US Ethanol Production and Use Under Alternative Policy Scenarios
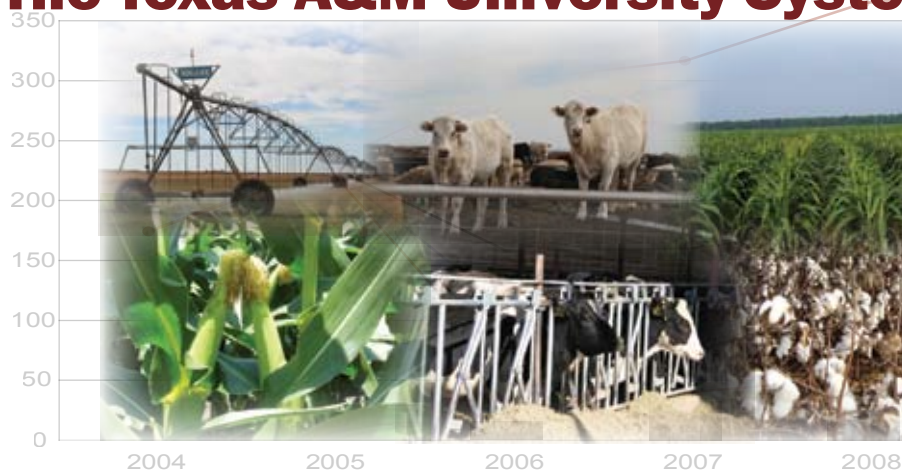
AFPC Research Report 06-1

August 2006

Agricultural and Food Policy Center
The Texas A&M University System

Teaching   Research   Extension

AFPC

US Ethanol Production and Use Under Alternative Policy Scenarios

AFPC Research Report 06-1

Henry Bryant
Joe Outlaw

Agricultural and Food Policy Center
Department of Agricultural Economics
Texas Agricultural Experiment Station
Texas Cooperative Extension
Texas A&M University

August 24, 2006

US Ethanol Production and Use Under Alternative Policy Scenarios

Abstract: Government policy in the U.S. strongly encourages ethanol production. Two prominent policy instruments are currently employed: a federal excise tax credit on each gallon produced and a "renewable fuel standard" (RFS) – a mandate that certain quantities of renewable fuels must be used. Recent market conditionals also encourage ethanol production. This study investigates the extent to which existing government and market-based incentives for ethanol production are redundant, and the levels of ethanol production that would be realized under alternative government program configurations.

Introduction

Ethanol production in the United States has grown dramatically in the last several years, rising from 1.8 billion gallons in 2001 to 3.7 billion gallons in 2005 (Renewable Fuels Association, 2006). Moreover, this rapid growth is poised to accelerate over the next two years as an additional 1.7 billion gallons of annual production capacity that is currently under construction becomes operational (American Coalition for Ethanol, 2006). Many additional projects are in the planning stages, and leading plant design and construction firms are booked through 2009.

Many benefits are perceived to result from the use of ethanol. Relative to the use of straight gasoline as a motor fuel, use of ethanol-blended gasoline results in lower carbon monoxide emission, particulate matter release, and lower tailpipe volatile organic compound (VOC) emission (International Energy Agency, 2004).[1] Production and use of typical US corn-based ethanol results in modestly lower total greenhouse gas (GHG) emission, relative to gasoline (Farrell, et al., 2006). Use of domestically produced renewable fuels reduces dependence on imported petroleum, thus increasing "energy security." Moreover, use of renewable fuels reduces dependence on petroleum-based fuels generally (no matter their origin). This is attractive given growing concerns regarding petroleum depletion and increasing petroleum demand due to rapid economic growth in developing nations.

These perceived benefits motivate the government policy of promoting domestic ethanol production. Two prominent policy instruments are currently employed to this end. First, a federal excise tax credit of $0.51 per gallon produced is available. Second, the Energy Policy Act of 2005 established a "renewable fuel standard" (RFS) - a mandate that certain quantities of renewable fuels must be used. A patchwork of state incentives also exists, including sales tax exemptions, motor fuel excise tax exemptions, producer payments, and use mandates. Numerous new ethanol-related government programs are also under consideration. Most notably, at the federal level, a proposal before the Senate would dramatically increase the mandated level of ethanol use.

---

[1] However, use of ethanol-blended gasoline results in higher nitrous oxide, evaporative VOC, and total VOC emission.

Not all incentives for ethanol production are government sponsored, however. Market conditions in recent years have been such that ethanol has enjoyed a high value as a substitute to gasoline. Crude oil prices approximately quadrupled from 1998 to 2005, and are forecast by many to remain relatively high for the foreseeable future.

This begs the question: to what extent, if any, are the various incentives for ethanol production redundant? For example, is the tax credit necessary? If projected ethanol production in 2006 of somewhat over 6 billion gallons would be realized even in the absence of the tax credit, the federal government will have unnecessarily foregone over $2.5 billion in tax revenue. Even if a tax credit of zero would not result in all of the benefits of ethanol use being realized, some intermediate level of tax credit (between zero and the current level) might. Or, alternatively, given the current level of the tax credit, does the RFS encourage any additional production? Given the market incentives and constraints on the rate at which ethanol production capacity can expand, are the government programs necessary at all?

This study probabilistically forecasts prices and production levels of ethanol for the next several years, under alternative configurations of government programs. Specifically, various alternative levels of the excise tax credit and RFS will be considered, in various combinations, including 1) a base scenario featuring the current levels of both programs, 2) both decreased and increased levels of the RFS (including levels reflecting proposals currently under consideration in congress), and 3) the elimination of both the excise tax credit and RFS. In addition to examining the effects of these alterative scenarios on the ethanol market, the major effects on agricultural markets are also considered.

Simulations are conducted using a model with three major components - fossil fuel markets, agricultural markets, and the ethanol market. Fossil fuel (crude oil and natural gas) prices are taken as exogenous, and observed derivative contract prices (futures and options) are used for probabilistic forecasting. An existing large-scale econometric model of agricultural markets, and simulations conducted using that model, are used to establish agriculture-related forecasts (FAPRI, 2006). Equilibrium displacement methods are used to adjust the levels of relevant agricultural variables emanating from this component based on activity in the ethanol market. The ethanol market component employs a simple mathematical programming approach. Ethanol demand is based on assumed levels of oxygenate use and gasoline prices, which impact fuel extension use. Ethanol supply is based on its cost of production, with natural gas and corn prices being the most important factors.

We first discuss relevant ethanol-related government programs and proposals. After describing the modeling approach, the various scenarios and the likely implications of each are presented.

