomic and infrastructure development.

Fuel and Feed: Distillers' Dried Grains with Solubles (DDGS)

The use of corn for ethanol production does not require a trade off between harvesting a corn acre for fuel or feed. One of the benefits of utilizing corn, or any grain-based feedstock, for ethanol production is the ability to separate out the starch for conversion to ethanol and to retain the protein, fat, fiber, vitamins, and minerals for use as an animal feed. This co-product of ethanol production, distillers' dried grain with solubles (DDGS) results from the concentration and drying of the components remaining after the starch portion of corn is converted to ethanol (Figure 1). For every bushel of corn processed in a dry-grind facility, on average, 2.73 gallons of ethanol and 16-18 lbs of DDGS are produced. As illustrated in Table 3, per acre of corn harvested, the protein, fat, fiber, and ash present in the original corn are retained for use as an animal feed, albeit in a more concentrated form.[3]

Table 3. Animal feed nutrients from an acre of corn (DM tons/A).

Compositional element	Corn	DDGS
Protein	0.31	0.29
Fat	0.16	0.12
Crude fiber	0.09	0.08
Carbohydrates	2.59	0.67

Note. Assumes 150 bu/A corn yield.

USDA estimates suggest that the theoretical maximum domestic market size for distillers' grains with current feeding recommendations is 40 million metric tons (mmt) (Cooper, 2006). This theoretical maximum assumes 100% market penetration of DDGS in dairy, beef, swine, and poultry markets at inclusion levels of 40%, 40%, 20%, and 10%, respectively. It is important to note that there is by no means universal agreement on these feeding levels and many animal nutritionists would offer much more conservative inclusion numbers.

In 2006, US dry-grind ethanol plants produced 4.9B gallons of ethanol, 72% of overall US ethanol production. Correspondingly, 14.6 mmt of DDGS were produced. USDA FAS records suggest 9% of this was exported. Within the domestic market, 45% of this product was utilized by dairy cattle, 37% by beef cattle, 13% by swine, and 5% by poultry (Markham, 2005). The production of 15B gallons of ethanol from corn grain would result in 37 mmt of DDGS and 50 mmt at 20B gallons.[4]

DDGS co-product sales are critical in minimizing ethanol production costs from corn and in maximizing the substitution of DDGS for corn as an animal feed,

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[1] *Haefele, Owens, O'Bryan, and Sevenich (2004).*

[2] *Ten percent based on theoretical yields of conversion used. Note NREL estimates of up to 13% (NREL, 1993).*

[3] *DDGS compositional data from Rasco et al. (1987).*

[4] *DDGS production for 2015 assumes current levels of ethanol production from wet mills and 2015 ethanol yield per bushel of corn at 3.3 gal.*

which allows for a greater number of corn acres to be taken for ethanol. Increasing global demand of DDGS is critical to maximize the potential of fuel ethanol production from corn grain while ensuring livestock feed needs are met. Corn utilized for ethanol still retains the most expensive components of animal feed usually obtained from ground corn or soybean meal: energy in the form of fat, amino acids in the form of protein, and phosphorous. DDGS is an attractive alternative source of protein, fat, polysaccharides, fiber, and phosphorous. Effective utilization of DDGS as an animal feed is critical to reducing the number of corn acres required for direct feed consumption. Yet, use of this alternative feedsource is limited today because of real and perceived issues relating to DDGS flowability, consistency, quality, and demonstrated feeding/meat quality results. A focus on product quality, consistency within the plant and the separation of the feed components by fractionating the incoming corn grain into germ, bran, and starch is critical to maximizing DDGS value for the ethanol plant and to prevent DDGS supplies from exceeding demand potential.

