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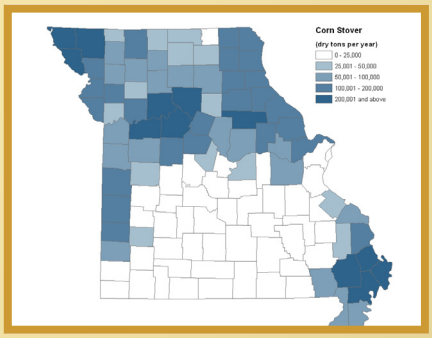

Feasibility of Corn Stover in Missouri

Report Submitted to:
Missouri Stover Products

UNIVERSITY OF MISSOURI
Extension
Commercial Agriculture Program

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Executive Summary

Corn stover is a co-product that is produced from corn grain production. Corn stover consists of the husk, cob, leaves and stalk that are left in fields after grain is harvested. Corn stover yields will vary with seed variety, soil and climatic conditions. Volume of corn stover is generally based on a dry weight of corn grain to residue ratio as 1:1. Each 35-45 bushels of corn grain per acre will produce approximately one ton of corn stover per acre. Missouri's five year corn yield average (140 bushels per acre) would represent approximately 3.33 dry tons per acre of corn stover.

Corn stover and corn cobs have potential as biomass feedstock for markets in Missouri. Markets that would be interested in this feedstock include power plants, cellulosic ethanol plants, and biomass densification businesses. Power plants could potentially co-fire corn stover along with coal and appear to be the most viable market to date. There are currently 23 operational coal fired electrical generation plants in Missouri. A one percent corn stover usage in all Missouri coal plants would require 518 thousand short tons of corn stover on an annual basis. The University of Missouri (MU) combined heat and power plant (CHP) is developing a new biomass fired boiler (expected to go online in 2012) and has been pioneering biomass usage in the state. While Missouri coal plants have demonstrated interest, further discussions and product trials would be needed to develop this market. Cellulosic ethanol plants in Missouri are in pilot/demonstration phases, but these plants or new ventures could develop in the future to utilize corn stover as a feedstock. Show Me Energy Cooperative is currently a biomass densification business in Missouri that produces pellets and does uses corn stover as one of its 26 feedstocks in the production of energy pellets.

There are many important characteristics of corn stover. Fertilizer nutrient estimates contained in one ton of corn stover expressed as pounds of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) is basically 15-6-25. Corn stover is typically composed of 38% cellulose, 26% hemi-cellulose, 19% lignin and 6% ash. One potential challenge with direct combustion of corn stover is the high alkaline content in the stover ash, which promotes increased slagging and fouling in most coal burning boilers.

Bulk density of corn stover is low when compared to fossil fuels. Transportation, storage and handling of corn stover, when compared to coal on a bulk density basis of pounds per cubic foot (lb/ft^3), results in some logistical challenges. Corn stover (dry basis) typically contains a higher heating value of 7,487 Btu per lb. The heat value of combusted corn stover can reasonably compare to some of the "western" coals utilized by most of the Missouri utility power plants.

Moisture content is a challenge with corn stover removal. The moisture content of corn stover components is higher than the corn grain component. As a general rule, stover moisture content is approximately two times the grain moisture content. Moisture contents of the corn stover components will influence harvest procedures and times of stover harvest. Problems that may be associated with corn stover harvest are a short harvest window, wet stover spoilage and soil compaction as a result of additional field passes especially if wet soil conditions exist. Moisture in corn stover also impacts the heating value of the product, thus energy plants will want corn stover to have low moisture content.

Environmental constraints associated with corn stover harvest must be thoroughly evaluated on each field. Soil erosion is the primary environmental concern in Missouri on cropland acres. All locations must be evaluated for soil erosion potential based on a number of variables such as soil type, climate data, topography, crop rotations, and tillage practices. The Revised Universal Soil Loss Equation Version 2 (RUSLE2) is one method to predict the soil loss.

The corn producing areas in Missouri that are located in river bottoms usually do not have slopes that make soil erosion a concern. The claypan and claypan-like soils found in North and Southwest Missouri have increased soil erosion potentials because of slow permeability that increases the runoff potential. Significant rill erosion can occur where land slopes are 2% or less because of these claypan soil properties. Stover harvest in these claypan and claypan-like soil areas of Missouri would require an in-depth site evaluation to insure that soil erosion would not be excessive.

An initial land slope evaluation for corn stover harvest in the non claypan and claypan-like areas of Missouri might be:

- 0% of the corn stover removed on land slopes greater than five percent,
- No more than 25% removal would be harvested from fields with land slopes of two to five percent, and
- No more than 50% of the corn stover would be harvested from fields with land slopes less than two percent.

Another environmental and production constraint is soil organic carbon (SOC) and soil organic matter (SOM) that are required to maintain soil quality, fertility and structure. Research, although limited, indicates that more crop residue will probably be needed to maintain SOC than would be required to control water and wind erosion. Residue removal rates greater than 25 percent reduce SOC.

Sustainable corn stover harvest will require a favorable site as not all sites will be suitable because of land slope, soil type and other limiting physical properties. Most sites will require the producer to adopt a crop rotation and a particular tillage system. The tillage system will probably be a limited or no-till system. Crop rotations may contain several years of continuous corn, soybeans and possibly a small grain crop to maintain adequate residue cover. A cover crop requirement after stover harvest might also be needed.

There are currently four harvest methods for corn stover. Each of these harvesting methods results in varying levels of residue removal.

1. Cob only – 15% removal of corn residue
2. Direct baling – no raking, combine spreader disabled, 25%-30% removal of corn residue
3. Rake/bale – 50% removal of corn residue
4. Cut/rake/bale –75% to 85% removal of corn residue

Each stover harvesting method indicates a difference in collection efficiency and that will vary depending on the equipment used. Farmers could own and operate the collection equipment or hire custom operators to perform this service.

Most corn stover markets will not want to take over ownership of corn stover after harvest, due to the large volume of bales and storage capacity needed. Options for corn stover storage include a centralized location or on-farm storage. Storage losses are an important consideration in determining the appropriate storage method. These losses are impacted by the baling method (round or square), storage method (inside, outside, etc.), time in storage, and weather conditions if outside. With the additional costs associated with covered or improved storage systems, it is difficult to justify making these investments unless the end market price of corn stover warrants it. Based on the preceding factors, the best option available to date is to utilize an uncovered round bale system.

Moving and hauling biomass products that have a low mass density are a logistical challenge. Most of the research has centered on moving bales or processed corn stover within a 50-mile radius of the end destination to minimize transportation costs. Hauling bales can be accomplished with the use of high-speed tractors and bale wagons and/or trucks with flatbed trailers. Custom operators could be contracted to provide this service or farmers could potentially purchase or use existing equipment. Transportation costs and equipment use will vary depending on the location of the end facility. Some energy plants may require corn stover to be processed and sized prior to arrival at the plant. This processing could involve tub-grinding, roll-press compaction, and other densification processes. Each of these steps could be performed at a centralized location by a custom hire operator with portable equipment.

Currently, prices for baled corn stover or corn cobs are limited due to the nature of an undeveloped market. Current contracts for Poet have listed a price of $40 per dry ton delivered FOB to the cellulosic ethanol plant in Emmetsburg, Iowa. These bales have been ranging from 1,200 to 1,300 pounds, with a moisture content of approximately 20%. Iowa Agricultural Bio Fibers is currently selling corn cobs at $65 (unground) and $75 (ground) per ton FOB. Potential market prices for corn stover and corn cobs were estimated by the MU CHP Plant superintendent based on pricing experiences with woody biomass and their expectations in the future. His future price expectations were $45 to $75 per ton for processed and delivered corn stover and $48 to $80 per ton for processed and delivered corn cobs. These prices factor a $3 to $5 price per million Btu, a preferred measure for valuing heat value by power plants.

Values are reported for 30% and 50% removal rates of corn residues based on Missouri average corn production, for both dollars per dry ton and dollars per acre. Based our findings and assumptions, it would suggest that corn stover removal costs of $59.67 to $67.96 per dry ton to supply a potential end market. Per acre costs assumed the Missouri average yields of corn stover (1.00 and 1.67 tons for 30% and 50% removal rates, respectively). Costs that were considered include the nutrient value, harvesting costs, transportation, storage, and grinding/compaction of corn stover. Based on these costs, the profitability (or loss) of corn stover removal on a dry ton basis can be found in Exhibit E1.

Exhibit E1 Corn Stover Profitability (or Loss), Per Dry Ton

Price received per dry ton of corn stover	Custom Hire Harvesting		Producer Harvesting	
	30% Removal ($ per dry ton)	50% Removal ($ per dry ton)	30% Removal ($ per dry ton)	50% Removal ($ per dry ton)
$40	($25.03)	($27.96)	($22.65)	($19.67)
$50	($15.03)	($17.96)	($12.65)	($9.67)
$60	($5.03)	($7.96)	($2.65)	$0.33
$70	$4.97	$2.04	$7.35	$10.33
$80	$14.97	$12.04	$17.35	$20.33

One option for corn stover is to separate the corn cobs and market as a standalone product. Current cost of production, slower harvesting rates and product yields for corn cobs are limiting factors in making cob harvest a feasible option. The investment needed to justify the purchase or rental of a collection system is significant. Breakeven prices for cobs will vary depending on farm size, grain yields and production methods. Purdue University estimated costs of corn cob removal for a 686 acre farm to range from $48 to $63 per ton. These costs do not include transportation or pre-processing of the cobs that may be required by end markets.

Potential corn stover business(s) in Missouri must decide how and what services that they wish to provide. Inventorying existing resources and learning the farmers' willingness for providing services will dictate how a business should be formed. Further negotiation concerning market prices and product specifications with end markets is important for market development. Site-specific cost analysis can then be conducted around the plant location and to aid farmers in the decision to be a biomass feedstock supplier.

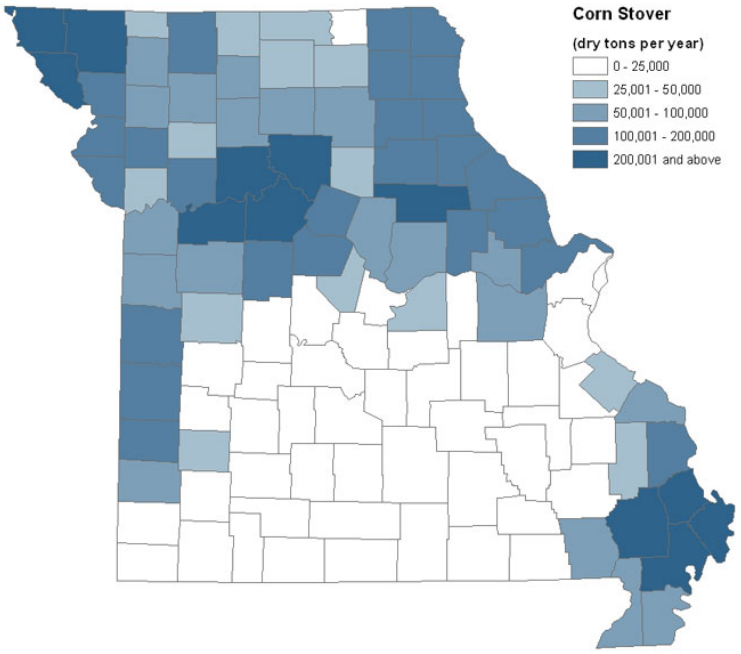
Chapter 1: Corn Stover Supply

Missouri is a significant contributor to corn production within the US. According to the United States Department of Agriculture (USDA), Missouri ranks 10th in corn production and produced 447 million bushels of corn in 2009. Corn production is an important economic contributor to Missouri's economy, reaching $1.4 billion in cash farm receipts in 2009. Along with corn grain production, an important co-product is being created on these farms, corn stover. The following sections detail the volume of corn stover produced, corn stover characteristics, and environmental factors that must be evaluated to ensure that stover removal does not compromise production potentials.

1.1 Potential Corn Stover Production

Numerous publications discuss the yield of stover from corn production. There is some slight variation in the literature on yields; however, most of the research cites a ratio of the dry weight of corn grain to residue ratio as 1:1. For every dry pound of corn grain produced, a corresponding dry pound of corn residue is produced. This ratio of corn grain to corn stover implies that higher corn yields per acre will result in larger amounts of residue produced. Based on this methodology, an estimation of total annual corn stover production in the state of Missouri is shown in Exhibit 1.1.1. The five year average of county harvested acres and corn yields reported by the USDA were used to estimate total corn stover production. Dry tonnage was estimated by factoring in a corn bushel weight of 56 pounds (with 15.5% moisture) and corn grain/residue ratio of 1:1. Strong concentrations of corn stover can found in the northwest, central, and southeast regions of Missouri.

Exhibit 1.1.1 Total Potential Corn Stover Production in Missouri (5-Year Average)



Detailed information concerning Missouri counties that had USDA county corn acreage and yields reported can be found in Exhibit 1.1.2. Corn stover energy estimations for each county were derived by taking an average British thermal unit (Btu) value for corn stover and multiplying it by the total dry tonnage of corn stover in each county.