Government-sponsored Ethanol Incentives

The recent history of ethanol-related federal government programs begins with the Energy Tax Act of 1978, which established an excise tax credit of $0.40 per gallon of ethanol used as motor fuel, at blends of up to 10% with gasoline.[2] The level of the excise tax credit was subsequently raised in increments, reaching its highest level at $0.60 per gallon by 1984. Various decreases from that level began in 1990, with the incentive settling at its present level of $0.51 per gallon in 2005. The American Jobs Creation Act of 2004 guarantees this level through 2010, and additionally removes the restriction that the credit apply to motor fuels blends with a maximum of 10% ethanol. (Collins and Duffield, 2005; Energy Information Agency, 2006; Renewable Fuels Association 2006).

The RFS was established in the Energy Policy Act of 2005. It specifies a schedule of minimum levels of renewable fuels to be used in the US, starting with 4 billion gallons in 2006. This amount increases by 700 million gallons each year through 2010, and 7.4 and 7.5 billion gallons must be used in 2011 and 2012, respectively. Beyond 2012, it is required that the proportion of renewable motor fuel used be equal to or greater than the proportion for 2012. Although rulemaking is not expected to be finalized until early 2007 (Machiele, 2006), the language in the Act suggests that ethanol will be the specific renewable fuel that is responsible for satisfying the RFS, given the quantities of other renewable fuels (especially biodiesel) that the market chooses to produce.

While the federal excise tax credit and RFS are the two primary, broadly applicable programs that provide ongoing incentives for ethanol production and use, there also exist various other federal programs. There are requirements that certain proportions of government vehicle fleets be capable of using alternative fuels, grants to fund research into production of ethanol from alternative feedstocks, and loan guarantees for pilot plants using alternative feedstocks.

Various state incentives also exist. Twenty-two states have either producer payments or income, sales, or excise tax credits/exemptions. State minimum use mandates exist in Hawaii, Minnesota, Montana, Washington (Renewable Fuel News, 2006a; American Coalition for Ethanol, 2006; Renewable Fuels Association, 2006).

The "Biofuels Security Act" (S. 2817) currently under consideration in the US Senate would enhance government-sponsored ethanol incentives, increasing the levels of the RFS for future years. The proposal strikes the previously established RFS schedule, and replaces it with milestones levels of minimum use of biofuels occurring in 2010, 2020, and 2030, at 10 billion, 30 billion, and 60 billion gallons, respectively. The proposal further stipulates that the plan Administrator will determine an appropriate level for the years other than these milestone years.

---

[2] Earlier, in 1862, the Union Congress established a $2 per gallon excise tax on ethanol to help pay for the Civil War. This excise tax was eliminated by the US Congress in 1906 (Energy Information Agency, 2006).

Modeling Approach and Data

The model used in this analysis is an annual model of the interaction between energy and agricultural markets, with most variables measured as US averages. The model has three major components. The first component reflects fossil energy markets. Raw fossil energy prices are taken as exogenous to the other components of the overall model. Observed prices for New York Mercantile Exchange (NYMEX) futures contracts and options on futures are used to develop probabilitistic price forecasts for crude oil and natural gas. Future paths of crude oil and natural gas prices are simulated assuming that spot prices evolve following a geometric Brownian motion. The volatility parameter for this evolution is inferred from nearby option premiums using the Black (1976) option pricing model.[3]

Crude oil and natural gas price forecasts are then used to develop price forecasts for the US average price of premium unleaded gasoline and methanol, respectively. These forecasts are made using simple linear models estimated using annual historical data from 1986 through 2005 for crude oil/gasoline, and 1991 through 2005 for natural gas/methanol. Closing prices for all contracts as of 15 June 2006 are employed.

The second major component of the overall model is the agricultural sector. Probabilistic price and quantity forecasts generated by the large-scale econometric model maintained by the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri are employed for this component. This model represents the interrelationships among domestic and international markets for all major agricultural commodities using approximately one thousand equations. Stochastic output representing five hundred possible futures states of the world are generated using the FAPRI model at least once per year. The FAPRI model is described in Adams (1994) and Brown (1994).

The output of the FAPRI model is adjusted to reflect activity in renewable fuels markets under alternative policy scenarios and fossil energy market conditions using equilibrium displacement methods. In all cases, some levels of ethanol and biodiesel production will already be reflected in the FAPRI output, and the adjustments are to these levels. Price elasticities of demand (own and cross price) and acreage response measurements have been collected from prior literature and averaged.

The chain of displacements to the FAPRI model output for corn and ethanol are as follows. First, the level of corn use for ethanol production emanating from the renewable fuels component of the overall model (discussed below) is compared to the level reflected in the FAPRI output. The difference in these levels is used, in conjunction with the price elasticity of non-ethanol demand for corn to adjust the price of corn. This price

---

[3] Technically, the volatility parameter inferred in this manner is applicable to the nearby futures contract rather than the spot price. The NYMEX contracts considered here have one delivery every month, however, and the nearby contract is thus never far from delivery. Moreover, spot prices for these commodities are often so uncertain that nearby futures prices are generally the best available proxy (Schwartz, 1997).

adjustment follows through to affect the levels of feed and export use.[4] Also, the change in price from the FAPRI scenario is carried forward to affect corn and soybean acres in the following year.

Soybean displacements follow a similar pattern, although the situation is complicated somewhat by crushing relationships. Producers of biodiesel (from virgin soybean oil) are assumed to purchase soybeans and crush them.[5] The price elasticity of non-biodiesel demand for soybeans is used to adjust the soybean price, to the extent that biodiesel production in the renewable fuels components deviates from the level reflected in FAPRI scenario. The price change is then used to adjust the levels of export and (non-biodiesel) crushing use. The price change is also fed forward to affect corn and soybean acres in the following year. The adjusted level of crushing affects the quantities of soybean oil and soybean meal available, and subsequently their prices.

The third major component of the overall model represents the renewable fuels markets. For the ethanol market, supply and demand are obtained from the optimizing behavior of producers and consumers. Demand follows two possible regimes. In one regime, a constraint on the minimum level of use is binding. This minimum level is the greater of the RFS (adjusted for biodiesel production) for a particular year, or the minimum level of ethanol needed for fuel oxygenizing in ozone "non-attainment" areas. Levels of reformulated gasoline (RFG) used in recent years are linearly extrapolated forward, and imputed minimum levels of ethanol use are calculated, assuming that the finished blended motor fuel will contain 5.7% ethanol by volume (this implies approximately 2% oxygen content by weight).[6] These minimum levels of use for coming years are illustrated in Figure 1. Under the current policy scenario, the RFS (and level of biodiesel that is produced) would determine the minimum level of ethanol that must be used, while under alternative scenarios oxygenate use may determine minimum ethanol use. The level of biodiesel to be used in future years is currently specified as an assumed proportion (0.5%) of total on-road diesel fuel use in coming years, which is forecast by linearly extrapolating use in recent years. This reflects the common perception that demand for biodiesel is likely to stem largely from its ability to enhance the lubricity of newly-required ultra-low sulfur diesel (ULSD) fuel. It is quite possible that greater quantities of biodiesel could be consumed, and this reflects a source of uncertainty regarding the model's results.

