Biofuels, Food & Feed Tradeoffs

Proceedings of a conference April 12-13, 2007, in St. Louis, Missouri.

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Agriculture as a Source of Fuel Prospects and Impacts, 2007 to 2017

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Introduction

For most of the period since 1978, when the first federal legislation to encourage ethanol production was enacted, US agriculture served in a relatively minor role as a source of renewable fuels. This situation has changed dramatically in the past five years as ethanol production has nearly tripled, and biodiesel production has increased ten fold, although at a much lower level than ethanol. As a result, this growth has recently elevated the prices of the major biofuel feedstocks, such as corn and soybean oil. Federal and state policies have encouraged this acceleration, prompted by a combination of 1) sharply rising energy prices, 2) increased dependence on supplies of crude oil from nations hostile to the United States or with unstable political structures, 3) growing environmental concerns including global warming, 4) issues related to balance of payments, 5) depressed farm prices and high farm program costs and 6) ongoing efforts to promote rural development.

Among the federal programs to support renewable fuels, blenders' tax credits amounting to $0.51/gallon (gal) on ethanol and $1.00/gal on biodiesel ($0.50 for non-virgin feedstock) have been particularly important. These provisions expire in 2010 for ethanol and 2008 for biodiesel. The *Energy Policy Act of 2005* established a "Renewable Fuels Standard" (RFS) of 7.5 billion gal for renewable fuels for 2012, a target which ethanol production alone is projected to exceed by a wide margin.

Structural Change

The advent of agriculture as a source of fuel as well as food and fiber represents a major structural change. It has been projected that the capacity of existing ethanol plants and plants under construction would reach 13.4 billion gal by 2009 compared with actual output of 4.9 billion gal in 2006 (Tierney, 2007; Renewable Fuels Association, 2007). Adding planned construction, Tierney (2007) estimates that ethanol capacity could actually be as high as 20.7 billion gal by 2009. Questions could be raised as to whether these plans will be executed and whether production will be at capacity. This study assumes that ethanol production will equal the 13.4 billion gal capacity in the 2009 crop year and increase linearly to 20.7 billion gal by 2017.

Based on planned construction, biodiesel capacity could reach 3.0 billion gal by the end of 2008. This compares to actual output in fiscal 2006 (ending in September 2006) of about 250 million gal and an estimated output in fiscal 2007 of 425 million gal (National Biodiesel Board, 2007). Although profits from biodiesel production from soybean oil have recently turned negative, this paper assumes that biodiesel production will increase to 1.5 billion gal by 2010 and expand linearly to 2.0 billion gal by 2017.

While these projections do not represent a large portion of total fuel demands, they are very significant for US agriculture as the source of feedstock supplies. Based on projections for 2017 in this analysis, ethanol would require about half of the corn crop and biodiesel about a fifth of the output of soybean oil, which, in turn, would comprise only about a third of the total feedstock for biodiesel (the other feedstock sources would be animal fat, yellow grease and corn oil extracted from distillers' dried grain with solubles (DDGS)). At 20.7 billion gal, ethanol would represent about 15% of the gasoline used for transportation by volumetric measure and 10% in terms of energy. At 2 billion gal, biodiesel output would approach 4% of the use of petroleum diesel for transportation.

These projections on ethanol and biodiesel production are based more on indicated plant capacity expansion and political targets than on strictly economic considerations. New government programs not now in sight will be needed to reach such targets and/or higher energy prices than assumed in this analysis. This paper addresses what will be needed in terms of feedstock to meet these objectives.

Preparations for Generating Projections

With such a dramatic increase in the demand for US agricultural products over such a short period of time, measuring the impacts poses significant challenges for econometricians. For that reason, the procedure outlined in this paper is one of trial and adjustment combined with more than the usual sets of assumptions for 10-year projections. The analytical tool is an econometric/simulation model of US agriculture called AGMOD designed to generate year-by-year projections (Fer-

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ris, 1991). The model includes major crop and livestock enterprises with an international sector for coarse grain, wheat and oilseeds. The international sector is aggregated into the major exporting nations, the European Union (15) and the rest of the world.