Exhibit 1.1.2 Corn Stover Potential for Missouri (5-Year Average)

County	Harvested acres	Total production (bu/yr)	Grain Yield (bu/ac)	Corn stover (dry tons per acre)[1]	Corn stover (dry tons per year)	Corn stover (million Btu)[2]
Adair	12,480	1,564,000	126.3	3.0	37,299	554,101
Andrew	51,880	7,132,000	137.7	3.3	168,975	2,526,759
Atchison	130,780	20,901,800	159.5	3.8	493,534	7,405,191
Audrain	75,960	9,174,400	120.5	2.9	216,564	3,250,351
Barton	42,980	5,395,800	124.7	3.0	126,808	1,911,650
Bates	48,880	6,178,200	125.5	3.0	145,141	2,188,843
Benton	9,500	1,039,000	110.1	2.6	24,738	368,102
Bollinger	12,060	1,607,300	134.5	3.2	38,367	569,442
Boone	22,140	2,632,600	120.5	2.9	63,101	932,690
Buchanan	45,440	6,624,800	145.9	3.5	156,902	2,347,066
Butler	20,080	2,962,200	147.5	3.5	70,086	1,049,463
Caldwell	15,600	1,722,800	112.4	2.7	41,486	610,362
Callaway	23,340	2,896,000	123.4	2.9	68,156	1,026,009
Cape Girardeau	33,400	4,760,200	143.0	3.4	113,021	1,686,467
Carroll	75,200	10,929,660	145.3	3.4	258,451	3,872,213
Cass	28,560	3,610,400	126.5	3.0	85,507	1,279,110
Chariton	65,840	9,222,200	140.5	3.3	218,867	3,267,286
Clark	49,680	6,767,600	137.5	3.3	161,645	2,397,658
Clay	8,160	1,166,800	139.5	3.3	26,929	413,380
Clinton	33,100	4,598,200	138.3	3.3	108,293	1,629,073
Cole	4,400	543,600	123.1	2.9	12,817	192,589
Cooper	40,380	5,222,800	128.6	3.0	122,901	1,850,359
Dade	11,880	1,378,800	117.1	2.8	32,920	488,488
Daviess	31,360	3,690,000	117.4	2.8	87,108	1,307,311
De Kalb	26,240	3,264,600	125.0	3.0	77,580	1,156,598
Dunklin	22,780	3,634,000	157.2	3.7	84,748	1,287,471
Franklin	17,360	2,383,600	137.4	3.3	56,427	844,473
Gasconade	4,940	629,200	127.2	3.0	14,863	222,916
Gentry	30,600	4,008,200	131.3	3.1	95,090	1,420,044
Grundy	28,200	3,493,600	124.2	2.9	82,881	1,237,730
Harrison	44,860	5,700,000	126.9	3.0	134,648	2,019,424
Henry	19,340	1,951,600	100.5	2.4	45,978	691,422
Holt	100,660	15,578,600	154.6	3.7	368,198	5,519,262
Howard	31,680	4,329,200	136.8	3.2	102,538	1,533,770
Jackson	17,720	2,438,400	137.3	3.2	57,555	863,888
Jasper	22,160	2,570,600	114.8	2.7	60,169	910,725
Jefferson	3,540	402,800	115.0	2.7	9,629	142,706
Johnson	31,920	3,812,000	119.8	2.8	90,476	1,350,534
Knox	37,880	4,885,600	130.0	3.1	116,493	1,730,894
Lafayette	94,940	14,157,600	149.0	3.5	334,696	5,015,823
Lawrence	6,780	808,000	116.9	2.8	18,759	286,262
Lewis	53,280	6,404,600	120.3	2.8	151,676	2,269,053
Lincoln	35,780	4,296,600	122.3	2.9	103,500	1,522,220
Linn	19,120	2,515,400	130.9	3.1	59,225	891,168
Livingston	25,220	3,273,200	130.7	3.1	77,989	1,159,645
Macon	24,700	3,441,400	139.0	3.3	81,209	1,219,236
Marion	51,900	6,911,800	133.2	3.2	163,539	2,448,746
Mercer	16,100	2,019,000	125.2	3.0	47,707	715,301
Miller	1,640	178,400	108.2	2.6	4,200	63,204
Mississippi	70,480	11,940,000	169.4	4.0	282,451	4,230,161

Exhibit 1.1.2 Corn Stover Potential for Missouri, Five Year Avg. (2005-2009) Continued

County	Harvested acres	Total production (bu/yr)	Grain Yield (bu/ac)	Corn stover (dry tons per acre)[1]	Corn stover (dry tons per year)	Corn stover (million Btu)[2]
Moniteau	11,920	1,290,000	108.7	2.6	30,645	457,027
Monroe	49,260	5,761,000	116.4	2.8	135,663	2,041,035
Montgomery	40,300	4,313,000	110.1	2.6	105,018	1,528,031
Morgan	4,440	429,160	97.1	2.3	10,200	152,045
New Madrid	73,560	12,171,000	165.5	3.9	288,041	4,312,001
Nodaway	114,680	15,588,400	135.6	3.2	367,819	5,522,734
Osage	8,960	1,163,300	129.5	3.1	27,449	412,140
Pemiscot	22,040	3,385,400	152.8	3.6	79,670	1,199,396
Perry	25,360	3,471,600	137.9	3.3	82,754	1,229,935
Pettis	51,380	5,583,400	109.7	2.6	133,381	1,978,114
Pike	47,820	5,733,000	122.9	2.9	139,006	2,031,115
Platte	39,480	5,669,600	143.7	3.4	134,192	2,008,653
Putnam	11,360	1,462,540	125.8	3.0	33,812	518,156
Ralls	45,460	5,530,200	122.4	2.9	131,694	1,959,266
Randolph	15,060	1,826,800	121.1	2.9	43,157	647,208
Ray	37,600	5,506,800	146.4	3.5	130,275	1,950,976
Saline	133,500	20,375,600	152.7	3.6	482,383	7,218,766
Schuyler	7,640	867,000	113.9	2.7	20,585	307,165
Scotland	35,500	4,538,600	128.0	3.0	107,477	1,607,957
Scott	70,620	11,742,600	166.2	3.9	277,632	4,160,225
Shelby	42,660	5,311,600	124.5	2.9	125,662	1,881,819
St. Charles	41,260	5,989,360	146.2	3.5	142,722	2,121,939
St. Louis	4,280	593,800	141.1	3.3	14,290	210,374
Ste. Genevieve	13,800	1,861,200	136.5	3.2	44,581	659,395
Stoddard	93,260	14,963,600	160.8	3.8	354,722	5,301,377
Sullivan	9,680	1,095,600	112.6	2.7	25,784	388,154
Vernon	42,700	5,370,000	125.6	3.0	126,932	1,902,510
Warren	17,140	2,113,640	124.6	2.9	50,537	748,831
Worth	12,300	1,577,200	128.1	3.0	37,279	558,778

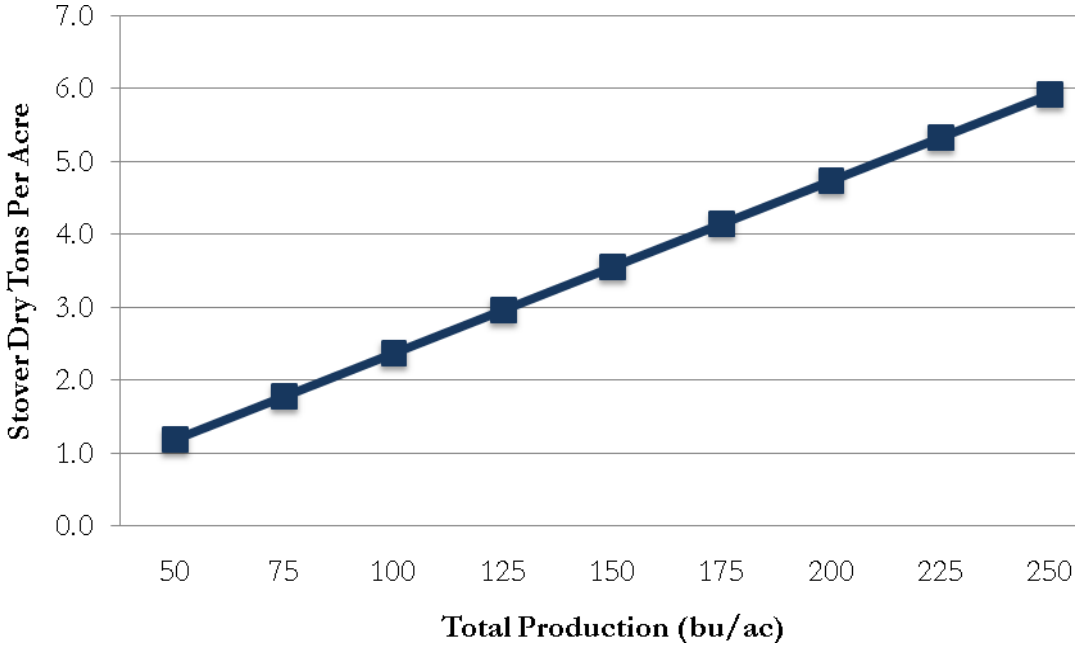
Source: USDA-NASS and University of Missouri

1) Assumptions include a bushel of corn at 56 lbs. with 15.5% moisture and 1:1 grain/stover ratio

2) 7,487 Btu per dry pound of corn stover residue (Argonne National Laboratory, 2008)

Fields that have higher grain yields also have higher production of corn stover. Exhibit 1.1.3 demonstrates the impact of increasing corn yields on the accumulation of corn stover. This exhibit is based on the same dry weight of corn grain/residue ratio of 1:1 that was used in previous exhibits. A corn field that produces 100 bushels per acre yield will produce about 2.4 dry tons of corn stover. If the grain yield reaches 200 bushels per acre, stover production would be estimated at 4.7 dry tons.

Exhibit 1.1.3 Corn Stover Production, with Various Corn Yields per Acre



1.2 Corn Stover Characteristics

The components of corn stover are the husk, cob, leaves, and stalk. Corn stover yields will vary with variety, soil and climatic conditions. Each 35-45 bushels of corn grain per acre will produce approximately one ton of corn stover per acre. If the estimated corn stover yield is based on pounds of dry matter and a 1:1 ratio of residue to grain, each 42 bushels per acre of corn grain will produce 2,000 pounds per acre (1 ton/acre) of stover (Shinners, 2007b; Sawyer and Mallarino, 2007).

Some references refer to corn stover as a "waste" material or a by-product. Fertilizer nutrients are exported from the field when corn stover is harvested and sold as an energy source. Several references cite the fertilizer nutrients contained in one ton of corn stover. Fertilizer nutrient estimates contained in one ton of corn stover expressed as pounds of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) is basically 15-6-25. Nitrogen removal was not considered in several of the citations if soybeans were going to be grown as the crop following the stover removal. Some Nebraska studies cited the potash content as 50 pounds per ton of stover (Wortmann et al., 2008; Brechbill and Tyner, 2008; Hay, 2010; Iowa Learning Farms, 2009; Sawyer and Mallarino, 2007).

The percentages of corn stover components based on a dry matter mass basis (Shinners, 2007b; Pordesimo et al., 2003) are:

- Stalk – 50 to 60% of corn stover residue
- Leaf – 19 to 21% of corn stover residue
- Cob – 8 to 15% of corn stover residue
- Husk - 8 to 13% of corn stover residue

The moisture content of corn stover components is higher than the corn grain component. Moisture contents of the corn stover components will influence harvest procedures and times of stover harvest. As a general rule, stover moisture content is approximately two times the grain moisture content. Exhibit 1.2.1 shows the moisture content of the stover components of corn grain moisture at harvest (Sokhansanj et al, 2002).

Exhibit 1.2.1 Moisture Content of Corn Stover at Harvest

Component	Moisture Content % (Field dried)
Grain	15%
Cob	19%
Husk	24%
Stalk and Leaves	33%

Source: Sokhansanj et al. (2002)

Corn stover harvested and stored at 30% or greater moisture will have increased dry matter and storage losses. In some cases, if the moisture content is high enough, there is danger of spontaneous combustion in the stover bales (Gould, 2007). Moisture in corn stover also impacts the heating value of the product, thus energy plants will want corn stover to have low moisture content.

This data would suggest that corn grain, in most cases, would be harvested at an earlier date than stover. Field loss and the resulting economic loss associated with delayed grain harvest when attempting grain and stover harvest with a "single pass" grain and stover harvesting system does not appear attractive for most producers.

Problems that may be associated with corn stover harvest are a short harvest window, wet stover spoilage and soil compaction as a result of additional field passes especially if wet soil conditions exist. These problems will be more pronounced during wet fall harvest periods. More stover harvesting problems would likely occur the further north the harvest location is located; however, annual average rainfall amounts increase from northwest to southeast in Missouri (Gould, 2007).

Biomass feedstocks have a variety of characteristics that are important considerations for an end user. Exhibit 1.2.2 details many of the key composition and chemical characteristics for various feedstocks. Corn stover is typically composed of 38% cellulose, 26% hemi-cellulose, 19% lignin and 6% ash (Lee et al., 2007). Bulk density of most biomass feedstocks tends to be low when compared to fossil fuels.

Exhibit 1.2.2 Composition of Selected Feedstocks (Percent of Dry Matter)

Feedstock	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Acid detergent lignin (%)	Crude Protein (%)	Ash (%)
Corn stover	38	26	19	4	5	6
Soybean residues	33	14	-	14	5	6
Wheat straw	38	29	15	9	4	6
Mischanthus	43	24	19	-	3	2
Tall fescue	25	25	14	-	13	11
Forage sorghum	34	17	16	-	-	5
Sweet sorghum	23	14	11	-	-	5
Sudangrass	33	27	-	8	12	12

Source: Lee et al. (2007)

One potential challenge with direct combustion of corn stover is the high alkaline content in the stover ash. High alkaline fuels have a tendency to result in increased slagging and fouling in most coal burning boilers. The slagging and fouling impact is site dependent and is based on boiler technology, coal quality, and stover blend percentages.

Exhibit 1.2.3 lists the heating values of corn stover and various other solid fuels. Heating values indicate the total amount of energy available in the fuel. The key difference between the higher and lower heating values is that the higher values include the energy contained in the water vapor in the exhaust gases. Corn stover (dry basis) typically contains a higher heating value of 7,487 Btu per lb., which is the value most commonly used by biomass combustors. The lower heating value for corn stover is 7,038 Btu per lb. It is important to understand that the heat content of corn stover can fluctuate with the climate, seed variety, harvest conditions, moisture, storage, and other production variables. Most central and eastern coals have much higher heating values than biomass feedstocks, however western coals compare more favorably. Like biomass, coal moisture content is an important component of heating value and can vary from 2 to 30 percent.