---

[4] Food, seed, and high fructose corn syrup use are assumed to be unaffected.
[5] The extent to which biodiesel producers will purchase oil versus crushing soybeans themselves going forward is highly uncertain. A single biodiesel plant that is planned for the Houston area will have a production capacity of 1.5 billion gallons per year (Renewable Fuel News, 2006b), as compared to total US production in 2005 of only approximately 75 million gallons (National Biodiesel Board, 2006). The details of the feedstock(s) that this plant will use and how it (they) will be acquired is being intentionally kept secret as of this writing, although it is known that there is limited soybean crushing capacity in the area. Additionally, other projects reflecting more than 700 million gallons of new biodiesel production capacity are scheduled to come online in 2006 and 2007 (National Biodiesel Board, 2006). Thus, there is great uncertainty regarding future biodiesel industry structure and practices.
[6] This reflects the removal of MTBE from use as a fuel oxygenate in the US.

The second regime for ethanol demand reflects fuel extension use, whereby ethanol is consumed as a substitute for gasoline. After accounting for differences in energy content, ethanol is nearly a perfect substitute for premium unleaded gasoline.[7] As such, rational consumers will consume ethanol to the extent that its price is less than that of premium gasoline, and the price of gasoline will effectively serve as a floor for ethanol prices (on an energy equivalent basis). Undiluted conventional (i.e., not reformulated or oxygenated) unleaded gasoline contains 125,071 British thermal units (BTU) per US gallon, while fuel ethanol contains 84,262 BTU per US gallon (Energy Information Administration, 2005). These values are used in conjunction with per gallon prices for these fuels to calculate per BTU prices. The demand schedule for ethanol, reflecting these two demand regimes, is illustrated in Figure 2.

Supply of ethanol is based on ethanol production technology, throughput prices, the excise tax exemption, and industry structure. The model contains two representative production technologies, wet and dry corn milling. Technical coefficients and unit costs associated with these technologies are based on averages of measurements from numerous sources (Althoff, Ehmke, and Gray, 2003; BBI International, 2001; Butzen and Hobbs, 2002; Coltrain, 2002, 2004; Crooks, 1997; Fortenbery, 2004; Frazier, 2002, 2003; Gerpen et al., 2004; Haas et al., 2006; Henderson, Kosstrin, and Crumb, 2006; Keeney and DeLuca, 1992; Kim and Dale, 2002, 2005; Lorenz and Morris, 1995; Marland and Turnhollow, 1991; McNew and Griffith, 2005; Morris and Ahmed, 1992; Nelson, Howell, and Weber, 1994; Patzek et al., 2005; Pimentel, 1991; Radich, 2004; Shapouri, Duffield, and Graboski, 1995; Shapouri, Duffield, and Wang, 2002; Shapouri, Gallagher, and Graboski, 2002; Sheehan et al., 1998; Strong, Erickson, and Shukla, 2004; Tiffany, 2001; Tiffany and Eidman, 2003; Tong and Porter, 2002; Tyson et al., 2004; VanWechel, Gustafson, and Leistritz, 2003; Wang, Saricks, and Santini, 1999; Whims, 2002; Wooley, 1999; Ye, 2000; Zappi et al., 2003). Industry structure information consists of the current nationwide production capacity for each of the two technologies. Total capacity as of May 2006 is 4.8 billion gallons per year (Renewable Fuels Association, 2006; American Coalition for Ethanol, 2006), of which approximately 1.3 billion gallons is wet mill (Urbanchuk, 2006). Ethanol production capacity for 2006 and 2007 reflects this existing capacity and new capacity that is currently under construction. After 2007, expansion of annual production capacity is assumed to occur at the rate of 1,500 million gallons per year.

The quantity of ethanol produced in each year is determined in sequence, from earliest to latest, with the impacts of ethanol production in agricultural markets feeding forward to the following years. For each year, the range of feasible ethanol production quantities is evaluated for possible solutions. If the marginal cost of ethanol production is above its imputed gasoline substitution value (net of the excise tax exemption) for all feasible quantities, then the minimum production constraint is binding (i.e., the quantity required for either the RFS or minimum oxygenate use will be produced). This is illustrated in Figure 3 (supply schedule a). If the marginal cost of production is below the imputed gasoline substitution value, then the maximum production constraint (based on

[7] Premium unleaded gasoline is more like ethanol than regular unleaded gasoline, owing to ethanol's high octane rating.

production capacity) is binding (supply schedule c). Finally, there may be an interior solution where some level of production results in a marginal cost that just equals the imputed gasoline substitution value (supply schedule b).

The supply schedule is upward sloping in spite of the fixed proportions production technology due to the fact that ethanol production must bid corn away from other uses, which is increasingly expensive as more corn is used. The marginal cost of ethanol production is reduced by the amount of the federal excise tax exemption and an assumed average level of state incentives of $0.03 per gallon.

Policy Scenarios and Results

Five policy scenarios are evaluated. First, we evaluate the current configurations of the RFS and excise tax exemptions, assuming that they are preserved in their present forms indefinitely (i.e., the excise tax exemption will be renewed and will apply after 2010). Second, we evaluate a scenario in which the excise tax exemption is eliminated. The third scenario looks at the effects of eliminating the RFS exemption. A fourth scenario considers the elimination of both the RFS and the excise tax exemption.

Finally, the fifth scenario considers the effects of the successful passage of senate bill S. 2817, and the increases in the RFS specified therein. As discussed above, the bill stipulates that 10, 30, and 60 billion gallons of biofuels will be produced in 2010, 2020, and 2030, respectively, and that the plan Administrator will determine the required levels for other years. We assume that for 2006 the level specified in the current RFS is maintained, and linearly increases to the 2010 level. We further assume linear increases in the RFS between the 2010 and 2020 levels.