Recent concerns have developed about the impact on the consumer from the increased price of corn, attributable to the demand on the corn supply coming from ethanol production, as animal feed costs are historically passed through to the consumer. In 2007, the National Corn Growers Association commissioned Advanced Economic Solutions (AES) for an evaluation of the impact of higher corn prices on consumer food prices. AES analysis suggests that at corn prices less than $3.00, there will be no consumer food-price impact. At corn prices between $3.50 and $4.00, AES agrees with USDA estimates of a consumer price increase of 2-3%, with maximum estimates of 5%. Because of the recent increase in corn prices, numerous additional studies have been recently commissioned to address food price concerns (Henderson, 2008; Informa Economics, 2007; Leibtag, 2008). The USDA recently published an analysis indicating that the recent increase in corn prices has been passed through to retail price at a rate less than 10% of the corn price change (Leibtag, 2008). They further indicate that food using corn makes up less than a third of retail food spending, suggesting that when corn prices increase by 50%, food prices would rise less than 1% point per year. For an average box of corn flakes at a price of $5.50 per bushel of corn, corn comprises $0.08 of the total retail price of $4.19/box. The Federal Reserve Bank of Kansas City, in a study released in early 2008, indicated that labor and energy costs account for 80% of the retail food price (Henderson, 2008). They note that in 2005, energy and transportation costs accounted for 8% of retail food costs (Henderson, 2008). Thus, *energy* prices, not corn prices, are the more significant component of increased food prices and reinforce the importance of maintaining our commitment to developing alternative fuels.

Green Ethanol from Corn Grain: Reduced Inputs

Similar to advancements already realized in the more mature sugarcane-to-ethanol industry, the next decade will result in significant reductions in the water and energy required for ethanol production from corn grain. The introduction of hybrids with reduced input needs and the commercialization of ethanol plant energy mining technologies, such as anaerobic digestion and combined heat and power (CHP), suggest that additional production and plant processing economic and energy costs can be reduced if not eliminated from future corn grain-to-ethanol production. Minimizing the external fuel needs of corn to ethanol processing reduces the second highest cost in the production of ethanol from corn grain. Water and energy inputs have already been reduced by up to 50% in the last decade. Additionally, these reductions open up cellulosic ethanol as well as carbon credit benefits to conventional ethanol plants.

Corn Grain to Ethanol: Near Term Technologies

Ethanol plants today are being designed and constructed by engineers bringing a breadth and depth of experience from other industries to what was once a narrow and limited field of research, development, and technology optimization. This cross pollination suggests the next decade will see significant design and engineering advancements that increase throughput, reduce operating costs, and increase product values diversity. Two of the technologies ready for introduction and optimization are fractionation and anaerobic digestion. Anaerobic digestion of the thin stillage stream resulting from separation of solid distillers' grains from the liquid existing after ethanol distillation has the potential to offset the majority of the natural gas use required for dry-grind fuel ethanol production. By feeding this high organic stillage to anaerobes, methane can be produced and used as the plant fuel source. The resulting animal feed has a higher protein content without dilution from the stillage, the overall fossil fuel needs of the plant are reduced as the stillage is no longer being dried on the feed, and the

Table 4. The challenges: Cellulosic ethanol from corn stover.

	Corn grain 2007 actual	Corn grain 2015 potential	Corn stover 2015 theoretical	Corn stover 2020 theoretical
Commercial stage	In operation	Pilot testing	Conceptual/laboratory testing	Conceptual
Capital cost per gallon	\$1.75 - \$2.00[21]	\$1.75-\$2.00[22]	\$7.00[23]	\$5.44[23]
Net feedstock cost per ethanol gallon	\$0.97[24]	\$0.97[24]	\$1.06[25]	\$0.67[25]
Operating cost per ethanol gallon (excluding feedstock/ depreciation)	\$0.60[26]	\$0.42[26]	\$1.22[27]	\$1.22[27]
Enzyme cost (EtOH gal)	\$0.03[28]	\$0.02[28]	\$0.30[25]	\$0.11[25]
Fermentation time (days)	2[28]	1[28]	7[25]	1.5[25]
Natural gas use (BTU/gal)	36,000[29]	0[30]	49,075[25]	49,075[25]
Alcohol content in beer	14-20%	25-35%	4%[25]	8%[25]

Note. [21] *Generally reported numbers on construction cost for 100 MGY ethanol plants resulting from 2006 and 2007 press releases of plant construction.*

[22] *Future ethanol capital costs assumed to be flat as construction costs and demand moderate.*

[23] *2015 cellulosic ethanol based on capital costs for the construction of current DOE projects \$1B for 140 MGY. Cellulosic reported potential costs at \$5.44 have been used for 2020 from NREL (2002). Thus, while the capital costs for stover are dated, they remain lower than the costs reported for the current pilot facilities or the costs of inflation and increased production demand reflective in the change for corn to ethanol conventional construction. This likely offsets any advances in technology that may yet occur, reducing capital costs.*