Exhibit 1.2.3 Lower and Higher Heating Values of Solid Fuels

Solid Fuels	Lower Heating Value (Btu/ton)	Lower Heating Value (Btu/lb)	Higher Heating Value (Btu/ton)	Higher Heating Value (Btu/lb)
Coal (wet basis)	19,546,300	9,773	20,608,570	
Bituminous coal (wet basis)	21,000,000	10,500	28,000,000	14,000
Subbituminous coal (wet basis)	16,600,000	8,300	23,000,000	11,500
Coking coal (wet basis)	24,600,497	12,300	25,679,670	12,840
Farmed trees (dry basis)	16,811,000	8,406	17,703,170	8,852
Herbaceous biomass (dry basis)	14,797,555	7,399	15,582,870	7,791
Corn stover (dry basis)	14,075,990	7,038	14,974,460	7,487
Forest residue (dry basis)	13,243,490	6,622	14,164,160	7,082
Sugar cane bagasse	12,947,318	6,474	14,062,678	7,031
Petroleum coke	25,370,000	12,685	26,920,000	13,460

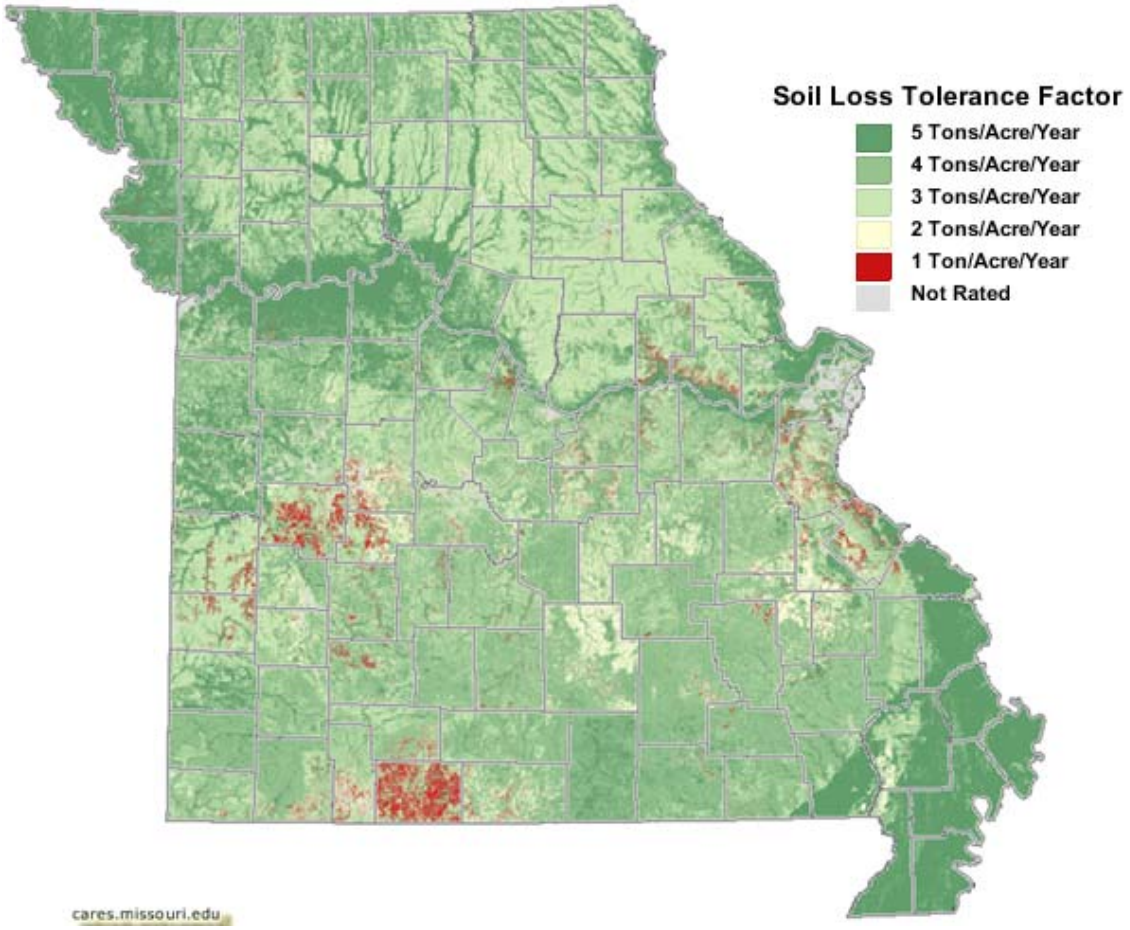
Source: Wright et al. (2009) and Environmental Protection Agency (1998)

1.3 Environmental Constraints

Environmental constraints associated with corn stover harvest must be thoroughly evaluated. This evaluation will determine whether, or in what situations, corn stover can economically be harvested in an environmentally sound manner.

Soil erosion is the primary environmental concern in Missouri on cropland acres. Numerous acres of cropland in Missouri are classified as highly erodible land (HEL) by the Natural Resources Conservation Service (NRCS). HEL determinations are made for all farms that participate in United State Department of Agriculture (USDA) programs. HEL land must be managed so that soil erosion losses are limited to a tolerable soil loss "T" for the production area to remain in conservation compliance and be eligible for USDA program participation. T factor represents the maximum amount of erosion at which the quality of a soil is maintained. Exhibit 1.3.1 shows a map of Missouri with shading for the soil loss tolerance factor, ranging for one to five tons per acre per year.

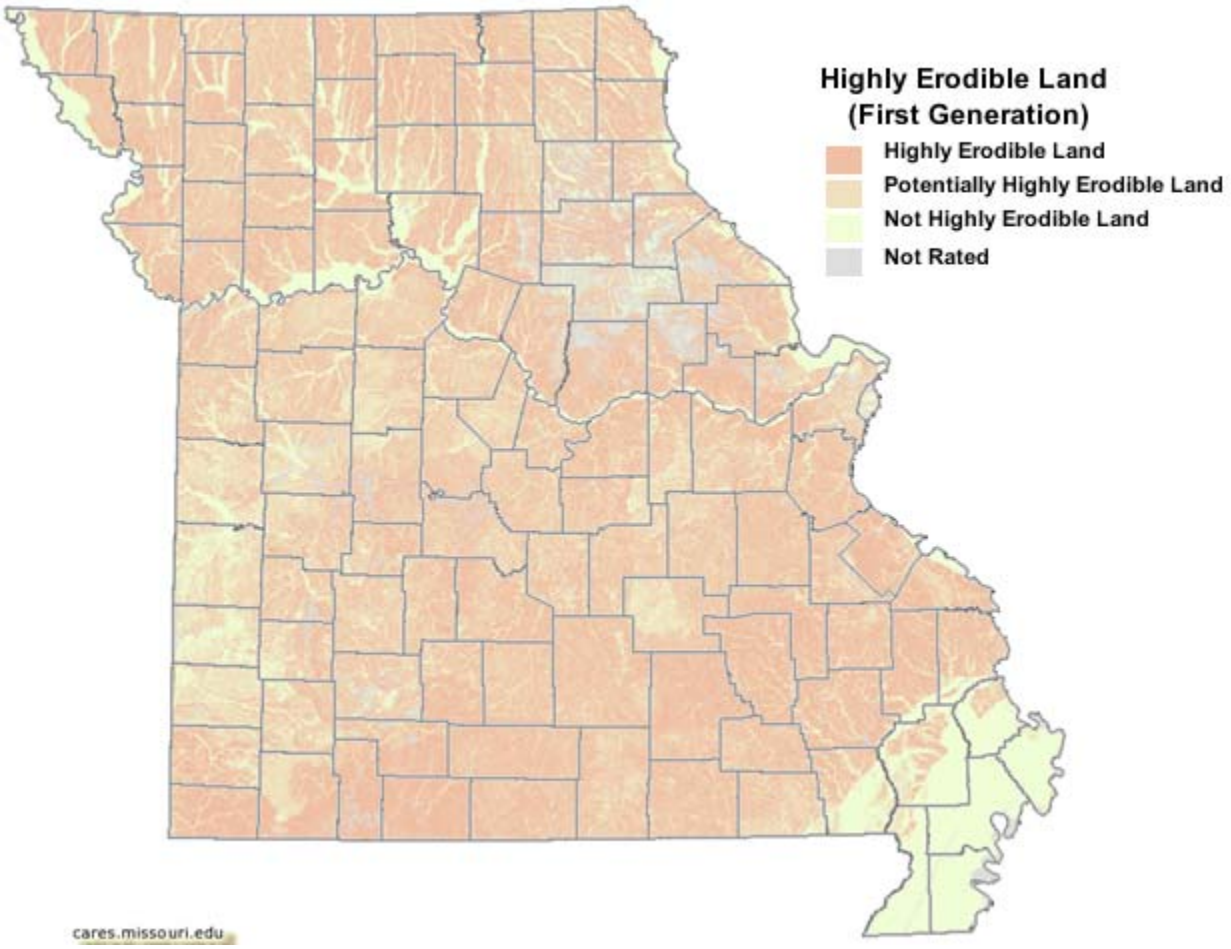
Exhibit 1.3.1 Missouri Soil Loss Tolerance Factor (T Factor)



Source: Center for Applied Research and Environmental Systems (CARES) (2010)

HEL determination is a broad classification of the erodibility of the soil at a particular site. More specific criteria are needed to evaluate the suitability of individual sites and to determine the potential of corn stover harvest areas at these sites. The potential of a corn stover harvest business is directly related to the potential corn stover tonnage that can be harvested in a known geographic area. Highly erodible land is land that has steeper slopes or other factors that increase the likelihood of erosion occurring within a particular soil area. Exhibit 1.3.2 for Missouri highly erodible land is based on the USDA-NRCS Soil Survey Geographic (SSURGO) data base.

Exhibit 1.3.2 Missouri Highly Erodible Land (HEL)



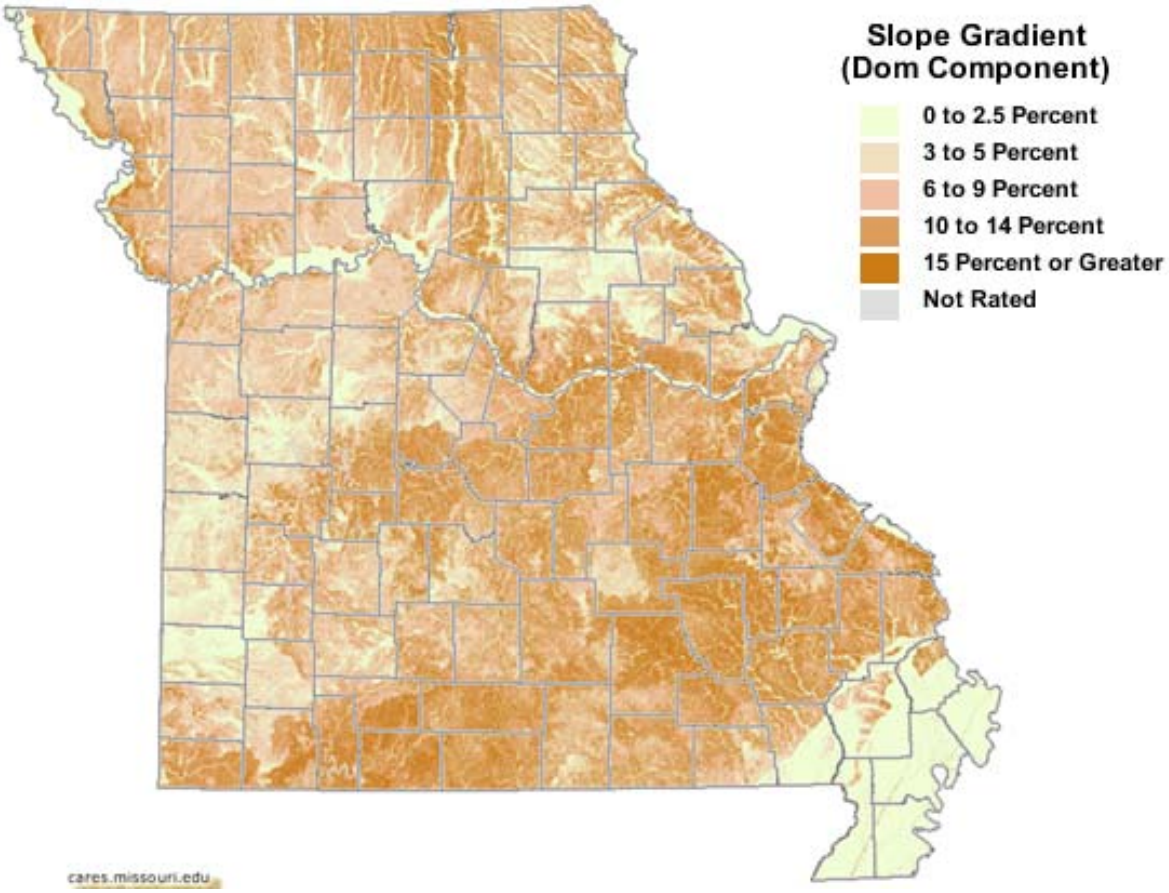
Source: Center for Applied Research and Environmental Systems (CARES) (2010)

Cropland slope as shown in Exhibit 1.3.3 is an easy parameter to evaluate. The claypan and claypan-like soil areas found in north and southwest Missouri are exceptions to using land slope as criteria for stover harvest sites. Claypan soils have reduced permeability and increase runoff potential. These inherent soil properties allow rill erosion on slopes of 2% or less. These claypan soils also have a low soil erosion tolerance because of previous erosion.

An initial land slope evaluation of corn stover harvest sites in the non claypan and claypan-like areas of Missouri are based on basic recommendations from Blanco-Canqui and Lal (2009) and adopted by Missouri NRCS are as follows:

- No corn stover would be harvested from fields with land slopes greater than five percent.
- No more than 25% of the corn stover would be harvested from fields with land slopes of two to five percent.
- No more than 50% of the corn stover would be harvested from fields with land slopes less than two percent.