Mean values across the five hundred stochastic runs were calculated for several key variables. Likely levels of ethanol use under the five scenarios are depicted in Figure 4. Under all scenarios, it is likely that the US will steadily increase ethanol production to some level above 10 billion gallons by 2012. The presence or absence of the excise tax exemption appears to have a greater impact on expected levels of ethanol use than alternative levels of the RFS. Scenarios that maintain the excise tax exemption result in likely levels of production of roughly 13 to 14 billion gallons in 2012, while those that do not include the exemption result in levels of production of roughly 10 to 11 billion gallons.

Expected ethanol prices under the five scenarios are presented in Figure 5. Again, the presence or absence of the excise tax exemption divides the results into two similar groups, with ethanol prices being lower by roughly the amount of the excise tax exemption when it is absent. In all scenarios the ethanol price is expected to gradually increase over the next few years. The levels of ethanol prices in most iterations reflect the perfectly elastic demand regime in which ethanol is used extensively as a gasoline substitute and production is at full capacity. Thus, the ethanol prices plotted in Figure 5 are closely related to expected levels of petroleum prices (taking ethanol's lower energy content in to account).

Expected corn prices are plotted in Figure 6. Under all scenarios, substantial increases in corn prices are anticipated. Scenarios including the excise tax credit result in prices over $3.50 per bushel in 2012, while other scenarios result in prices only somewhat over $3.00 per bushel. Prices under the S. 2817 scenario are highest of all at nearly $4.00 per bushel in 2012. At expected levels of petroleum prices, demand for corn derived from ethanol production is likely to be substantial and highly inelastic, and ethanol producers will pay to bid corn away from competing uses.

Expected feed use of corn and corn exports are depicted in Figures 7 and 8. Even as overall corn production increases (not shown), these traditional uses of corn are expected to decline as ethanol production increases. The decline is gradual for feed use, with 2012 levels expected to be less than 10% below current levels. The decline is more dramatic for exports, with declines of roughly 25% from current levels by 2012 in scenarios where the excise tax credit is maintained.

Further insight into possible outcomes under alternative configurations of government programs is gained by examining the distributions of some variables over all iterations. The cumulative distribution functions (CDFs) for the five scenarios over all iterations for total cumulative ethanol production over 2006 through 2012 are presented in Figure 9. In all scenarios, cumulative probability increases to unity at just under 69 billion gallons due to the production capacity constraints and assumptions regarding the rate of industry expansion. If the excise tax credit was removed, there would be approximately a 25% chance that cumulative production over this time frame would be under 50 billion gallons. In the absence of either of the two major government incentives, cumulative production could even fall below 30 billion gallons in the presence of greatly reduced petroleum price and below trend corn yields. By contrast, with the excise tax exemption in place, there is little probability of total production falling below 50 billion gallons. Under S. 2817, we are virtually guaranteed cumulative ethanol production of more than 60 billion gallons over 2006 through 2012, which represents essentially the full output of all existing plants and all plants that can be feasibly constructed over the forecast horizon.

CDFs for the average corn price over the period 2006 through 2012 over all trials for the five scenarios are presented in Figure 10. Under all scenarios, the average corn price distributions suggest prices are quite likely to be substantially higher than they have averaged in recent years. The five CDFs almost fail to cross one another, and can therefore be ranked by the first-order stochastic dominance criterion for most pairs of scenarios. From the point of view of a corn producer, the S. 2817 scenario is clearly the most preferred scenario, while the scenario with no RFS and no tax credit is least preferred. The average price of corn is unlikely to be less than $2.50 per bushel under the former scenario, but may well be so under the latter.

The CDFs in Figure 10 also illustrate the effects of alternative government policy configurations on corn price uncertainty. The corn price is more uncertain under reduced government incentives for ethanol production, as ethanol production is freer to alternate between high and low output levels reflecting high and low petroleum prices. By

contrast, more government incentives serve to reduce the probability that low output conditions will be encountered. In the extreme, S. 2817 essentially requires that all existing and anticipated ethanol production facilities run at full capacity, and the possibility of low ethanol output levels is essentially eliminated.

Conclusions

Our results suggest that substantial increases in levels of ethanol production and use would be likely in coming years, even in the absence of government programs, due to the powerful market-based incentives that are likely to continue for some time. Broadly speaking, between the two major federal government programs the excise tax exemption has a greater impact on likely market outcomes than the RFS. The elimination of the former would reduce expected ethanol production somewhat, while the effects of alternative levels of the latter are generally fairly small. Expected outcomes in agricultural markets under the alternative scenarios are commensurate with the levels of ethanol production in those scenarios.

That the government-based incentives have only modest impacts on expected levels of ethanol production does not imply that those incentives are redundant given the market incentives, however. Substantial decreases in petroleum prices or years of poor corn production could result in diminished profitability for ethanol producers, and substantially reduced levels of production in the absence of government incentives. If such market conditions were protracted, ethanol industry contraction would be likely, reducing the ability of the industry to resume high levels of ethanol production in the event that favorable conditions resumed. In this regard, the government-based incentives can be thought of as ensuring that any benefits of ethanol production and use will be realized, even as conditions in agricultural and fossil energy markets evolve.

References

Adams, G. M. (1994): "Impact Multipliers of the US Crops Sector," Unpublished Ph.D. dissertation, University of Missouri.

Althoff, K., C. Ehmke, and A. Gray. "Economic Analysis of Alternative Indiana State Legislation on Biodiesel." Center for Food and Agricultural Business, Department of Agricultural Economics, Purdue University, July 2003.

American Coalition for Ethanol (2006), website www.ethanol.org accessed on May 3, 2006.

BBI International. *Ethanol Plant Development Handbook*. Cotopaxi, CO: BBI International, 2001.

Black, F. (1976), "The Pricing of Commodity Contracts," *Journal of Financial Economics*, 3:167-179.

Brown, D. S. (1994): "Structural Models of US Livestock and Dairy," Unpublished Ph.D. dissertation.

Butzen, S., and T. Hobbs. "Crop Processing III: Wet Milling." Crop Insights. Pioneer, 2002.

Collins, K. J. and Duffield, J. A. (2005), "Energy and Agriculture at the Crossroads of a New Future," in *Agriculture as a Producer and Consumer of Energy* (Outlaw, J.; Collins, K.; and Duffield, J.; eds.)

Coltrain, D. "Biodiesel: Is it Worth Considering?" Paper presented at Risk and Profit Conference, Mahattan, KS, August 15-16, 2002.

Coltrain, D. "Economic Issues with Ethanol, Revisited." Department of Agricultural Economics, Kansas State University, September 2004.

Energy Information Agency (2005), *Annual Energy Review 2004*, US Depatment of Energy, Washington, DC.