[24] *2007 corn price of \$3.55 per bushel with a co-product credit of \$0.90 per bushel.*

[25] *Stover feedstock costs were assumed at \$65/ton stover at 15.5% moisture. Yields of 61.25 gallons/ton in 2015 and 97.44 gallons/ton in 2020 were assumed. Yield estimates taken from Sheehan et al. (2004) and NREL (2002).*

[26] *Generally accepted industry fermentation times and operating costs for corn-based ethanol.*

[27] *Pacheco (2006) minus feedstock costs; numbers not decreased in 2020 as no viable means to perceive operating costs would be less than corn to ethanol, fewer plants with more specialized components and inputs.*

[28] *Enzyme company conversations.*

[29] *Standard industry guarantees.*

[30] *2015 operating costs for corn-based ethanol reduced by natural gas use no longer required.*

water remaining can be recycled back into the process, instead of evaporated into the atmosphere.

Fractionation in a dry-grind ethanol plant mimics the more capital-intensive and operationally expensive methodology of a corn wet mill to separate the incoming grain into germ, bran, and starch streams. By processing only the starch stream to ethanol, plant throughput is increased, plant inputs are decreased, and higher-value co-products are produced. The germ can be processed to oil; the protein remaining from the starch fraction utilized as a high-protein animal feed; and the bran is available for corn kernel fiber-to-ethanol conversion, to burn in order to offset some of the plants natural gas use, or in combination with other process streams as an animal feed. Utilizing both technologies not only increases the utility and value of the DDGS produced, but by separating out the lower-value components, these technology introductions reduce the amount of total DDGS production per gallon of ethanol. If all dry-grind ethanol production utilized fractionation, the modified DDGS produced from 15B gallons of total ethanol production would be reduced by 9 mmt, from 37 to 28 mmt. Utilization of both technologies would further reduce the modified DDGS produced.

Corn Stover: Additional Upside

Current reviews suggest that a maximum of 30% of corn stover from corn acres with the highest corn grain yields per bushel have the potential to be economically harvested. Other environmental factors—wind, erosion, and soil moisture—further impact the available acres (Hoskinson et al., 2006; Nelson, 2002; Wilhelm et al., 2004). This provides an estimated 60M tons of corn stover available for ethanol production. Estimates of the available stover do not increase as corn grain yield increases; historic data suggests stover yields decrease as corn yields increase, thus no additional production upside exists without additional high-producing acres being planted (Hoskinson et al., 2006; Nelson, 2002; Wilhelm et al., 2004). In addition to the harvest, collection, and storage, challenges stover presents additional difficulties with its low density, high capital, and conversion costs relative to corn-based ethanol–even with technology advancements. These challenges include liberating the five- and six-carbon sugars from their biomass matrix, creating a fermentation broth clean enough for biological organisms to thrive and thus convert the sugars to ethanol in a reasonable time frame, and concentrating the matrix to allow for isolation of the ethanol from the beer. While costs are likely to decrease with an increased number of plants, the cap of stover utilization at 4.4B gallons suggests at most the construction of a few hundred plants. This limited market will not provide significant opportunities for *high volume* capital cost reductions or commodity enzyme pricing for a specific application competitive with corn-grain ethanol enzymes. Assuming all of the logistical and technical hurdles can be solved, at a minimum, this will require a feedstock cost significantly below that of corn-based ethanol to be economically competitive. Based on other operating cost estimates, and anticipated corn-grain feedstock costs, the feedstock cost of corn stover would need to be approximately $0.22 per gallon (approximately $20/ton, excluding capital depreciation). Current best estimates for stover feedstock costs are $1.06 per ethanol gallon (see Table 4).

Summary

Corn-grain-based ethanol has the real and viable potential of producing 15B gallons of ethanol by 2015, with more corn available for other uses (e.g., food, feed, and export) than exists today. With the incorporation of these near-term technologies and increased corn production, corn-grain-based ethanol is also well poised to remain the lowest-cost ethanol production per gallon of any significant volume. Continued support and investment in corn-based ethanol technologies will assure that this is possible. This potential reflects the extrapolation of tangible agronomic- and process-technology gains already demonstrated field or lab/plant. Continued support and investment in corn-based ethanol technologies will assure this is possible and further address the concerns about ensuring adequate feedstock for fuel, feed, and food. Additional, albeit limited, upside potential of 4.4B gallons of ethanol exists from creating an economically viable means of converting corn stover to ethanol–cellulosic ethanol. These technologies, despite decades of research and investment, remain at early stages of economic viability and will likely carry significantly higher production costs.