Special attention was given to the significant change in the composition of the concentrate feed sector. The projections of ethanol production encompass the attendant increase in the production of the major livestock feed byproducts of corn gluten feed and meal from wet mills and DDGS from dry mills. Almost all of the increase in these byproduct feeds will be DDGS. To model this rapid increase in the availability of mid-protein feeds, an approach outlined by Ferris was applied (Ferris, 2006). This involved the conversion of feeds to energy and protein equivalents and the construction of synthetic prices for energy and protein.

The key assumptions involved in generating forecasts for 2007 to 2017, in addition to the aforementioned projections for ethanol and biodiesel production, were as follows:

1. Crude oil prices, as measured by the US Department of Energy (DOE)'s "composite refiner acquisition cost," will be $5/barrel (bbl) below the New York Mercantile Exchange's futures quotes for light, sweet crude (basis, Cushing, OK) through 2012 and hold the 2012 level through 2017. The futures quotes were as of the closing of March 30, 2007.
2. The blenders' tax credits for ethanol and biodiesel will be extended through 2017.
3. The essence of the 2002 farm bill will be extended.
4. Macro-economic and demographic assumptions are in line with those of the US Department of Agriculture (USDA) and DOE.

Equations relating wholesale gasoline and diesel prices to crude oil prices provided the base for ethanol and biodiesel price projections. Ethanol prices were generated with a margin of $0.15/gal over wholesale gasoline prices (the average for 2005). Biodiesel prices were set at $1.00/gal over the energy equivalent of wholesale petroleum diesel prices. This was 92% of petroleum diesel prices plus the $1.00/gal representing the blenders' tax credit.

While corn for grain is well established as the predominate feedstock for ethanol production, the future of soybean oil from the domestic crush is tentative. Nearly 90% of the annual output of soybean oil is consumed domestically as food, a demand which is expected to continue to grow. Exports have averaged about 1.3 billion pounds (lb) in recent years which, if diverted to biodiesel would provide enough feedstock for less than a fifth of a billion gallons. Other vegetable oils could be tapped; but their production is small compared to soybean oil, and their prices are normally higher.

Rising soybean oil prices would be reflected in soybean prices to farmers and encourage increased acreage. However, soybeans are crushed more for the meal than for the oil. Even with the elevated prices on soybean oil forecast for the 2006 crop year, their value to processors would represent only about 40% of the returns; with meal representing the other 60%. More important is the strong competition in prospect emanating from the relatively much higher margins from corn versus soybeans. Corn and soybean acreages overlap in major growing areas.

Since biodiesel can be produced from any vegetable oil or animal fat, recycled materials are candidates. This includes yellow grease collected from restaurants and institutions by rendering companies. It is used mostly to add energy and palatability to livestock feeds and for export. Other candidates include inedible tallow, choice white grease and poultry fat, byproducts of the slaughtering industry. However, conversion of these sources to biodiesel involves higher processing costs. Also, the blenders' tax credit for yellow grease is half ($0.50/gal versus $1.00/gal) that for "virgin" vegetable oils such as soybean oil, corn oil, cottonseed oil, canola oil, etc. and for animal fats.

In the wet milling of ethanol, food grade corn oil is a major byproduct. In dry milling, food grade corn oil can be produced if extracted ahead of the ethanol process. Alternatively, corn oil can be extracted from DDGS amounting to about 10% of the weight of the DDGS. However, the quality would not be food grade but would be acceptable for biodiesel production. To date, very little corn oil has been produced from either process. Because of the projected growth in ethanol from dry mills and the biodiesel requirement for feedstock beyond the availability of soybean oil and secondary sources, the presumption is that corn oil from DDGS will become a major venture in the next 10 years. Also, DDGS without oil features improved handling characteristics and is more suitable for dairy rations.

While market forces alone may not assure that the biodiesel industry can depend on domestic sources for feedstock, some satisfaction can be taken knowing that the soybean oil in soybeans normally exported would provide ample inputs along with the other named sources. The question is, "How can the biodiesel industry outbid foreign customers for US soybeans?" This will be difficult because foreign demands for feedstock for biodiesel are also expanding along with growing markets for vegetable oils for food and oilseed meals as livestock feed.

Analytical Procedure

A value from solving econometric models for long range projections is the feedback of information to the modeler. Of-ten the initial runs of these models suggest that the forecasts are unrealistic or unacceptable. Such trial and error procedures are needed to pave the way for model improvement or the development of reasonable assumptions. This approach is being applied in this study because of the many unknowns involving the prospects for renewable fuels and new legislation.