Crooks, A. C. "Cooperatives and New Uses for Agricultural Products: An Assessment of the Fuel Ethanol Industry." United States Department of Agriculture: Rural Business-Cooperative Service, September 1997.

FAPRI. "Implications of Increased Ethanol Production for U.S. Agriculture." College of Agriculture, Food and Natural Resources, University of Missouri, Columbia, August 22, 2005.

FAPRI. "FAPRI 2006 U.S. and World Agricultural Outlook," FAPRI Staff Report 06-FSR 1. Food and Agricultural Policy Research Institute, Iowa State University and University of Missouri-Columbia, January.

Farrell, A. E.; Plevin, R. J.; Turner, B. T.; Jones, A. D.; O'Hare, M. O.; Kammen, D. M. (2006), "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, 311(27 January): 506-508.

Fortenbery, R. T. "Biodiesel Feasibility Study: An Evaluation of Biodiesel Feasibility in Wisconsin." Staff Paper. University of Wisconsin-Madison Department of Agricultural & Applied Economics, August 2004.

Frazier, R. "Biodiesel Production Potential in Michigan and Ohio." Paper presented at Ohio/Michigan Biofuels Conference, Perrysberg, Ohio, December 2002.

Frazier, R. "Statewide Biodiesel Feasibility Study Report." Frazier, Barnes, and Associates, October 20, 2003.

Gerpen, J. V., et al. "Biodiesel Production Technology." Subcontractor Report. National Renewable Energy Laboratory, July 2004.

Haas, M. J., et al. "A Process Model to Estimate Biodiesel Production Technology." Bioresource Technology 97, no. 4(2006): 671-678.

Henderson, M., H. Kosstrin, and B. Crumb. "Corn to Ethanol: Production Process & Operations and Maintenance Costs." R. W. Beck, March 2006.

International Energy Agency (2004), "Biofuels for Transport: An International Perspective." Monograph, Organization for Economic Co-operation and Development, Paris, France

Keeney, D. R., and T. H. DeLuca. "Biomass as an Energy Source for the Midwestern U.S." American Journal of Alternative Agriculture 7(1992): 137-143.

Kim, S., and B. E. Dale. "Allocation Procedure in Ethanol Production System from Corn Grain." The Internation Journal of Life Cycle Assessment 7, no. 4(2002): 237-243.

Kim, S., and B. E. Dale. "Environmental Aspects of Ethanol Derived from No-Tilled Corn Grain: Nonrenewable Energy Consumption and Greenhouse Gas Emissions." Biomass Bioenergy 25(2005): 475-489.

Lorenz, D., and D. Morris. "How Much Energy Does it Take to Make a Gallon of Ethanol?" Institute for Local Self-Reliance, 1995.

Machiele, P. (2006), "The Renewable Fuels Standard," presentation given by the Director of the Fuels Center at EPA's Office of Transportation and Air Quality at the 11th Annual National Ethanol Conference, Las Vegas, Nevada, February 21

Marland, G., and A. F. Turnhollow. "CO2 Emissions From the Production and Combustion of Fuel Ethanol From Corn." U.S. Department of Energy, February, 1991.

McNew, K., and D. Griffith. "Measuring the Impact of Ethanol Plants on Local Grain Prices." Review of Agricultural Economics 27, no. 2(2005): 164-180.

Morris, D., and I. Ahmed. "How Much Energy Does it Take to Make a Gallon of Ethanol?" Institue for Local Self-Reliance, December 1992.

Nelson, R., S. A. Howell, and J. A. Weber. "Potential Feedstock Supply and Cost for Biodiesel Production." Paper presented at National Bioenergy Conference, Reno, Nevada, October 2-4, 1994.

Patzek, T. W., et al. "Ethanol from Corn: Clean Renewable Fuel for the Future, or Drain on Our Resources and Pockets?" Environment, Development and Sustainability 7(2005): 319-336.

Pimentel, D. "Ethanol Fuels: Energy Security, Economics, and the Environment." Journal of Agricultural and Environmental Ethics 4(1991): 1-13.

Radich, A. "Biodiesel Performance, Costs, and Use." Energy Information Administration, August 2004.

Renewable Fuel News (2006a), "State Motor Fuel Taxation and Regulation," 23(no. 18, 1 May): 13.

Renewable Fuel News (2006b), "Dynoil Plans to Build World's Largest Biodiesel Plant," 23(no. 19, 8 May): pp. 1, 6.

Renewable Fuels Association (2006), website www.ethanolrfa.org accessed on May 3, 2006.

Schwartz, E. S. (1997), "The Stochastic Behavior of Commodity Prices: Implications for Valuation and Hedging," *Journal of Finance,* 52:923-974.

Shapouri, H., J. A. Duffield, and M. S. Graboski. "Estimating the Net Energy Balance of Corn Ethanol." U.S. Department of Agriculture, Economic Research Service, Office of Energy, July 1995.

Shapouri, H., J. A. Duffield, and M. Wang. "The Energy Balance of Corn Ethanol: An Update." U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses., July 2002.

Shapouri, H., P. Gallagher, and M. S. Graboski. "USDA's 1998 Ethanol Cost-of-Production Survey." U.S. Department of Agriculture, January 2002.

Sheehan, J., et al. "Life Cycle Inventory of Biodiesel and petroleum Diesel for Use in an Urban Bus." Final Report. National Renewable Energy Laboratory, May 1998.

Strong, C., C. Erickson, and D. Shukla. "Evaluation of Biodiesel Fuel." College of Engineering, Montana State University – Bozeman, January 2004.

Tiffany, D. G. "Biodiesel: A Policy Choice for Minnesota." Staff Paper. Department of Applied Economics, College of Agriculture, Food and Environmental Sciencies, University of Minnesota, May 2001.

Tiffany, D. G., and V. R. Eidman. "Factors Associated with Success of Fuel Ethanol Producers." Department of Applied Economics, College of Agicultural, Food, and Envirnomental Sciences, University of Minnesota, August 2003.

Tong, L., and S. Porter. "The Biodiesel Plant Development Handbook." Independent Business Feasibility Group, LLC, November 2002.

Tyson, K. S., et al. "Biomass Oil Analysis: Research Needs and Recommendations." Technical Report. National Renewable Energy Laboratory, June 2004.

Ubranchuk, J. M. (2006), "Contribution of the Ethanol Industry to the United States Economy," LECG, LLC, Wayne, Pennsylvania, February 21.

VanWechel, T., C. R. Gustafson, and F. L. Leistritz. "Economic Feasibility of Biodiesel Production in North Dakota." Paper presented at American Agricultural Economics Association Annual Meeting, Montreal, Canada,, July 27-30, 2003.