Exhibit 1.3.3 Missouri Slope Gradients



Source: Center for Applied Research and Environmental Systems (CARES) (2010)

There are six general areas in Missouri that produce sizeable corn acres. These are:

- Northwest Missouri
- Northeast Missouri
- Central Missouri
- West Central
- Southeast Missouri
- River Corridors

The corn producing areas that are located in river bottoms usually do not have slopes that make soil erosion a concern. The clay-pan soils in Northeast Missouri have increased soil erosion problems because of slow permeability that increases runoff potentials. Other areas will have constraints on individual fields that require evaluation.

All upland locations must be evaluated for soil erosion potentials based on a number of variables. The Revised Universal Soil Loss Equation Version 2 (RUSLE2) is one method to predict the soil loss. RUSLE2 is very detailed equation with multiple inputs that predicts soil loss from a specified area or field. Use of RUSLE2 requires extensive training to correctly make the inputs so that soil loss is correctly estimated. NRCS and other trained personnel can assist producers in making RUSLE2 evaluations. Major input parameters for use in RUSLE2 include:

- Soil type that is taken from the NRCS soil survey of the site,
- Climate is also an input in the model,
- Topography (slope percent and slope length – slope length may be changed with terraces or other mechanical practices),
- A choice of crop rotations with reasonable yield goals, and
- An extensive list of tillage options and other field operations which include direction of farming with respect to the land slope (Karkee et al, 2010).

Another environmental and production constraint is soil organic carbon (SOC) and soil organic matter (SOM) that are required to maintain soil quality, fertility and structure. Research, although limited, indicates that more crop residue will probably be needed to maintain SOC than would be required to control water and wind erosion. Residue removal rates greater than 25 percent reduce SOC. The Renewable Energy Assessment Project (REAP) of the Agricultural Research Service (ARS) is involved with an in-depth study of soil carbon, tillage methods, cover crop usage, and corn stover removal in an attempt to better assess the interaction of these production variables and establish some guidelines for corn stover harvest. (Asrar, 2007; Blanco-Canqui and Lal, 2007; Blanco-Canqui and Lal, 2009; Comis and Perry, 2009; Cruse and Herndll, 2009; Karkee et al, 2010; Wilhelm et al., 2007)

Tillage methods influence soil erosion and, possibly, the quantity of biomass required by the soil to maintain SOC. Biomass quantities were eight times greater to maintain SOC in limited/no-till continuous corn and corn-soybean rotations are more than that required to control erosion from water. The quantity of biomass required to maintain SOC for plow tillage in both rotations was approximately two times the biomass required to control water erosion (Hay, 2010). Another study estimates that 2-3 tons of residue per acre needs to remain on the land to maintain SOC. (Wortmann et al., 2008)

Corn stover, due to the large physical properties and volume of stalks, contributes to additional mechanical wear and break-down of harvesting equipment. This is especially true if harvesting equipment designed for the harvest of grass and legume forages is used for corn stover harvest. There are, however, several farm equipment manufacturers that are developing and marketing corn stover and other biomass harvesting machines that should improve harvesting equipment reliability.

Sustainable corn stover harvest will require a favorable site as not all sites will be suitable because of land slope, soil type and other limiting physical properties. Most sites will require the producer to adopt a crop rotation and a particular tillage system. The tillage system will probably be a limited or no-till system. Crop rotations may contain several years of continuous corn, soybeans and possibly a small grain crop to maintain adequate residue cover. A cover crop requirement after stover harvest might also be needed.

The National Crop Residue Management Survey that is conducted by the Conservation Technology Information Center shows U.S. corn production data in regards to residue management and tillage practices. There was a total of 83 million corn acres in the 2008 summary, further broken down into two tillage categories: conservation tillage and other tillage practices. Conservation tillage practices allow for at least one-third of the soil covered with crop residue after planting. In other tillage practices, reduced-till leaves approximately 15-30% of the residue on the surface, while intensive-till results in less than 15% remaining after planting. The conservation tillage category averaged 33 million acres (40%), while other tillage practices totaled 50 million acres (60%).

Of the total conservation tillage acres, no-till comprised 17 million acres (21%), mulch-till was 15 million acres (17.8%), and ridge-till was the least utilized at one million acres (1.4%). In regards to other tillage practices, reduced-till was used on 20 million acres (24.3%), while intensive-till had 30 million acres (35.5%) in practice on corn acreage.

Corn stover harvest might not be done annually in continuous corn and also might be limited to some percent of the stover produced on any field. Stover harvest limits may be 25 percent on steeper slopes and capped at 50 percent on all fields. These stover harvest limitations will be based on land slopes or, in many cases, on detailed evaluations with tools such as RUSLE2.

There is research from Iowa that indicates that a minimum corn grain yield of 110 bushels per acre is required in continuous corn production fields and a minimum corn grain yield of 170 bushels per acre in corn-soybean rotation field before any stover should be harvested (Hay, 2010).

Corn stover harvest may provide an opportunity for livestock producers to utilize additional manure nutrients to replace the fertilizer nutrients exported in the stover. Manure will also add organic materials to the soil that will aid in maintaining the SOC levels in the soil (Fronning et al., 2008).

Continued evaluation of corn stover harvest practices will be needed to ensure maintenance of SOC so that soil structure and productivity are maintained. Research projects at the University of Missouri's Bradford and Greenley Farms are being conducted to:

- Determine the optimum nutrient management practices for environmentally safe and economically viable bio-fuel crop production.
- Evaluate long-term effects of bio-fuel crop production on selected chemical, physical and microbiological properties of cropland.

Chapter 2: Corn Stover Demand

2.1 Overview of Marketplace

Federal energy policies are moving towards an increase in renewable energy sources. For example, the proposed American Clean Energy Security Act would have established a renewable electricity standard of 20% by 2020. If emission reduction legislation would be enacted, the carbon credit market could potentially evolve toward higher prices for these credits as many of the affected industries would need offsets to achieve compliance. While none of the current renewable energy bills passed in the 2010 legislative session, it demonstrated that there is political pressure at the federal level for renewable energy and cap-trade programs. Federal support for renewable energy projects in recent years has increased and there have been financial incentives offered in research dollars, production incentives, grants and loans for renewable energy.

Changing attitudes and an increased awareness for renewable energy sources has slowly changed Missouri's energy portfolio (See Exhibit 2.1.1). Ethanol plants (note as million gallons per year [mGy]) and wind energy installations have created the most renewable energy capacity when compared to other technologies in Missouri. Wind energy projects are leading the Missouri renewable energy industry with 99 MW under construction. Approximately 16.2 megawatts (MW) are currently under construction for biomass (including the University of Missouri (MU) Biomass Combined Heat and Power Project) in Columbia. This MU project will contribute 10-16 MW of electrical energy depending on the campus thermal load.

Exhibit 2.1.1 Missouri's Renewable Energy Projects (Power Generation and Ethanol)

Technology	Installed projects (12/09)	Projects under construction
Wind	358 MW	99 MW
Grid-Connected Solar	0.2 MW	0 MW
Biomass	0 MW	16.2 MW
Bioethanol	261 mGy	0 mGy

Source: American Council on Renewable Energy (2010) and University of Missouri Power Plant

Renewable energy is being promoted at the state level through various programs. Programs such as net metering, green power purchases, and a renewable portfolio standard will have impact on the evolution of renewable energy programs in Missouri.

Corn stover and corn cobs have potential as biomass feedstock. Corn stover and corn cobs currently are being used, on a limited basis, on various industrial or livestock related applications. Markets are starting to develop for corn stover and other biomass feedstock. Burning biomass in power plants, cellulosic ethanol plants, biomass densification businesses and other biomass applications are being investigated. Markets for corn stover and corn cobs in the state of Missouri must be thoroughly investigated and, if economically feasible and environmentally sound, developed to support renewable energy efforts.

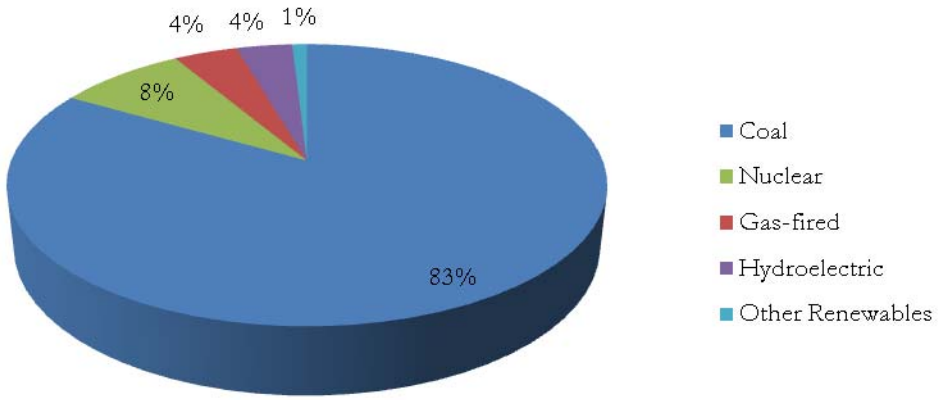
2.2 Missouri Power Plants

The electricity used to power homes and businesses in Missouri comes largely from fossil fuels and other non-renewable sources (See Exhibit 2.2.1). Coal has a long history in Missouri. Missouri was the first state to produce coal commercially west of the Mississippi and historically, coal has dominated electricity generation in Missouri. Today Missouri mines produce small quantities of coal. Coal is used to generate a significant portion of Missouri's electricity generation. More than 80% of electricity generation for Missouri's residential and commercial electricity consumers comes from coal fired generators.

Coal is still mined on a very small scale in Missouri; however, the state no longer has any major coal mines. The remaining coal in Missouri occurs in very narrow bands to be mined economically. A large percentage of Missouri coal has a high sulfur content, which leads to significantly higher emissions and requires the installation of sulfur scrubbing technologies. Over 90% of the coal used in Missouri power plants comes from Wyoming and is transported by train.

Nuclear generation is the largest source of non-coal electricity generation in Missouri. Missouri is home to one nuclear plant in Callaway County that supplies approximately 8-10% of Missouri's annual electricity. Gas and hydroelectric sources annually supply 4% to Missouri's electrical grid system.

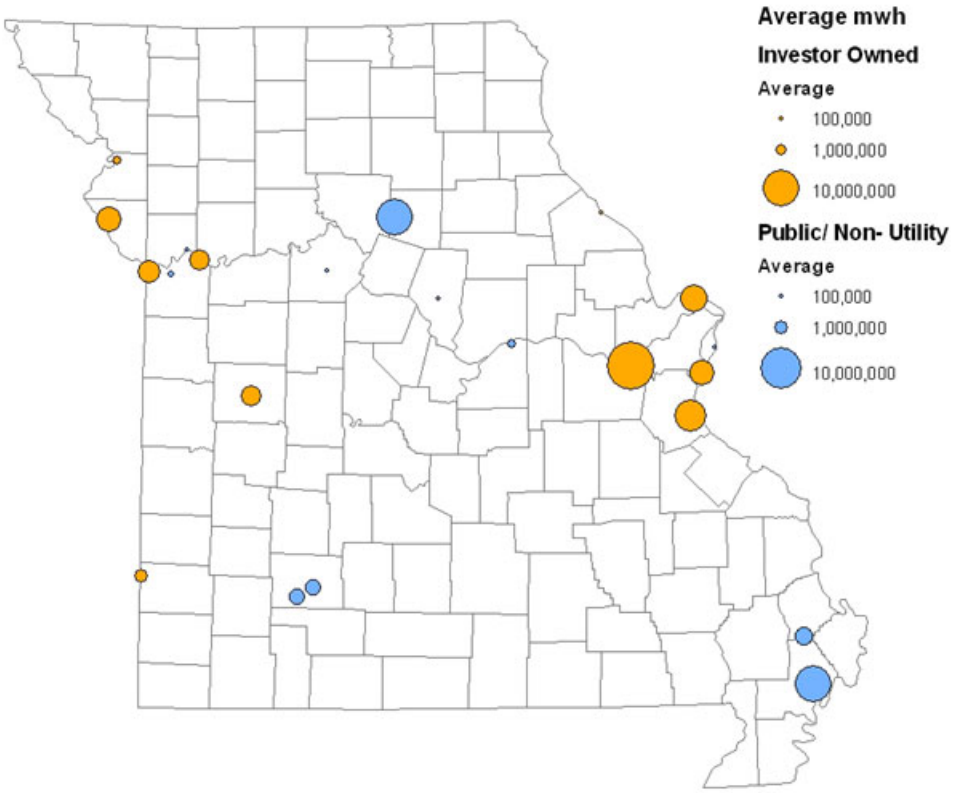
Exhibit 2.2.1 Missouri Electricity Sources, January – June 2010



Source: US Energy Information Administration

There are currently 23 operational coal fired electrical generation plants in Missouri and eleven (11) of these generation plants are investor-owned businesses. Coal plant city locations and average megawatt hour power production (depicted by size of the circle in relation to the exhibit key) for these plants is shown in Exhibit 2.2.2. Exhibit 2.2.3 demonstrates the top ten plants in Missouri and lists their primary energy sources and operating companies. Eight of these plants utilize coal as a primary source.