After several trials, the following additional assumptions were employed:

1. The price of soybean oil was set at the level which would render the profit of biodiesel production from soybean oil at break even for new plants, including a return to equity.
2. All of the exports of soybean oil were diverted to biodiesel production.
3. One third of the output of yellow grease, inedible tallow, choice white grease and poultry fat was used for biodiesel.
4. Corn oil was extracted from one half of the production of DDGS.
5. Presuming that the intent of renewable fuels legislation is to grow the feedstock domestically, the balance of the requirements for biodiesel production was acquired by retaining soybean exports. The needed increase in crushing of soybeans in the model was the main "over-ride" of AGMOD.

Projections of yellow grease production were based on a study by the National Renewable Energy Laboratory which sampled 30 randomly selected metropolitan areas and found an average production of about 9 lb per capita annually (Wiltsee, 1998). Past production of inedible tallow, choice white grease and poultry fat was obtained from the US Census Bureau (US Census Bureau, 2006). Projections were tied into AGMOD's forecasts of beef, pork and poultry production.

Results

The results from the analysis are contained in Tables 1-3. As shown in Table 2, crude oil prices are projected to hold near $60/bbl. These projections form the base for the estimated gasoline and diesel prices which in turn determine the wholesale prices on ethanol and biodiesel Deducting processing costs from ethanol prices and assuming conversion rates will improve toward 3 gal of ethanol per bushel (bu) of corn, the farm price of corn resulting in this projection set averages about $3.40/bu, near the breakeven level for new dry mill ethanol plants (Table 1). Ethanol processing costs were based on a USDA 2002 survey and adjusted by input price changes following (Shapouri and Gallagher, 2005).

The forecasted price of soybean oil was established by deducting biodiesel processing costs from the projected biodiesel prices assuming a conversion rate of 7.5 lb of soybean oil/gal on biodiesel. Biodiesel production costs were derived from a "process model" of the USDA's Eastern Regional Research Center and adjusted for subsequent changes in input prices (Haas, *et al.*, 2006). The price of crude, degummed soybean oil at Decatur, IL, was thereby established at about $0.30 to $0.32/pound for the 2007 to 2017 period as the breakeven feedstock cost for biodiesel production (Table 1). If prices on soybean oil move above the breakeven level, biodiesel producers will shift more to animal fats, yellow grease and corn oil extracted from DDGS as feedstocks. Also plants will be operating below capacity. Even in fiscal 2007, the biodiesel industry operated at an estimated 42% of capacity.

Because of the importance of corn to the agricultural economy, corn prices heavily impact the entire livestock feed sector along with production and prices of livestock and competing crops. While gross margins per acre increase on soybeans in the projection period over recent levels, the gross margins on corn escalate much more. Consequently, major shifts of soybean acres to corn are projected for the 2007 to 2009 crop years (Table 1). This compounds the problem of generating increased supplies of soybean oil and other virgin vegetable oil for biodiesel production. The result is reflected in Table 2 under the subtitle "Biodiesel Feedstock." With animal fat representing a major share of the feedstock in the early part of the projection period, corn oil from DDGS could reach the level of soybean oil in the later years.

The attractiveness of animal fat (including yellow grease) and corn oil from DDGS as feedstock for biodiesel is reflected in the section under "Biodiesel Returns" in Table 2. Also note under "Energy Prices," that the prices on yellow grease are projected to be about two-thirds of the prices for soybean oil. Positive returns are projected for biodiesel production from both animal fat and corn oil from DDGS. The implicit price for corn oil from DDGS is the midpoint between 1) the per pound price of DDGS (about $0.05) plus the extraction costs and 2) the price of soybean oil – a split between the cost for corn oil leaving the ethanol plant and the prevailing feedstock input price for the biodiesel plant. However, competition would eventually bid up prices on yellow grease and corn oil from DDGS to breakeven levels. Pretreatment costs for yellow grease were obtained from a study at Iowa State University (Canakci and Van Gerpen, 2001) and extraction costs for corn oil from DDGS were derived from research at the Michigan Biotechnology Institute International (McCalla, 2006).