Wang, M., C. Saricks, and D. Santini. "Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions." Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, January 1999.

Whims, J. "Ethanol Case Prelude." Department of Agricultural Economics, Kansas State University, May 2002.

Wooley, R., et al. "Process Design and Costing of Bioethanol Technology: A Tool for Determining the Status and Direction of Research and Development." Biotechnology Progress 15, no. 5(1999): 794-803.

Ye, S. "Supply and Demand of Soybeans as Feedstocks for Soy Diesel." Market Research
Report. Agricultural Marketing and Development Division, Minnesota
Department of Agriculture, June 2000.

Zappi, M., et al. "A Review of the Engineering Aspects of the Biodiesel Industry."
Mississippi University Consortium for the Utilization of Biomass MSU
Environmental Technology Research and Applications Laboratory, Dave C.
Swalm School of Chemical Engineering, Mississippi State University, August
2003.

Figure 1: Approximate Minimum Use of Ethanol as a Fuel Oxygenate and the Current Renewable Fuel Standard
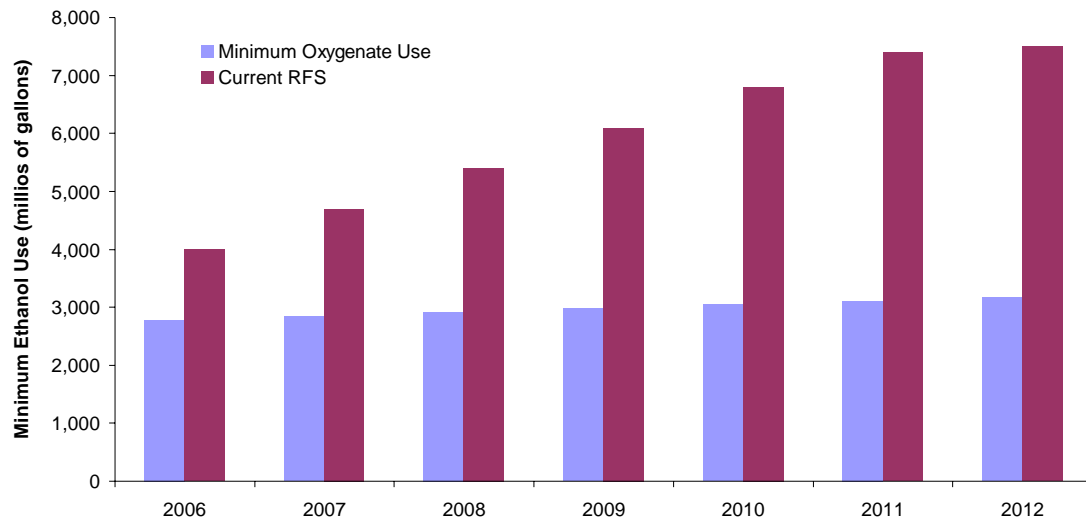
Figure 2. Demand for Ethanol
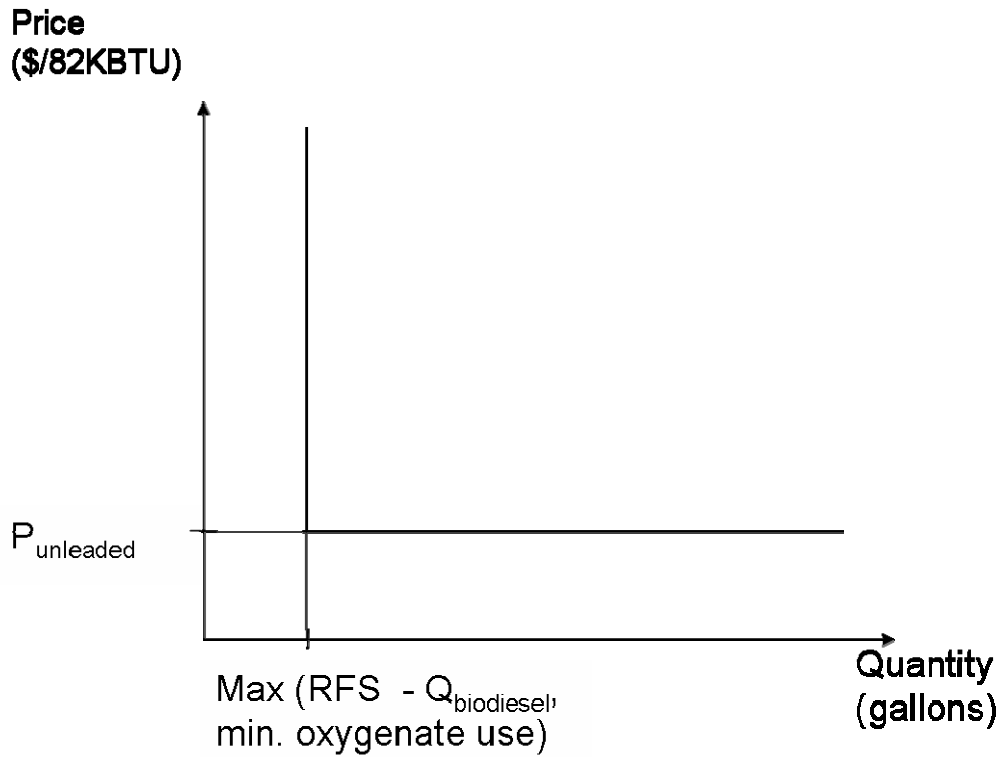
Figure 3. Possible Ethanol Market Equilibria
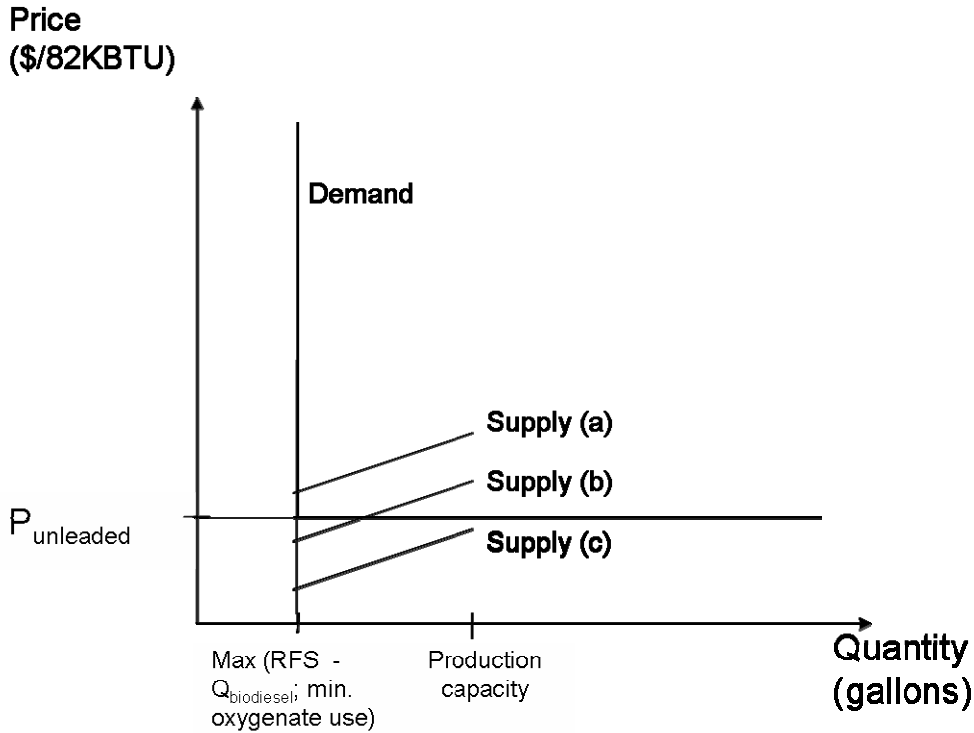
Figure 4: Expected Ethanol Production and Use Under Alternative Scenarios
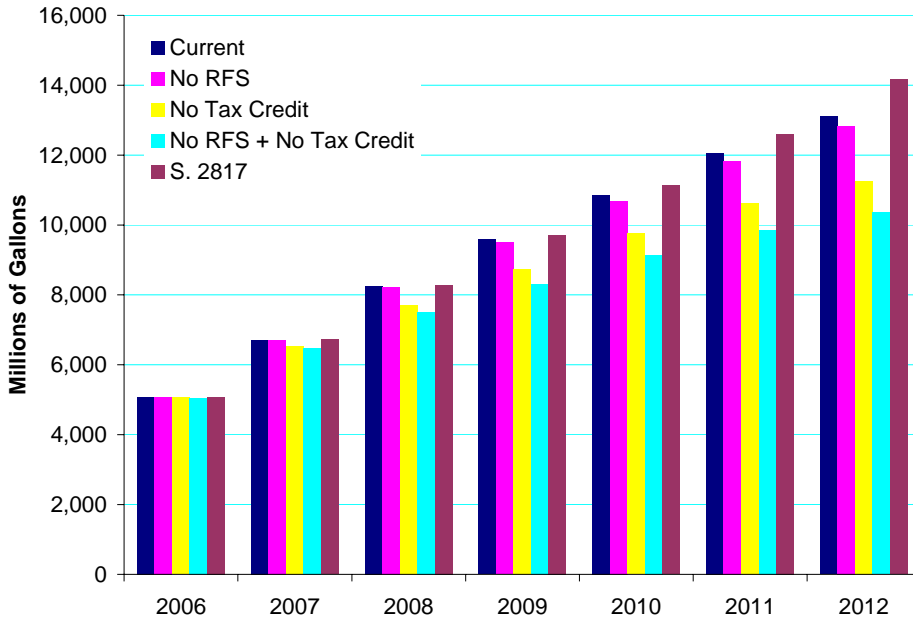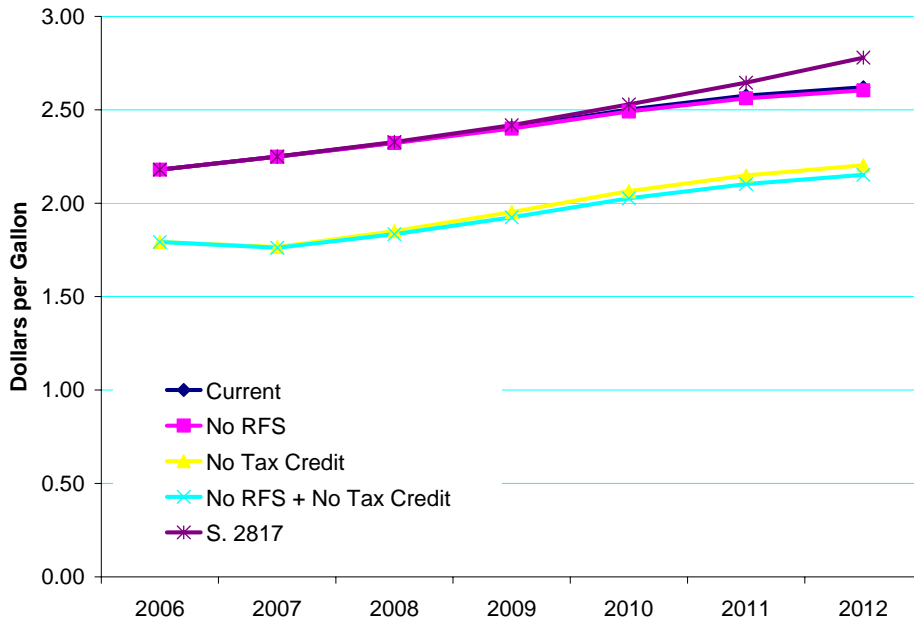
Figure 5: Expected Ethanol Price Under Alternative Scenarios