Exhibit 2.2.2 Missouri Coal Plant Location and Average MWh Production



Source: US Energy Information Administration

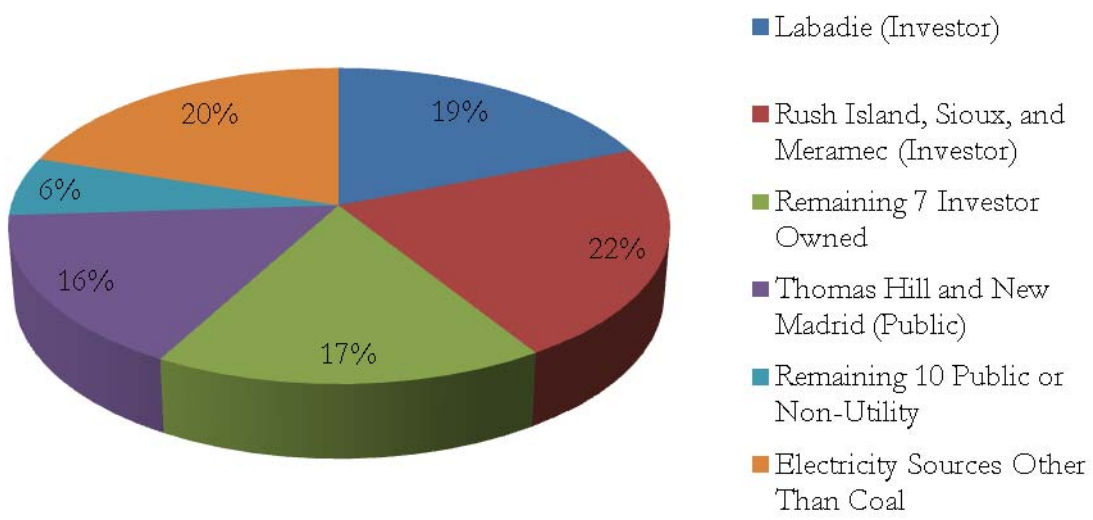
Exhibit 2.2.3 Missouri Ten Largest Plants by Generation Capacity, 2008

Plant	Primary energy source or technology	Operating company	Net summer capacity (MW)
1. Labadie	Coal	Ameren UE	2,406
2. Callaway	Nuclear	Ameren UE	1,190
3. Rush Island	Coal	Ameren UE	1,181
4. New Madrid	Coal	Associated Electric Coop, Inc	1,160
5. Thomas Hill	Coal	Associated Electric Coop, Inc	1,120
6. Sioux	Coal	Ameren UE	993
7. Hawthorn	Coal	Kansas City Power & Light Co	980
8. Meramec	Coal	Ameren UE	950
9. Iatan	Coal	Kansas City Power & Light Co	651
10. Aries Power Project	Gas	Dogwood Energy LLC	620

Source: US Energy Information Administration

Electric power generation by coal plants are summarized in Exhibit 2.2.4. The largest coal plant in Missouri is Labadie Power Plant in Franklin County. Labadie Power Plant generates 19% of the total amount of electricity for the state. Rush Island, Sioux, and Meramec in Jefferson, St. Charles, and St. Louis Counties, respectively, generate another 22% of the total electricity generated in Missouri. The largest public utility coal plants—Thomas Hill and New Madrid in Randolph and New Madrid Counties—generate 16% of the total electricity generated in the state. The remaining ten public utilities or non-utility coal plants generate another 6%. The remaining seven investor-owned coal plants generate another 17% of the electricity used in Missouri.

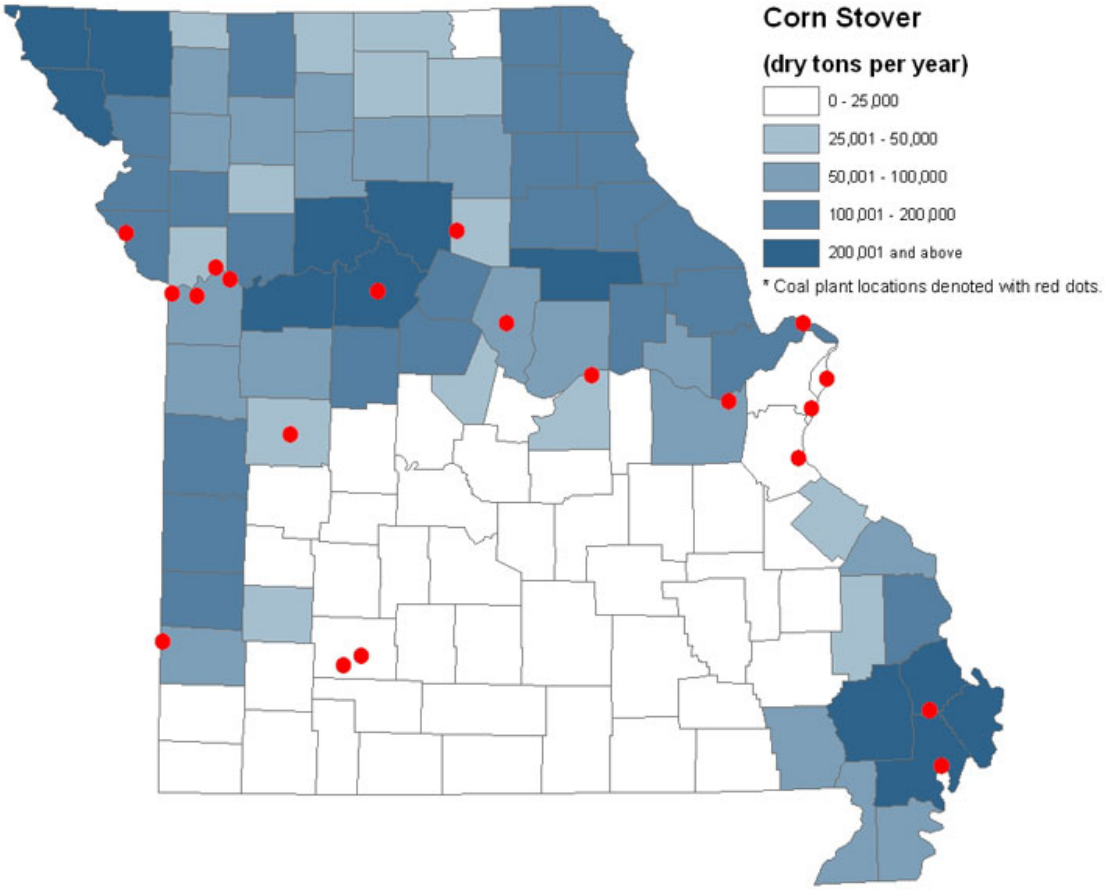
Exhibit 2.2.4 Power Plant Generation by Plant and Ownership



Source: US Energy Information Administration

Transporting corn stover feedstock has logistical challenges because of the low density of the stover. The supply of corn stover and the location of Missouri's coal fired electrical generation plants are important because transportation of corn stover is a major economic consideration of biomass burning. Exhibit 2.2.5 shows Missouri coal plant locations (reported by US Energy Information Administration) along with county level corn stover production. This exhibit shows annual corn stover production and coal fired plant locations. No reductions are made for areas where environmental or soil sustainability restrictions may limit corn stover harvest.

Exhibit 2.2.5 Missouri Corn Stover and Coal Plants



<u>Renewable Portfolio</u>

With the changing attitudes towards energy and an increased awareness for renewable sources, Missouri's energy portfolio is slowly changing (see Exhibit 2.2.6). Before 2006, Missouri had no large generation capacity from sources such as wind, landfill gas or agricultural by-products. The major source of renewable energy in Missouri has traditionally come from hydroelectric plants. Wind has been increasing in recent years, jumping to 163 megawatts in net summer capacity in the year 2008. Between 2004 and 2008, Missouri's renewable electric power industry capacity rose approximately 32%.

Exhibit 2.2.6 Missouri Renewable Electric Power Industry Net Summer Capacity

Energy source	2004	2005	2006	2007	2008
	Megawatts				
Geothermal	-	-	-	-	-
Hydro Conventional	556	552	552	552	566
Solar	-	-	-	-	-
Wind	-	-	-	57	163
Wood/Wood Waste	-	-	-	-	-
Municipal Solid Waste/Landfill Gas	-	-	3	3	5
Other Biomass	-	-	-	-	-
Total	**556**	**552**	**555**	**612**	**734**

Source: US Energy Information Administration

Missouri Renewable Portfolio Standard

Coal is likely to remain the dominant electricity generation source in Missouri. The role of coal in electricity generation will be minimized by renewable sources in the future. Missouri is one of 32 states with a Renewable Portfolio Standard. In November 2008, Missouri voters passed Proposition C, which requires investor-owned utilities to increase renewable energy sources to 2% by 2011, 4% by 2012, 8% by 2015, 11% by 2020 and 15% by 2021. Bonus credits are awarded whenever the renewable sources are produced in the state. Renewable Energy Certificates (REC) is used to document renewable energy that is delivered to the electric grid and document compliance with renewable standards. Missouri investor owned electric utilities that would need to comply with this standard include Ameren UE, Kansas City Power & Light, KCPL-Greater Missouri Operations Company and the Empire District Electric Company.

In addition to Missouri's Renewable Portfolio Standard pressuring investor owned firms to use renewable energy, other firms in the state are voluntarily allowing consumers the choice of buying renewable energy. Twelve of Missouri's distribution cooperatives supplied by Associated Electric Cooperative, Inc offer their customers' green power energy. Renewable energy sources that have supplied the green power program have come from wind farms, hydropower sources and co-firing biomass in coal plants. The biomass energy was historically generated at Central Electric Power Cooperative's Chamois Power Plant, but this plant is not currently using biomass today. Primary source of their green energy is currently coming from wind farms. This green power is sold in 100-kWh monthly increments at price premiums ranging from 2 to 3.5¢/kWh to participating cooperatives. Additionally, Ameren UE has a voluntary program called "Ameren UE Pure Power", where residential and business customers can pay more on their utility bill to help Ameren UE purchase RECs.

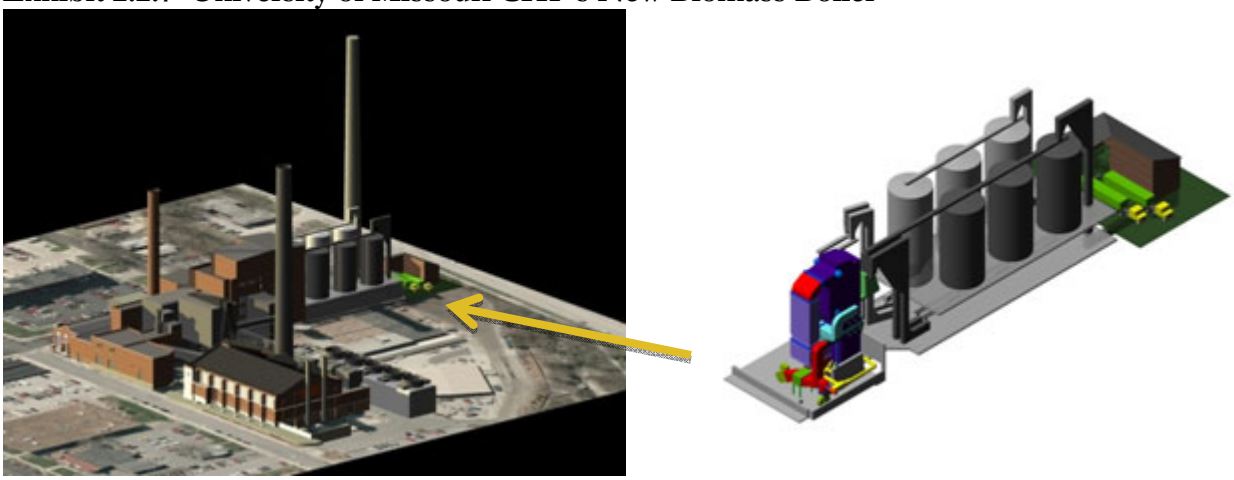
Missouri's Renewable Portfolio Standard will require more renewable energy sources in the future. The US Energy Information Administration (EIA) places the majority of Missouri within the Mid-America Interconnected Network (MAIN). According to the EIA's Annual Energy Outlook for 2010, MAIN states, which include Illinois, most of Missouri and Wisconsin, will see an increase in electricity generated from conventional hydropower; biogenic municipal waste (includes landfill gas and municipal sewage sludge); wind; and wood and other biomass (including agriculture by-products). From 2008 to 2035, electricity generated from conventional hydropower is expected to increase by 0.9%; from biogenic municipal waste by 4.5%; from wind by 6.8%; and from wood and other biomass by 25%. Over the same time period, coal use for electricity generation is only expected to rise by 0.5%, natural gas by 2.7% while petroleum use is expected to fall by 0.5% and nuclear is expected to remain constant.

University of Missouri Combined Heat and Power Plant (CHP)

In the past few years the University of Missouri (MU) began co-firing biomass fuel sources in its existing boilers. The biomass provides environmental benefits and is helping MU increase its use of sustainable resources. Citing Missouri's agriculture and wood industries as a reason the University was well-suited to use biomass fuels, the University began test co-firing corn cobs and other biomass feedstocks such as switchgrass and wood waste. These tests demonstrated the feasibility of biomass co-firing in MU's combined heat and power (CHP) plant and the associated benefits of biomass fuels. Biomass co-firing is environmentally sound, is sustainable, and provides regional economic benefit by buying local biomass versus out of state coal or gas.

Due to the initial success of using biomass as fuel, the University of Missouri evaluated biomass as a fuel choice in addition to conventional fuels for a boiler needed to serve the campus. This evaluation concluded that a biomass fired boiler provided MU with the best value to serve its energy needs. The new boiler is being fabricated (See Exhibit 2.2.7) and is expected to go online in 2012. This new boiler will increase usage of biomass feedstock to approximately 100,000 tons annually and reduce MU's use of coal by 25%. Most of the biomass burned by the new boiler will come from wood waste and other woody sources, such as logging residues, forest management cuttings, storm-damaged trees, mill waste, development clearing, and chopped pallets. The University also expects using agricultural residues such as corncobs and corn stover as a fuel source in its new boiler. Long term, the University may utilize specifically grown energy crops such as short rotation woody biomass and perennial grasses that could be grown on non-traditional crop land. Several MU research projects are underway to determine the best energy crops for this region

Exhibit 2.2.7 University of Missouri CHP's New Biomass Boiler



Design graphics courtesy of Sega, Inc, Project Designer

Co-firing Corn Stover and Cobs

Co-firing is a practice that involves substituting biomass (such as agriculture residue or wood waste) for a portion of coal in an existing furnace. It is also a method for reducing CO_2 emissions for power plants. Direct co-firing biomass in existing boilers tends to cost 2-5 times less to incorporate than other bio-electricity generation options (Berndes et al, 2010). This presents an opportunity for existing power plants to add renewable fuel sources to their electricity production and add another market opportunity for farmers.