To provide for both the expanding use of soybean oil as a food and as a fuel and to ensure that the feedstock requirement for biodiesel would be met from domestic sources, AGMOD's initial solution was overridden by increasing the

Table 1: Projections of Selected Corn, Feed Grain and Soybean Variables plus Total Harvested Acres and Farm Land Values for 2007 to 2017.

Item	Unit	2004	2005	2006	2007	2008	2009	Year 2010	2011	2012	2013	2014	2015	2016	2017
Corn															
Harvested Acreage	Acres	73.6	75.1	70.6	80.5	81.6	84.7	85.6	82.2	82.4	82.1	81.9	82.2	82.1	82.7
Yield	Bushels/Acre	160	148	149	153	154	156	158	160	162	164	166	168	170	172
Production	Million Bushels	11807	11112	10535	12275	12607	13242	13559	13185	13381	13486	13623	13829	13975	14230
Feed Grain															
Production	Million Metric Tons	319	299	280	325	339	358	369	359	370	374	376	384	388	394
Utilization															
Feed	"	166	163	158	149	144	141	143	139	139	142	141	141	141	142
Ethanol	"	34	41	55	79	114	128	136	143	150	157	164	171	178	182
Other Domestic	"	40	41	41	42	42	42	43	43	43	43	43	44	44	44
Exports	"	51	60	62	54	50	47	45	43	36	34	32	29	30	30
Ending Stocks	"	59	55	22	28	19	22	27	21	26	26	25	27	25	23
Corn Farm Price	Dollars/Bushel	2.06	2.00	3.20	3.21	3.66	3.56	3.35	3.62	3.44	3.46	3.55	3.46	3.61	3.71
Corn Gross Margin[1]	Dollars/Acre	209	157	310	309	377	363	334	382	356	361	379	366	394	413
Soybeans															
Harvested Acreage	Acres	74.0	71.3	74.6	66.7	68.8	68.4	69.2	72.2	72.5	73.4	74.0	74.3	74.8	74.6
Yield	Bushels/Acre	42.2	43.0	42.7	42.0	42.4	42.8	43.2	43.6	44.0	44.4	44.8	45.2	45.6	46.0
Production	Million Bushels	3124	3063	3188	2802	2918	2928	2990	3148	3191	3257	3317	3359	3413	3432
Crush	"	1696	1739	1780	1706	1697	1818	2004	2050	2094	2116	2143	2177	2206	2279
Exports	"	1097	947	1100	1070	1104	1219	928	762	917	1012	1026	1022	1026	1006
Ending Stocks	"	256	449	595	465	426	159	150	242	266	240	232	236	261	252
Farm Price	Dollars/Bushel	5.74	5.66	6.45	7.86	7.91	8.68	8.66	7.96	7.79	7.93	8.05	7.99	8.03	8.09
Gross Margin[1]	Dollars/Acre	172	165	192	246	246	280	281	252	248	255	262	261	264	269
Soybean Oil															
Production	Million Pounds	19360	20393	20165	19382	19300	20709	22846	23407	23927	24218	24547	24971	25329	26201
Utilization															
Biodiesel	"	177	384	1690	1414	1138	1370	3508	3787	4073	4347	4624	4902	5184	5601
Other	"	17439	17955	17360	17483	17921	18140	18427	18639	18834	19008	19225	19473	19727	20004
Imports	"	26	35	30	200	200	200	300	300	300	300	300	300	300	300
Exports	"	1324	1153	1500	1000	1000	0	0	0	0	0	0	0	0	0
Price, Decatur, IL[2]	Cents/Pound	23.0	23.4	30.0	32.9	30.4	31.3	30.6	30.4	30.2	30.2	30.2	30.1	30.1	30.0
Soybean Meal															
Production	Million Tons	41	41	42	38	38	40	44	45	46	47	47	48	49	50
Feed Utilization	"	34	33	34	32	28	26	26	25	26	26	26	26	26	26
Exports	"	7	8	9	6	9	14	19	20	21	21	22	22	23	24
Price, Decatur, IL[3]	"	183	174	200	237	250	285	287	253	246	253	259	256	258	261
Acres Harvested[4]	Million Acres	210	207	202	208	210	215	220	223	225	226	228	229	229	230
Price of Farmland[5]	Dollars/Acre	2315	2698	3037	3163	3210	3429	3665	3973	4271	4522	4753	4977	5223	5471

Notes: [1] Gross margins over variable costs

[2] Crude, degummed

[3] 48% protein

[4] Total harvested acres of coarse grain, wheat and soybeans

[5] Corn Belt states

Table 2: Projections of Variables Related to Renewable Fuels for 2007 to 2017.