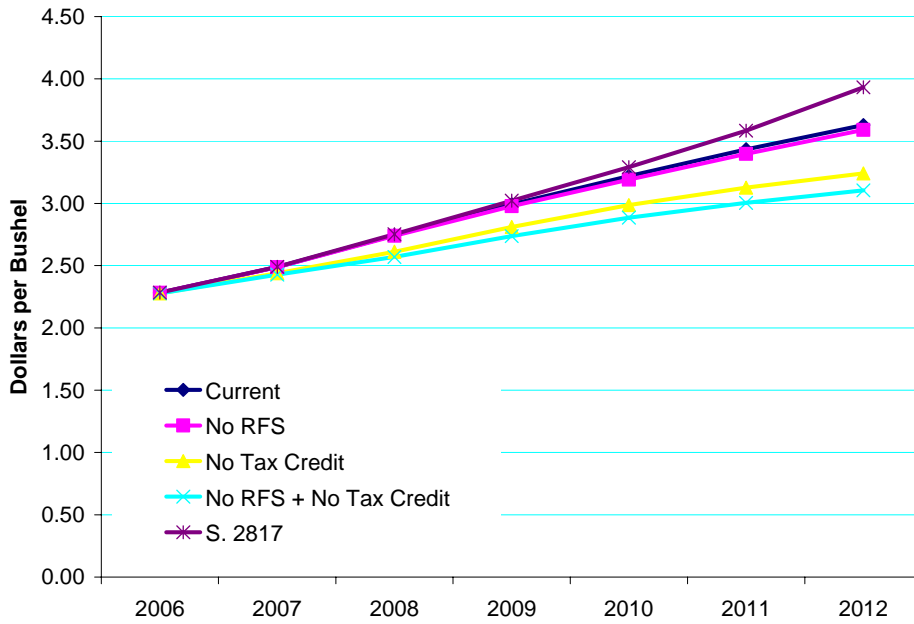**Figure 6: Expected Corn Price Under Alternative Scenarios**
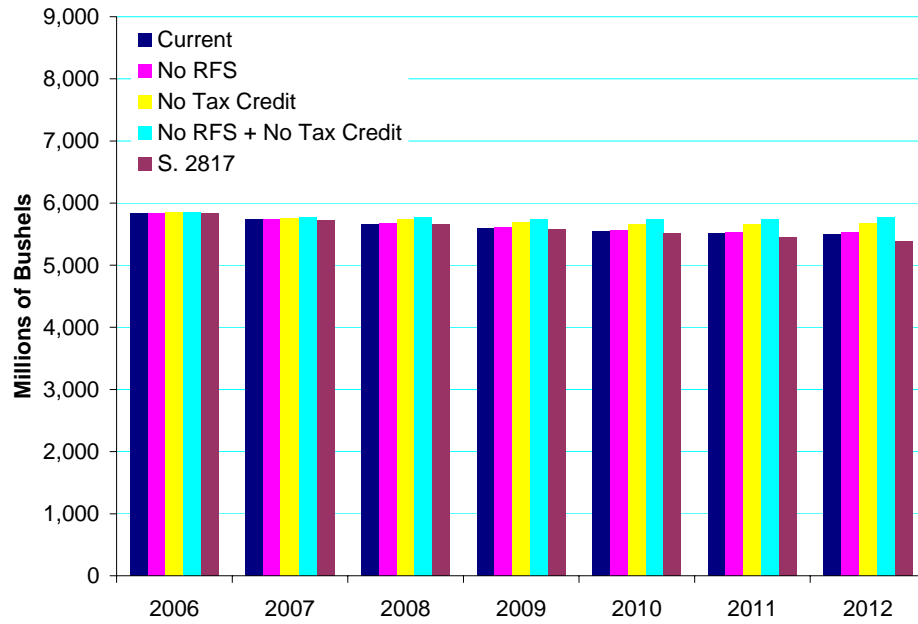
Figure 7: Expected Feed Use of Corn Under Alternative Scenarios