References

Cooper, G. (2006). A brief, encouraging look at ‘theoretical’ distillers grains markets. *Distillers Grains Quarterly*, *First Quarter*, 114-117.

Fraley, R. (2006, October). *Untitled*. Presentation to the Citigroup “Ethanol on the Cob” conference, New York.

Fraley, R. (2007, March). *Yield can fuel ethanol explosion*. Presentation at USDA’s Agricultural Outlook Forum *Agriculture at the Crossroads: Energy, Farm & Rural Policy*, Arlington, VA.

Haefele, D., Owens, F., O’Bryan, K., Sevenich, D. (2004, December). Selection and optimization of corn hybrids for fuel ethanol production. In *American Seed Trade Association’s Proceedings of the 59th Annual Corn and Sorghum Research Conference*, Alexandria, VA.

Henderson, J. (2008). What is driving food price inflation? *The Main Street Economist*, *3*(1), 1-5.

Hoskinson, R.L., Karlen, D.L., Birrell, S.J., Radtke, C.W., & Wilhelm, W.W. (2006). Engineering, nutrient removal, and feedstock conversion evaluations of four corn stover harvest scenarios. *Biomass and Bioenergy*, *31*(2-3), 126-136.

Informa Economics. (2007, November). Analysis of potential causes of consumer food price inflation. Memphis, TN: The Renewable Fuels Foundation. Available on the World Wide Web: http://www.ethanolrfa.org/resource/facts/food/documents/Informa_Renew_Fuels_Study_Dec_2007.pdf.

Korves, R. (2008, January). The potential role for corn ethanol in meeting the energy needs of the United States in 2016-2030. ProExporter Network.

Leibtag, E. (2008, February). Corn prices near record high, but what about food costs? *Amber Waves*, *6*(1), 10-15.

Madson, F.W., & Monceaux, D.A. (2003). *Fuel ethanol production*. KATZEN International, Inc.

Markham, S. (2005, February). *Distillers dried grains and their impact on corn, soymeal, and livestock markets*. Presented at the USDA Agricultural Outlook Forum, Washington, DC.

National Renewable Energy Laboratory Brief (NREL). (1993). *NREL getting extra “corn squeezins:” Cooperative agreement uses cellulosic fiber to get more ethanol from corn* (Technology Brief). Golden, CO: Author.

NREL. (2002, October). *Determining the cost of producing ethanol from corn starch and lignocellulosic feedstocks*. Golden, CO: Author.

Nelson, R.G. (2002). Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States—Rainfall and wind-induced soil erosion methodology. *Biomass and Bioenergy*, *22*(5), 349-363.

Pacheco, M. (2006, June). *Invited testimony for the US Senate Committee on Energy and Natural Resources*. Washington, DC.

Rasco, B.A., Dong, F.M., Hashisaka, A.E., Gazzaz, S.S., Downey, S.E., & San Buenaventura, M.L. (1987). Chemical composition of distilllers' dried grains with solubles (DDGS) from soft white wheat, hard red wheat and corn. Journal of Food Science, *52*(1), 236-237.

Sanders, R. (2007, April). *Reducing dependence on feed grains for biofuels*. Presentation at the Farm Foundation's Biofuels, Food & Feed Tradeoffs conference, St. Louis, MO. Available on the World Wide Web: http://www.farmfoundation.org/projects/documents/Sanders41207st.pdf.

Sheehan, J., Aden, A., Paustian, K., Killian, K., Brenner, J., Walsh, M., & Nelson, R. (2004). Energy and environmental aspects of using corn stover for fuel ethanol. *Journal of Industrial Ecology*, 7(3-4), 117-146.

USDA National Agricultural Statistics Service (NASS) website. (n.d.). Available on the World Wide Web: http://www.nass.usda.gov/index.asp.

Wilhelm, W.W., Johnson, J.M.F., Hatfield, J.L., Voorhees, W.B., & Linden, D.R. (2004). Crop and soil productivity response to corn residue removal: A literature review. *Agronomy Journal*, *96*, 1-17.