Item	Unit	2004	2005	2006	2007	2008	2009	Year 2010	2011	2012	2013	2014	2015	2016	2017
Energy Prices															
Crude oil[1]	Dollars/Barrel	37	50	60	60	64	64	62	62	61	61	61	61	61	61
Wholesale gasoline[2]	Dollars/Gallon	1.29	1.67	1.97	1.94	1.91	1.92	1.87	1.86	1.85	1.86	1.87	1.88	1.89	1.89
Wholesale diesel[3]	"	1.19	1.74	2.01	1.95	2.06	2.07	2.02	2.01	2.00	2.01	2.01	2.02	2.03	2.03
Ethanol[4]	"	1.69	1.80	2.56	2.09	2.06	2.07	2.02	2.01	2.00	2.01	2.02	2.03	2.04	2.04
Biodiesel[5]	"	2.09	2.83	2.86	2.79	2.90	2.90	2.86	2.85	2.84	2.85	2.85	2.86	2.86	2.87
Yellow grease[6]	Cents/Pound	14.1	13.2	18.5	18.8	18.8	18.9	18.2	18.7	18.3	18.3	18.5	18.3	18.6	18.8
Biodiesel Feedstock															
Soybean oil	Million Pounds	177	384	1690	1414	1138	1370	3508	3787	4073	4347	4624	4902	5184	5601
Other virgin oil	"	0	0	0	368	410	427	437	445	453	461	469	475	481	490
Animal fat[7]	"	0	0	0	3461	3443	3454	3473	3494	3509	3537	3563	3587	3611	3631
Corn oil from DDGS	"	0	0	0	0	3432	3866	4103	4339	4575	4810	5045	5282	5515	5638
Total	"	215	699	1882	4293	6705	9116	11520	12065	12611	13156	13701	14246	14792	15360
Biodiesel Returns[8]															
Yellow grease	Dollars/Gallon	-0.11	0.61	0.73	0.15	0.27	0.26	0.22	0.24	0.20	0.22	0.21	0.20	0.20	0.18
Corn oil from DDGS	"	-0.06	0.76	0.70	0.31	0.35	0.36	0.33	0.33	0.32	0.31	0.30	0.29	0.28	0.27
By-Product Feed Prices															
Corn gluten feed[9]	Dollars/Ton	53	55	77	79	87	90	88	86	83	84	86	85	87	89
Corn gluten meal[9]	"	268	274	305	322	332	376	382	339	334	344	352	351	354	359
DDGS[10]	"	75	87	110	90	98	106	104	99	95	97	99	98	100	102

Notes: [1] Refiner acquisition cost, composite of domestic and imported
[2] Refiner prices for resale
[3] Refiner prices for resale, No. 2
[4] Rack prices, F.O.B. Omaha
[5] Upper Midwest, *Jacobsen's Biodiesel Bulletin*
[6] Illinois, *Jacobsen's Biodiesel Bulletin*
[7] Includes yellow grease
[8] Over variable and fixed costs
[9] Illinois points
[10] Lawrenceburg, IN

Table 3: Projections of Livestock Variables for 2007 to 2017.