One potential challenge with direct combustion of corn stover is the high alkaline content in the stover ash. High alkaline fuels have a tendency to result in increased slagging and fouling in most boilers. The extent of impact is site dependent and based on boiler technology, coal quality, and stover blend percentages. While chemical analysis of the stover may aid in determining co-firing feasibility, the true test is site specific empirical testing. Based on its initial testing of corn cobs and wood chips (See picture in Exhibit 2.2.8), MU predicts that it may be able to co-fire 5 to 10% corn stover biomass in their stoker boilers. The biomass potential may be much less in utility boiler technologies such as pulverized coal.

Exhibit 2.2.8 Coal and Biomass Mixture

Photo courtesy of Gregg Coffin, MU CHP Plant

According to the Federal Energy Management Program, co-firing is feasible for utilities and other coal plants when most or all of the following conditions are met:

- Coal prices are high
- Annual coal use is significant
- Local or facility-generated supplies of biomass are abundant
- Local landfill tipping fees are high and it is costly to dispose of biomass
- Plant staff and management are highly motivated to implement the co-firing project

Exhibit 2.2.9 illustrates corn stover tonnage needed to displace certain levels of coal consumption in existing Missouri facilities. Plant fuel consumption data (short tons [2,000 pounds] and MMBtu [one million Btus]) was gathered from the US Energy Information Administration (EIA) for the year 2008. Corn stover was assumed to provide 14.974 MMBtu per short ton. The plant's projected fuel consumption (MMBtu) was divided by the assumed corn stover heat value to estimate how many tons of stover would be needed to replace the required MMBtu for 1% and 5% consumption percentage levels. A one percent corn stover usage in all Missouri coal plants would require 518 thousand short tons of corn stover on an annual basis.

Exhibit 2.2.9 Estimated Corn Stover Tonnage for Missouri Plant Coal Replacement

Missouri Facility Name	Total fuel consumption in 2008 (short tons)	Total fuel consumption in 2008 (MMBtu)	1% of fuel displaced (short tons)	5% of fuel displaced (short tons)
Asbury			9,322	46,612
Hawthorn	2,163,506	36,563,359	24,417	122,089
Montrose	2,026,988	35,376,617	23,625	118,126
Sibley	1,477,409	27,565,737	18,409	92,045
Lake Road	480,450	9,167,594	6,122	30,611
Labadie	10,201,605	178,780,817	119,394	596,970
Meramec	3,609,369	62,916,337	42,017	210,085
Sioux	3,058,536	58,946,772	39,366	196,830
Columbia	50,437	1,311,362	875	4,378
Blue Valley	208,631	4,753,501	3,174	15,872
Marshall	55,193	1,228,398	820	4,101
James River Power Station	1,146,961	20,001,266	13,357	66,786
New Madrid	4,398,433	75,791,063	50,615	253,075
Thomas Hill	4,224,573	72,841,821	48,645	243,227
Chamois	313,272	5,620,875	3,753	18,768
Missouri City	34,182	802,093	535	2,678
Iatan	2,512,995	42,635,840	28,473	142,366
Rush Island	5,254,765	88,151,938	58,870	294,350
Southwest Power Station	591,234	10,307,948	6,883	34,419
Sikeston Power Station	1,121,843	19,351,412	12,923	64,616
Ashland Inc	124,700	2,743,400	1,832	9,160
Anheuser Busch St Louis	141,523	3,299,552	2,203	11,017
University of Missouri Columbia	177,191	4,015,625	2,681	13,408
Total	**44,154,172**	**776,132,734**	**518,311**	**2,591,589**

Source: 2008 Fuel consumption reported by US Energy Information Administration

There are additional variables and challenges to utilizing biomass when compared to using coal in co-fired combustion plant systems. The heat value of combusted corn stover can reasonably compare to some of the "western" coals. The combusted heat values will vary for both products but in many cases corn stover will produce 70-80 percent of the lower heat value of coal when compared on a per pound basis (Wright et al, 2009).

Transportation, storage and handling of corn stover, when compared to coal on a bulk density basis of pounds per cubic foot (lb/ft^3), results in some logistical challenges. Bulk density of coal ranges from 40 – 60 lb/ft^3 while corn stover biomass is much less. Corn stover baled in large round bales is usually in 5-7 lb/ft^3 and 6–10 lb/ft^3 when baled in large square bales. The result is increased volumes of combustible material that must be transported, stored and handled (Wright et al, 2009; Shinners, 2007b).

Studies indicate that increasing the bulk density of corn stover to a minimum bulk density of 15-16 lb/ft3 would ease the transportation problem as trucks could potentially be loaded to capacity for most rural roads. On-site storage of large bale stover packages should not present long term storage problems as space would be available. Large stover package storage, at point of use, might be limited depending on the combustion plant site development and space that might be available for storage (Shinners, 2007).

Types of boilers (stoker, cyclone, pulverized) currently used in electrical generating plants will dictate how the corn stover needs to be processed and resized. Further investments may be needed in a separate fuel feed and/or burner system. Some boilers may exhibit problems and not be suitable for using corn stover. Coal plants would most likely conduct some boiler trials to test the usage of corn stover at a specific facility. Associated Electric Cooperative does not currently use biomass in any of their coal fired generating plants; however, Jeff Johns, manager of transmission policy, identified these potential challenges to using corn stover in their existing plants:

- Fuel handling, fuel preparation and fuel delivery
- Derating of unit to accommodate a target biomass blend
- Boiler operating performance
- Boiler reliability (i.e. long term affects of burning the biomass)

Communications have been made with Associate Electric Cooperative and Ameren UE concerning their interest in co-firing corn stover. Associated Electric Cooperative identified three plants that would most likely be suitable for co-firing stover; Chamois, New Madrid and Thomas Hill. Ameren UE has been conducting some very preliminary research related to biomass and corn stover in particular as a co-firing fuel at some of our existing coal fired power plants. Both businesses indicated interest, but further discussions and product trials would be needed to potentially create a new Missouri market for corn stover by co-firing with coal.

Green Energy Power Plant

Several companies are investigating the intensive use of corn stover as a feedstock for electric power generation within the US. There are plans in Rock Falls, Illinois for the development of a 25 megawatt biomass electric generation plant. BioPro Rock Falls, LLC is planning to use corn stover as the primary feedstock for the plant. BioPro Power, a separate company, will be responsible for all aspects of harvest and delivery of corn stover to this proposed plant. Approximately 50% of stover will be removed from fields of participating farmers. Farmers are not being asked to be investors in the power plant; they are only being secured for access to their corn fields. The access payment rates for farmers have not been yet finalized. Construction of the power plant is expected to be complete by late spring of 2012. This is not a market for corn stover in Missouri; however, it does show movement in the US for developing biomass generation.

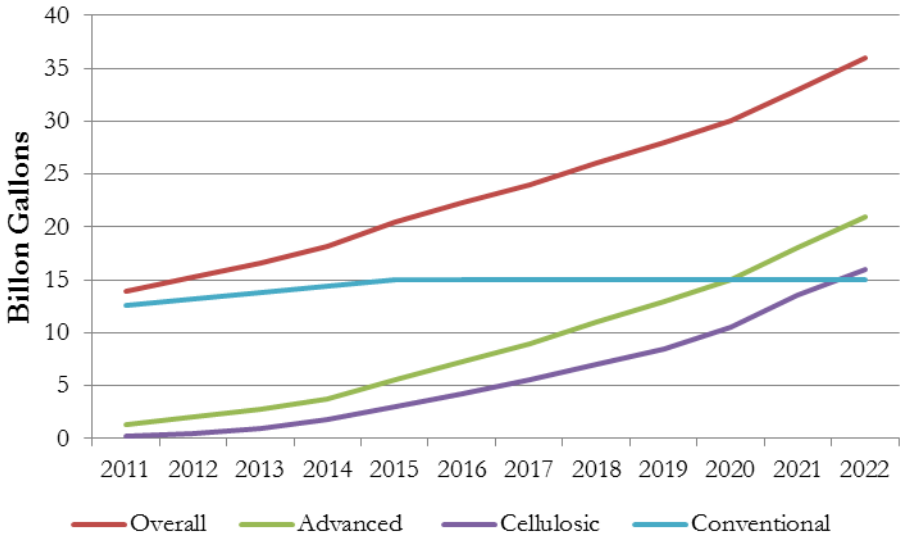
2.3 Cellulosic Ethanol Plants

Ethanol is an alternative fuel or blending agent for traditional gasoline, and is used in most automobiles today. Corn-based ethanol is currently the dominate form of ethanol used in the United States. Ethanol fuel from other sources is being developed and some sources may soon be available for commercial use.

Renewable Fuel Standards (RFS)

There are several factors driving the ethanol fuel market today. One major factor is the Energy Independence and Security Act (EISA) of 2007 and the expansion of the Renewable Fuel Standards (RFS) created by the 2005 Energy Policy Act. EISA requires the use of 36 billion gallons of biofuel per year by 2022 (See Exhibit 2.3.1). The Renewable Fuel Standard also requires the minimum standard of cellulosic ethanol to be 16 billion gallons. US Environmental Protection Agency (USEPA) recently lowered the cellulosic mandate for 2010 to 6.5 million gallons because the cellulosic industry was unable to meet the original 2010 mandate. Significant expansion will be required to reach the future annual mandates for cellulosic ethanol.

Exhibit 2.3.1 EISA Renewable Fuel Standard Mandates



Source: Thompson et al. (2010)

EISA also provided financial support for cellulosic ethanol businesses. Ethanol suppliers can receive a $1.01 gallon tax credit per gallon for cellulosic ethanol and also receive a 50% depreciation deduction for eligible plants through 2012.

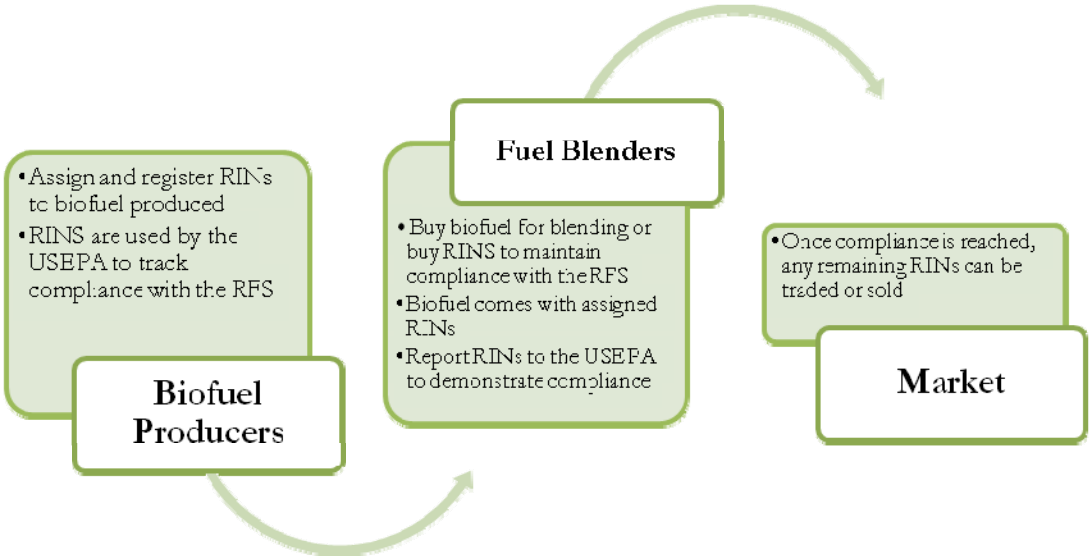
Ethanol is currently used in most states as a fuel additive. The standard, maximum blend for most vehicles is E10. E10 is a 10% ethanol and 90% petroleum-based gasoline blend. USEPA recently allowed the blend level to increase to E15—which is a 15% ethanol and 85% gasoline blend—for automobiles manufactured during and since 2007. USEPA is awaiting further research data to possibly allow E15 in automobiles manufactured from 2001-06. The State of Minnesota and the Renewable Fuels Association (RFA) have completed a study showing blends up to E20—blends of 20% ethanol and 80% gasoline—to be useable in automobiles manufactured since 2000.

Vehicles manufactured to use increased amounts of ethanol are the flex-fuel vehicles which can use ethanol blends up to E85. Flex-fuel vehicles account for only 3.5% of all non-diesel automobiles currently on the road in the United States. Higher acceptable ethanol blends for non-flex-fuel vehicles will increase the demand for ethanol as some refiners and importers seek to maximize ethanol use. Refiners and importers may be motivated to increase ethanol use in blending because any amount of ethanol blended over the USEPA compliance level results in a potential economic product—as tradable or sellable Renewable Identification Number (RIN).

Renewable Identification Number (RIN)

Entities supplying gasoline to the marketplace, either through refinement or importation, are bound to the requirements of the Renewable Fuel Standard. To ensure compliance, the USEPA tracks the biofuel portion of the blended fuel through the use of RINs, which their function is presented in Exhibit 2.3.2.

Exhibit 2.3.2 How RINs Work



Source: Thompson et al. (2010)

The Renewable Fuel Standard mandates a certain amount of biofuels in the market and the USEPA uses RINS to ensure compliance with the mandate. When the cost to blend gasoline with ethanol is greater than the cost of RINs, the refiner or importer will likely choose to purchase RINs. Anyone who is registered with the USEPA can buy and sell RINs.