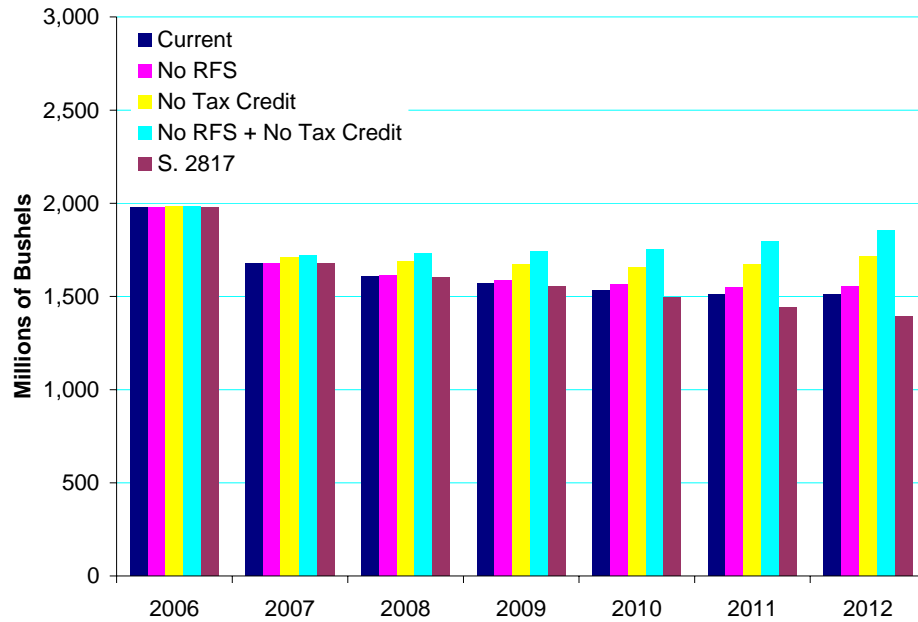**Figure 8: Expected Corn Exports Under Alternative Scenarios**

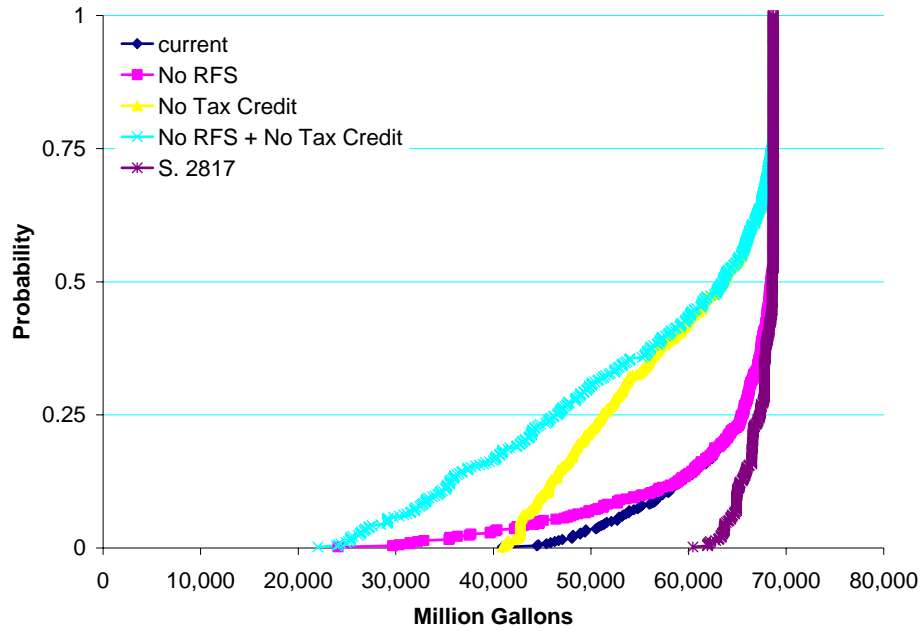**Figure 9: Cumulative Distribution Functions for Cumulative 2006-2012 Ethanol Production**

Figure 10: Cumulative Distribution Functions for Average 2006-2012 Corn Price