Item	Unit	2004	2005	2006	2007	2008	2009	Year 2010	2011	2012	2013	2014	2015	2016	2017
Livestock Production															
Beef	Million Pounds	24650	24787	26258	26786	26758	27162	27575	27821	27860	28066	28178	28282	28420	28514
Pork	"	20529	20705	21075	21682	20754	19902	19262	19147	19254	19499	19807	20000	20158	20228
Broiler	"	33699	34986	35369	35516	35756	35815	36005	36332	36744	37213	37706	38196	38677	39164
Turkey	"	5383	5432	5612	5704	5825	5884	5929	5981	6044	6106	6166	6215	6255	6294
Egg	"	7443	7509	7572	7600	7741	7800	7862	7941	8034	8137	8248	8361	8475	8593
Milk	"	170900	176900	181800	183918	187645	188623	189072	190389	191979	194097	197011	200151	203099	205444
Livestock Prices															
Choice steers[1]	Dollars/Hundredweight	84.75	87.28	85.41	92.78	89.05	87.51	86.18	85.54	86.51	86.68	87.97	88.65	89.07	89.97
Barrows and gilts[2]	"	52.51	50.05	47.26	46.89	50.70	56.72	62.07	64.10	64.78	64.12	63.37	63.05	62.93	63.43
Broilers[3]	Cents/Pound	74.1	70.8	64.4	74.0	70.7	77.1	83.0	87.3	91.3	94.3	97.7	100.8	104.1	108.0
Turkeys[4]	"	69.7	73.4	77.0	78.8	76.9	81.6	85.7	88.3	90.5	91.9	93.9	96.0	98.3	101.0
Eggs[5]	Cents/Dozen	82.2	65.5	71.8	91.1	73.4	78.7	83.3	86.1	88.5	89.8	91.3	92.4	93.6	95.3
Milk, average farm	Dollars/Hundredweight	16.05	15.14	12.90	15.36	15.37	15.46	15.65	15.88	16.19	16.68	16.73	16.61	16.42	16.29

Notes: 1 Nebraska, Direct, 1100-1300 lbs.

2 National Base, Live equivalent 51-52% lean

3 Wholesale, 12-city average

4 8-16 lbs, hens, Eastern Region

5 Grade A large, New York, volume buyers

domestic crush and reducing exports of soybeans. By 2017, this represented about 700 million bu, a third of the domestic crush. With domestic feeding of soybean meal already diminished by the competition from the byproduct feeds of ethanol production, the combined impact was to increase substantially the exports of soybean meal. This, plus the increase in ethanol byproduct feeds, pressured the high protein feed market internationally and domestically. However, the predominance of the strong corn market more than offset the increased supplies of the mid and high protein feeds as reflected in Tables 1 and 2.

Even though the strong corn market pulled acreage out of soybeans for a few years, the longer run impact on the combination of all coarse grain, soybeans and wheat was for a substantial acreage expansion. This amounted to a 28 million acre increase between 2006 and 2017 (Table 1). Presumably about a third would come out of the Conservation Reserve Program. The elevated returns to cash crops will also extend the secular rise in farmland prices. Corn Belt farmland values could rise from the $3,000/acre level to $5,000/acre in the next 10 years (Table 1).

As shown in Table 3, livestock production and prices will obviously depart from scenarios sans expanding renewable fuels. In general, livestock production will be lower and prices higher. Specifically, the major impacts are the reduced production of pork and broiler meat production, which are more than offset by higher prices, a reflection of the inelastic demand for these products. These results suggest livestock and food industries have legitimate concerns about the rate of expansion in the construction plans for renewable fuels, particularly for ethanol.

Caveat

Some of the assumptions in this analysis may seem extreme such as the phasing out of soybean oil exports and restricting exports of soybeans. Alternatively, options could be explored in which the feedstock for renewable fuel production could be imported. The projections do provide a perspective on the volumes which would be involved. In any case, the econometric models such as AGMOD allow analysts to quickly evaluate alternative scenarios.

What About Cellulosic Ethanol?

We conservatively assume in our projections that production of cellulosic ethanol either from agricultural residues or from dedicated energy crops such as switchgrass will be small through 2017. Though cellulosic ethanol is considered the best biofuel alternative for reducing crude oil imports and greenhouse gas emissions, commercial feasibility of cellulosic ethanol on a large scale remains a formidable challenge for a number of reasons (Collins, 2007).

While significant progress has been made in various unit processes such as pretreatment, hydrolysis, enzyme production, fermentation and distillation in the conversion of cellulosic feedstocks into ethanol, major technical uncertainties remain, such as effective hydrolysis of recalcitrant cellulose, fermentation of pentose sugars, system integration, commercial scale up and overall process optimization. A number of potential technical pathways are still competing for dominance. No commercial facilities or fully integrated demonstration plants, which are necessary to prove technical and economic viability and to secure financing, are currently operational. Capital requirements for cellulosic ethanol plants are much higher than for corn-ethanol dry mills. The estimated capital costs of annual capacity of ethanol ranges from $2.85/gal (Aden, *et al.*, 2002) to $5.44/gal (McAloon, *et al.*, 2000) for cellulosic plants compared to a range of $1.05/gal to $3.00/gal for corn ethanol plants and $0.20/gal to $1.00/gal for expansion of existing plants (Shapouri and Gallagher, 2005).