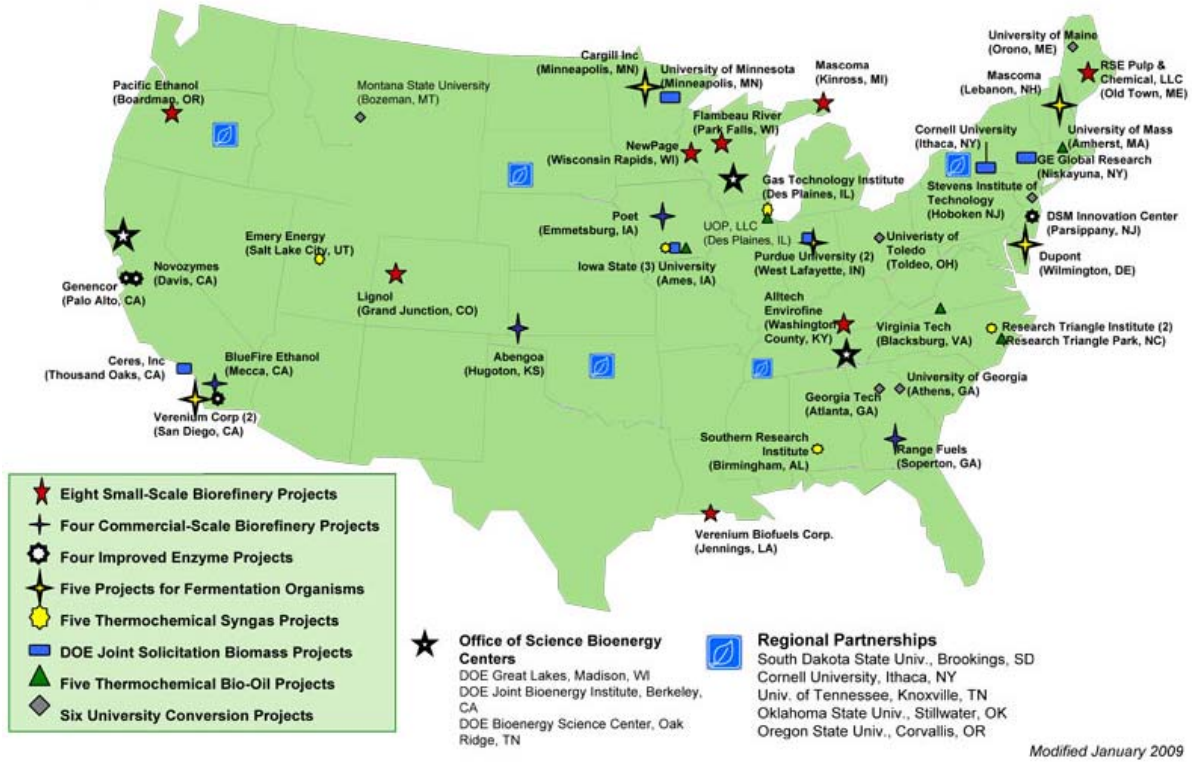
USEPA has mandated an approximate 8% renewable fuel to gasoline blend for 2011. State law in Missouri, however, requires renewable fuel blends of 10%. Refiners planning to serve the state of Missouri have additional incentives. Every gallon of ethanol used to meet Missouri's E10 requirement that is above the USEPA's requirement can be separated from its RIN and the RIN can then be sold or traded. The market for RINs is currently in its early stages and trading or sales will evolve in the future.

Cellulosic Ethanol

Cellulosic ethanol is seen as one of the largest potential source of next-generation biofuels. Cellulosic ethanol is generally produced from the nonedible parts of plants. Corn stover, switch grass, woodchips, forestry residues, urban waste, and byproducts of lawn maintenance can all serve as feedstock for cellulosic ethanol plants. Agricultural resources alone can produce one billion dry tons of biomass for cellulosic ethanol each year and still meet food, feed, and export demands.

The technology to produce cellulosic ethanol has been known for over 100 years. Recent technological improvements have been made that allow commercialization of the cellulosic process. The Renewable Fuel Standard, Departments of Energy (DOE) and production incentives are currently driving production projects of cellulosic ethanol plants around the country. Exhibit 2.3.3 shows the various major DOE biofuel locations across the US.

Exhibit 2.3.3 Major DOE Biofuels Project Locations



Source: US Department of Energy

The 2010 capacity of US cellulosic ethanol plants is 10.3 million gallons, according to the USDA-ERS. Challenges of the cellulosic ethanol industry include reducing high operating and capital costs, and establishing reliable feedstock supply networks. There are a number of companies pursuing various cellulosic ethanol technologies that will have future impact on agriculture.

Of the 20 cellulosic ethanol plants currently in project development, five of these will use agricultural residues or corn stover as feedstock. The largest of these five plants is POET located in Emmetsburg, Iowa (also known as Project Liberty). POET is currently in the development stage and hopes to reach commercial production by 2012. POET plans to produce 25 million gallons of cellulosic ethanol annually, by processing 770 tons per day of corn cobs, leaves, husks, and stalk. POET Biomass, a separate project, is to develop biomass material sources and coordinate the delivery of biomass materials for POET's cellulosic ethanol plant and other alternative energy projects.

Another company, Dupont Danisco Cellulosic Ethanol, is operating a small demonstration facility in Vonore, Tennessee. It is converting agricultural residue (corn cobs) and bioenergy crops (switchgrass) into ethanol. The facility will have a maximum capacity of 250,000 gallons of ethanol per year and will achieve commercial scale production by 2012. The plant is producing approximately 85 gallons of ethanol per ton of residue and hopes to achieve 90 gallons per ton for commercial scale production. Capital costs are presently $5 to $6 per gallon of operating capacity. The goal is to achieve $4 to $5 when commercial production capacity is realized. Manufacturing costs are currently $2 per gallon; however, the goal is to reach $1.50 per gallon.

The current list of Missouri-based cellulosic plants is shown in Exhibit 2.3.4. ICM currently has plans to modify its ethanol plant at Lifeline Foods in St. Joseph to produce ethanol from captive corn fiber, switchgrass and energy sorghum. This plant is supported by a $25 million Department of Energy grant. Energy sorghum and switchgrass feedstock will be contracted from local farmers.

Exhibit 2.3.4 Next Generation Biofuels in Missouri

Company	Plant location	Plant type	Technology	Biofuel	Production capacity in 2011 (in millions)	Biomass
Gevo	St. Joseph	Demo	Bio	Biobutanol	1.0	Crops
ICM	St. Joseph	Pilot	Bio	Ethanol	0.5	Ag Residue/Energy Crops

Source: USDA - Economic Research Service (2010)

Plans have also been made to build a cellulosic ethanol plant in Saline County, Missouri. The Saline Green Project is headed by Pure Energy Inc. and EcoAlgae. The plant is planned to be carbon-neutral by using algae to process carbon dioxide that results from plant operations. This project is currently stalled as project leaders look for additional capital resources.

Carbon Credits

If a maximum level of carbon emission is set, companies wishing to or required to emit less than that maximum level have two options for reducing greenhouse gas emissions:

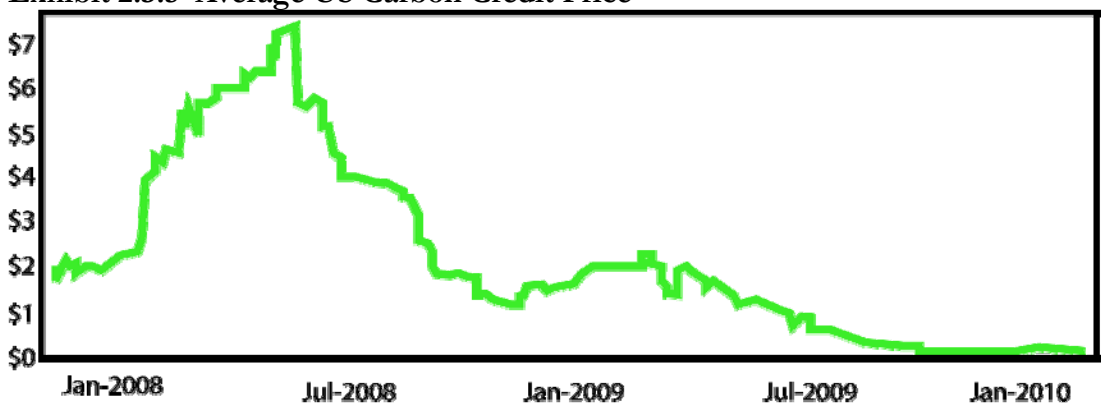
- Purchase carbon credits to offset the amount of carbon dioxide released over the maximum level.
- Make upgrades to existing facilities to bring down the amount of greenhouse gas emission.

In the US, participation in a carbon emissions reduction program is presently voluntary. Legislation to require participation, called cap-and-trade, is currently stalled in Congress and is not likely to move forward in the near future.

The Chicago Climate Exchange oversees the trade of carbon credits in the US. Participating companies make voluntary, but legally-binding, greenhouse gas reduction goals. Facility upgrades to meet these emission reduction goals are made or carbon credits are purchased to offset any greenhouse gas released above the goal amount. Each carbon credit is equal to one metric ton of carbon dioxide. Carbon credits are created whenever a company emits less greenhouse gas than allowed. Companies that are carbon-neutral or whose operations cause a carbon-deficit benefit the greatest from carbon credit trading ventures.

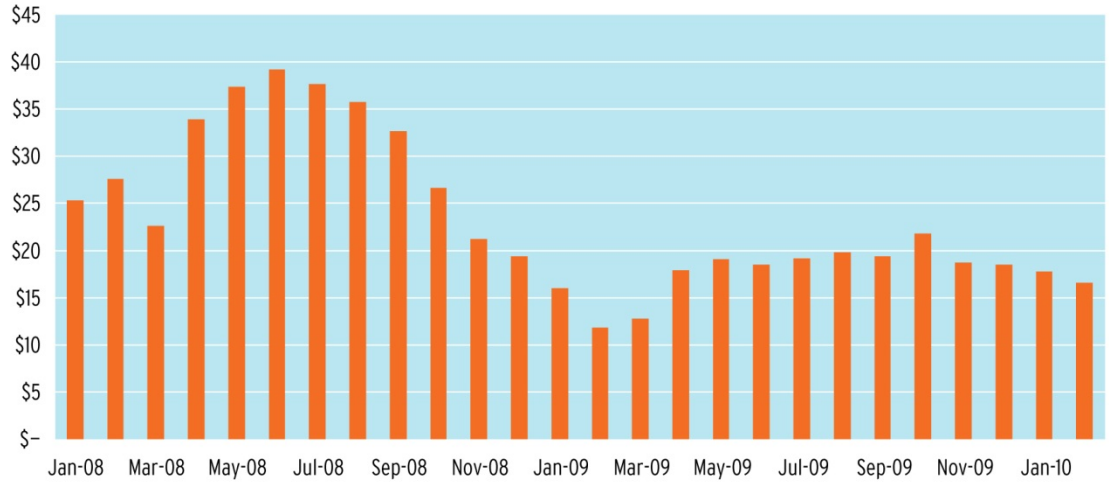
The US does not regulate carbon credits in the same manner as countries which have signed the Kyoto Protocol. Carbon credits originating in the US are not generally available to sell outside of the US. Countries with cap-and-trade mandates have carbon credit prices higher than prices in the US voluntary market. In the European Union, a metric ton of carbon dioxide is referred to as a European Union Allowance (EUA). In January 2010, the average price of a EUA was $17 and the average price of a US carbon credit was $0.05 (see Exhibits 2.3.5 and 2.3.6).

Exhibit 2.3.5 Average US Carbon Credit Price



Source: Chicago Climate Exchange (2010)

Exhibit 2.3.6 Average European Union Allowance (EUA) Price



Source: World Bank (2010)

2.4 Corn Stover Densification Businesses

Some business models have been developed that focus on the densification of biomass products. Biomass feedstocks have low bulk densities. Biomass feedstocks, in their original form, present handling, transportation and storage challenges because of these low bulk densities. Densification processes compress corn stover into to pellet or briquette form. Two examples of businesses currently pelletizing crop residues are Show-Me Energy Cooperative in Missouri and Next Step Biofuels in Nebraska.

Show Me Energy Cooperative

Show Me Energy Cooperative (SMEC) is a non-profit and producer-owned cooperative located in Centerview, Missouri. It is the first producer-owned biomass cooperative in the US and is a certified Collection, Harvest, Storage and Transportation (CHST) Biomass Crop Assistance Program (BCAP) facility. The cooperative's mission is to "establish an innovative, profitable, leading model for production of biomass based fuels which may be replicated across the country by small producer owned cooperatives that will provide a positive economic impact on the regions where they are located."

SMEC currently produces biomass energy pellets from biomass delivered to the plant by local producers. The SMEC facility has a capacity of 100,000 tons per year. The facility processes 26 different feedstocks, including corn stover. They purchase crop residue in large round bales based on weight, moisture content and BTU content of the residue. The biomass undergoes a densification process that reduces the volume of the material by one-third. SMEC also removes silica, potassium and magnesium in their proprietary process. Pellets currently contain 8,000 Btu per lb. SMEC plans to have a pellet product that will achieve 15,000 Btu per lb. by 2012.

Market outlets include local consumers and poultry operations; that usually purchase pellets in bulk quantities. SMEC has worked closely with the Kansas City Power and Light plant in Sibley, Missouri (located within 40 miles of the pellet production facility) to co-fire the biomass pellets along with coal. SMEC recently announced plans to develop and build its own 22 megawatt power plant.

Exhibit 2.4.1 Show-Me Energy Cooperative

Photo courtesy of Show-Me Energy Cooperative

Next Step Biofuels

Next Step Biofuels, located in Gretna, NE, currently produces PowerPellets™ from corn stover. Next Step Biofuels has developed a proprietary process for making corn stover pellets. These pellets are designed for use in heat/power generation, bio-refining, bio-chemicals or in residential heating applications. The company recently partnered with Omaha Public Power District to begin test burning PowerPellets™ in the plant's boilers. This co-firing test will use pellets to replace five percent of the coal burned in various power district boilers during a one month test period.