Expert opinion is that biomass conversion facilities will need to be large (5,000 to 10,000 tons/day) to be economical, and the configuration of appropriate supply chains for biomass and logistics of harvesting, storage and transport remain unresolved. Significant new investments will also be necessary in harvesting and storage infrastructure. Sokhansanj and Wright (2000) estimate that biomass refineries using 508 million tons of biomass will require investments of $31 billion in baling and harvesting equipment and $10.6 billion in storage structures. Further, energy crop production and investments in conversion facilities suffer from the classic "chicken and egg" problem. Farmers are unlikely to grow biomass in large enough quantities unless there is an assured market, and investors are unlikely to invest in conversion facilities until adequate feedstock supplies are assured. Growing dedicated energy crops, such as switchgrass, is not attractive at current yields of 4 to 5 tons/acre and significant improvements in yields through breeding and research are necessary (Walsh *et al.*, 2003; Wright 2004). The projected higher returns for corn production and potential revenues from corn stover, if cellulosic ethanol were to become commercially viable, will only exacerbate the problem.

Hence, we assume in our projections that the contribution of cellulosic ethanol will be minor even by 2017. Following a similar logic, the early release version of the Annual Energy Outlook 2007 from DOE projects that cellulosic ethanol will contribute less than 2% of total fuel ethanol produced in the United States by the year 2030, despite a projected quadrupling of fuel ethanol output between 2007 and 2030 in the reference case (Energy Information Administration, 2007). Similarly a recent University of Tennessee study analyzing the economic and agricultural impacts of ethanol and biodiesel expansion assumes that cellulosic ethanol becomes commercially viable by 2012; but initial feedstocks will be forest and mill wastes; and dedicated energy crops will become primary cellulosic feedstock only by 2017 (De La Torre Ugarte, *et al.*, 2006).

On February 28, 2007, DOE announced that it will invest up to $385 million for six biorefinery projects over the next four years to help bring cellulosic ethanol to market (US Department of Energy, 2007). The total investment in these facilities including industry cost share is more than $1.2 billion. These plants use a variety of cellulosic feedstock such as urban yard and wood waste, wheat and barley straw, corn stover, switchgrass, wood residues and woody energy crops. By 2011, when fully operational, these biorefineries are expected to produce about 130 million gal of cellulosic ethanol per year. Technical and commercial success of these DOE funded plants and several other proposed plants will be a critical first step in the future commercial development of the cellulosic ethanol industry. However, we expect that cellulosic ethanol production will continue to be relatively minor through 2017.

References

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton and B. Wallace. *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-current Dilute Acid Prehydrolysis for Corn Stover.* NREL/TP-510-32438. Golden, CO: US Department of Energy, National Renewable Energy Laboratory, June 2002. [Accessed September 11, 2007.] Available from http://www1.eere.energy.gov/biomass/pdfs/32438.pdf

Canakci, Mustafa and John Van Gerpen. *A Pilot Plant to Produce Biodiesel from High Free Fatty Acid Feedstocks.* Paper No. 016049. Presented paper, 2001 ASAE Annual International Meeting, Sacramento, CA, July 30-August 1, 2001. [Accessed September 11, 2007.] Available from http://asae.frymulti.com/request.asp?JID=5&AID=4209&CID=sca2001&T=2

Collins, Keith. *Statement of Keith Collins Chief Economist, U.S. Department of Agriculture Before the U.S. Senate Committee on Agriculture, Nutrition and Forestry, January 10, 2007.* Washington, DC: US Department of Agriculture, Office of the Chief Economist, 2007 [Accessed September 11, 2007.] Available from http://www.usda.gov/oce/newsroom/congressional_testimony/Collins_011007.pdf

De La Torre Ugarte, Daniel, Burton English, Kim Jensen, Chad Hellwinckel, Jamey Menard and Brad Wilson. *Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion.* Knoxville, TN: The University of Tennessee, Department of Agricultural Economics, December 2006. [Accessed September 11, 2007.] Available from *http://www.nlc.state.ne.us/epubs/E5700/B052-2006.pdf*

Energy Information Administration. *Annual Energy Outlook 2007 with Projections to 2030.* Report # DOE/EIA-0383(2007) Washington, DC: US Department of Energy, Energy Information Administration, February 2007. [Accessed September 11, 2007.] Available from http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2007).pdf

Ferris, John N. *Modeling the US Domestic Livestock Feed Sector in a Period of Rapidly Expanding By-Product Feed Supplies from Ethanol Production.* Staff Paper 2006-34. East Lansing, MI: Michigan State University, Department of Agricultural Economics, November 2006.

Ferris, John N. *Understanding "AGMOD" – An Econometric Model of US and World Agriculture.* Staff Paper #91-5. East Lansing, MI: Michigan State University, Department of Agricultural Economics, 1991.

Haas, Michael, Andrew McAloon, Winnie Yee and Thomas Foglia. "A Process Model to Estimate Biodiesel Production Costs." *Bioresource Technology* 97(4) (2006): 671-678. [Accessed September 11, 2007.] Available from http://www.sciencedirect.com

McAloon, Andrew, Frank Taylor, Winnie Yee, Kelly Ibsen and Robert Wooley. *Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks.* NREL/TP-580-28893. Golden, CO: US Department of Agriculture and US Department of Energy, National Renewable Energy Laboratory, October 2000. [Accessed September 11, 2007.] Available from http://www.ethanol-gec.org/information/briefing/16.pdf

McCalla, Darold F. Personal communication, Michigan Biotechnology Institute International, Lansing, MI, November 2006.

National Biodiesel Board. *Biodiesel: The Official Site of the National Biodiesel Board.* Jefferson City, MO: National Biodiesel Board, 2007. [Accessed September 11, 2007.] Available from http://www.biodiesel.org/

Renewable Fuels Association. *Industry Statistics.* Washington, DC: Renewable Fuels Association, 2007. [Accessed September 11, 2007.] Available from http://www.ethanolrfa.org/industry/statistics/#A

Shapouri, Hosein and Paul Gallagher. *USDA's 2002 Ethanol Cost-of-Production Survey.* Agricultural Economic Report Number 841. Washington, DC: US Department of Agriculture, Office of Energy Policy and New Uses, July 2005. [Accessed September 11, 2007.] Available from http://www.usda.gov/oce/reports/energy/USDA_2002_ETHANOL.pdf

Sokhansanj, Shahab and Lynn Wright. "Impact of Future Biorefineries on Feedstock Supply Systems. Paper 021073. Presented paper, 2002 ASAE Annual International Meeting/CIGR XVth World Congress, Chicago, IL, July 28-31, 2002. [Accessed September 11, 2007.] Available from http://bioenergy.ornl.gov/papers/asae2002/bioerefiner.html

Tierney, William. Personal communication, John Stewart & Associates, Washington, DC, February 2007.

US Census Bureau. *Fats and Oils – Production, Consumption and Stocks: 2005.* Current Industrial Reports M311K(05)-13. Washington, DC: US Census Bureau, Manufacturing and Construction Division, June 2006. [Accessed September 11, 2007.] Available from http://www.census.gov/industry/1/m311k0513.pdf

US Department of Energy. "DOE Selects Six Cellulosic Ethanol Plants for Up to $385 Million in Federal Funding." Press Release 4827. Washington, DC: US Department of Energy, February 28, 2007. [Accessed September 11, 2007.] Available from http://www.energy.gov/news/4827.htm

Walsh, Marie, Daniel De La Torre Ugarte, Hosein Shapouri, Stephen Slinsky. "Bioenergy Crop Production in the United States: Potential Quantities, Land Use Changes, and Economic Impacts on the Agricultural Sector." *Environmental and Resource Economics* 24(4)(April 2003): 313-333.

Wiltsee, G., *Urban Waste Grease Resource Assessment.* NREL/SR-570-26141. Golden, CO: National Renewable Energy Laboratory, November 1998. [Accessed September 11, 2007.] Available from http://www.epa.gov/region09/waste/biodiesel/resources/NRELwaste grease assessment.pdf

Wright, Lynn "Energy Crop Resources and Technologies." Presentation, Global Climate Energy Program, Biomass Energy Workshop, Stanford University, Palo Alto, CA, April 27, 2004. [Accessed September 11, 2007.] Available from http://gcep.stanford.edu/pdfs/energy_workshops_04_04/biomass_1_wright.pdf