Next Step Biofuels serves as the biomass collector with participating farmers. Cooperating farmers sign a seven year contract that allows Next Step Biofuels to remove corn stover from the farmer's fields at a rate of $20 per dry ton. The company handles all of the shredding, baling, and transportation of stover from the fields to their processing facility.

Exhibit 2.4.2 Next Step Biofuels

Photo courtesy of Next Step Biofuels

2.5 Other Corn Stover Uses

Traditionally, corn stover has been used in various applications. Some of the more predominate uses include utilization as livestock feed, livestock bedding and various industrial applications.

Corn stover or cobs can be fed to beef cattle. One method is to temporarily fence off a corn field after harvest and release beef cattle into the field to "glean" off a portion of the residue. Generally, one acre of corn residue will provide 60 days of grazing for a 1,000 lb. animal (Myers, 2010). Cattle tend to consume about 20% of the total residue available. Myers recommends only grazing for a short period of time, soon after corn harvest, and only in well drained fields. Grazing corn stover allows the potential for soil compaction from cattle trampling the soil especially during wet soil conditions.

Corn stover can also be baled or ensiled for cattle. This practice can be accomplished with existing hay or silage harvesting equipment. Challenges that exist in Missouri relative to these practices are collecting stover at appropriate moisture levels. In many cases the moisture content of the stover might not be high enough for silage or low enough for bales to store without spoilage. Weather often causes harvest delays and results in a small stover window, which reduces stover feed quality. Soil compaction from harvesting equipment can result in wet fall weather conditions.

Corn stover does not contain many nutrients if used for livestock feed. Corn stover and/or corn cobs rank low in digestibility, protein and energy value (See Exhibit 2.5.1). Supplementation is usually necessary to meet the nutritional needs of cows and calves during fall and early winter when corn residues are normally fed.

Exhibit 2.5.1 Nutrient Content of Corn Residues

Feedstuff	DM	CP	UIP	TDN	NE_m	NE_g	ADF	Ca	P
	%	% DM	% CP	%	Mcal/lb.	Mcal/lb.	%	%	% DM
Corn stover	90.0	4.8	30.0	45.0	0.47	0.07	46.0	0.49	0.09
Corn cobs, ground	90.0	2.8	30.0	48.0	0.44	0.19	44.0	0.12	0.04

Source: Lardy and Anderson (2009)

Corn residue has also been used as livestock bedding, especially in years when small grain straw is limited in availability. Bedding should be baled at a low moisture level after drying in the field following grain harvest.

Gasification is another method of converting corn feedstock to a natural gas replacement. Chippewa Valley Ethanol Plant is a cooperative-owned ethanol plant located in Benson, Minnesota. The plant broke ground on a commercial-size biomass gasifier that uses corn cobs as its primary feedstock in 2006. The gas generated from corn cobs by the biomass gasification system displaces the use of natural gas for plant operations. The plant hopes to replace as much as 90 percent of its natural gas consumption by using the gas generated from the gasifier system. To displace 90 percent of the natural gas, the plant would require 300 tons of biomass per day for the gasification system. The plant is owned by the Chippewa Valley Ethanol Company, which is 95% owned by the Chippewa Valley Agrafuels Cooperative.

Additionally, corn stover has historically found some uses in the industrial sector. Examples would include fiberboard, pulp and paper and chemicals. There are new markets emerging for the use of corn stover and/or corn cobs, according to Biorefining Magazine (Sims, 2010). MCG BioComposites based in Iowa is manufacturing garden markers, made of 20% corn cob flour mixture. Their company focuses on the sales, marketing and distribution of green bio materials. Recovery I Inc., an environmental company that specializes in handling oil spills, is using corn cobs as an absorbing agent in their oil reclamation applications. More uses for corn residue will evolve in the future as other industries develop practical applications that can use this residue in a cost effective manner.

Chapter 3: Technical Analysis of Corn Stover Removal

3.1 Harvesting and Collection

Various systems are used to harvest both low moisture (approximately 20%) and high moisture (approximately 40% moisture) corn stover. Low moisture stover harvesting systems typically involves the use of large bales or loose stacks. High moisture corn stover can also be harvested with a forage chopper and ensiled either in silage bags or plastic wrapped bales (Shinners et al, 2007a). This analysis will focus on low moisture stover removal. Markets for corn stover used in electric generation plants will probably require minimal moisture and be purchased on a dry matter basis.

Moisture contents of the corn stover components will influence harvest procedures and times when stover can be harvested. Corn stover harvested and stored at 30% or greater moisture will have increased dry matter and storage losses. In some cases, if the moisture content is high enough, there is danger of spontaneous combustion in the stover bales (Gould, 2007).

Gould's data would suggest that corn grain, in most cases, would be harvested at an earlier date than stover. Field loss and the resulting economic loss associated with delayed grain harvest when attempting grain and stover harvest with a "single pass" grain and stover harvesting system does not appear attractive for most producers.

Problems that may be associated with corn stover harvest are a short harvest window, wet stover spoilage and soil compaction as a result of additional field passes especially if wet soil conditions exist. These problems will be more pronounced during wet fall harvest periods. More stover harvesting problems would likely occur the further north the harvest site is located (Gould, 2007).

There are currently four methods of corn stover removal, with varying levels of residue removal. Each method indicates a difference in collection efficiency and can be affected by the equipment used in removal. There are differences in the literature regarding removals rates (Petrolia, 2008; Schechinger and Hettenhaus, 2004; Prewitt et al., 2007). Average removal rates are approximately:

1. Cobs only – 15% removal of corn residue,
2. Direct baling – combine spreader disabled, no raking, 25%-30% removal of corn residue,
3. Rake/bale – 50% removal of corn residue, and
4. Cut/rake/bale – 75% to 85% removal of corn residue.

Cob only removal would involve the use of a cob collection system with a harvester/cart combination. Cob collection systems represent a significant cost in the harvest of corn cobs. Acreage needed to justify the purchase or rental of a collection system is significant.

Direct baling is baling directly from the windrow produced by grain harvesting. This can be accomplished by disengaging the chopper on the combine when harvesting corn. A tractor and large baler follow to bale up the windrow. The rake/bale option increases corn stover removal but adds the raking operation prior to baling (approximately 50% stover removal). This would result in second pass, first with the tractor/rake and second with the tractor/baler. The last stover harvesting option is to shred prior to raking and baling. This option will achieve a 75 to 85% removal of corn stover. Flail shredders can be set to produce a windrow and possibly eliminate the need for additional raking.

Each harvesting method has its implications with the field drying of corn stover. A short harvest window, due to unfavorable weather conditions, can be a challenge for baling corn stover at low moisture contents. Windrowed corn stover slows field drying as the stover is not spread out in a thin layer. Shredding corn stover tends to speed up field drying (Sokhansanj et al., 2002). Raking stover "fluffs" the stover and also allows for faster drying than windrow produced behind the combine.

New Collection Equipment for Corn Stover and Corn Cobs

Producers have numerous options for biomass collection and processing. Innovations include stand-alone machines that separate cobs from stover, cob separation machines attached to the combine and machines that bale biomass during the grain harvest operation.

Biomass baling systems have been intensely researched and have received considerable public attention. Major manufacturers, including AGCO, are incorporating baling systems into the designs of new equipment. Grain harvesting machines are modified to allow attachment of large balers.

These balers can be used to bale hay or other biomass products. Most of these systems produce large square bales. Large square bales are more efficient to handle, store, and transport than small square bales or large round bales.

AGCO has incorporated two existing machinery products into their biomass collection equipment package. A Caterpillar Lexion Class VIII combine attached to a Hesston large square baler is the prototype grain and biomass single pass harvesting system from AGCO (See Exhibit 3.1.1). According to AGCO, powering the baler requires an additional 90 horsepower that must be supplied by the combine. AGCO reports a very limited demand for these units at the present time.

Exhibit 3.1.1 Caterpillar Lexion Combine with a Hesston baler

Photo courtesy of AGCO

Traditional corn stover collection methods involve collecting residue directly from the combine into a large storage wagon pulled behind the harvester.

Another stover collection concept is to collect the residue from the harvester and separate the cobs from the other stover components. This produces a more specific final product.

Redekop Manufacturing (See Exhibit 3.1.2) of Saskatoon, Saskatchewan manufactures a machine that collects residue directly from the combine. The cobs are separated from the stover with the H165 Cob Harvester. Redekop also manufactures a C180 Cob Cart to transfer the cobs to a pile at the end of the field.

Exhibit 3.1.2 Redekop C180 Cart during unloading (left) and H165 Harvester (right)

Photos courtesy of Redekop Manufacturing

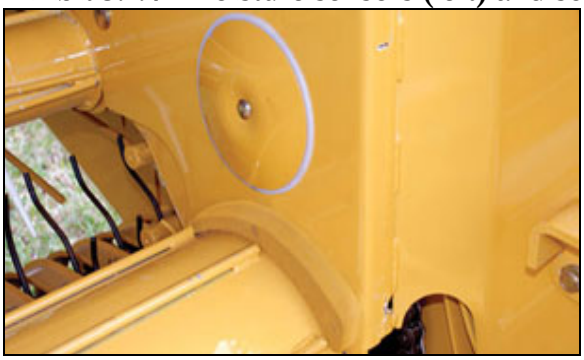
Vermeer Manufacturing has developed the CCX770 Cob Harvester (See Exhibit 3.1.3). This machine combines cob collection and removal of other stover residues from the cobs. The other separated residues are returned to the soil surface. The CCX770 is self-powered and does not need hydraulic power from the combine to operate. Vermeer currently offers its CCX770 Cob Harvester for rental to biomass collection facilities in the Midwest and to select retail outlets.

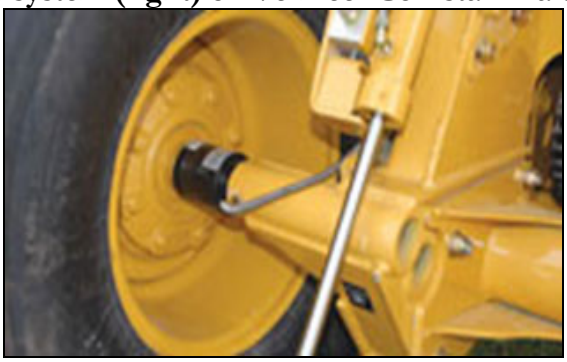
Exhibit 3.1.3 Vermeer CCX770 Cob Harvester in field (left) and unloading position (right)

Photos courtesy of Vermeer and the Brownfield Network

Vermeer has also designed a large round baler specifically for baling corn stalks. The "605 Super M Corn Stalk Special" has special features such as a powered windguard to maintain baler capacity and aid in plug clean-out, large flotation tires, three belt sensors for bale shape monitoring, and a scale system. Moisture sensors located in the baler's collection area side panels report moisture data. Moisture content of the corn stover is needed to maximize the Btu-producing potential of biomass that is used as a fuel for power plants. A scale system has been incorporated to work in conjunction with the moisture sensors to provide an accurate stover moisture reading (See Exhibit 3.1.4).

Exhibit 3.1.4 Moisture sensors (left) and scale system (right) on Vermeer Cornstalk Baler





Photos courtesy of Vermeer

Case IH, John Deere and Claas Lexion are also conducting research and product development for the simultaneous collection of corn stover and cobs. This product, called corn cob mix (CCM), involves collecting grain and cobs together in the grain tank. CCM is transferred to a grain cart for separation and processing. Demco and Unverferth manufacturers are also developing grain cart systems to handle and process CCM.

John Deere has partnered with Iowa State University to develop a machinery system to transfer corn stover biomass from the combine directly to a collection cart. John Deere has worked in conjunction with Hillco (See Exhibit 3.1.5) to provide to the biomass collection efforts. The Hillco Cart can be used with John Deere 9670, 9770 and 9870 Series combines without warranty problems.

Exhibit 3.1.5 John Deere 9770 Combine with Hillco Attachment and Cob Collection Cart

Photo courtesy of John Deere

Capital costs for corn stover collection systems are a purchasing constraint for many producers. Various biomass collection system prices are shown in Exhibit 3.1.6.

Exhibit 3.1.6 Pricing of Biomass Collection Systems

Manufacturer	Product	Type	List price	Retail price	Rental price
AGCO	Hesston Corn Stalk Baler	Baler	Not commercially available		
Hillco	Separation Attachment	Harvester	$32,485	N/A	N/A
Hillco	Cob Wagon	Cart	$37,900	N/A	N/A
Redekop	H165 Harvester	Harvester	$60,000	N/A	N/A
Redekop	C180 Collection Cart	Cart	$37,500	N/A	N/A
Vermeer	Super M Cornstalk Baler	Baler	$55,801	$47,000	N/A
Vermeer	CCX770	Harvester/Cart	$133,000	$120,000	$30,000

Prices as of 10/20/2010

The continued development of biomass collection equipment is contingent on several factors. A market system which will support large-scale biomass production, delivery and consumption is required.

Agricultural producers must analyze the value-added benefit of biomass collection and find the benefits to be economically feasible and environmentally sound. Conservation compliance and participation in USDA programs along with biomass markets must be considered. The cost of additional equipment and labor to efficiently collect biomass for renewable fuel production will also need to be evaluated.

3.2 Storage

There are three primary storage options for corn stover (USEPA, 2007).

1. Corn stover is hauled directly to the plant with no storage at the farm.
2. Corn stover is stored on farm and then transported to the plant as needed.
3. Feedstock is stored at an intermediate storage facility and then transported to the plant.

Most corn stover markets do not want delivery of corn stover at harvest. The large volume of the bales and area needed to store this volume is often not available on the generation plan site. A limited amount of stover storage, usually less than a one-month supply, is stored on the generating facility site. The remaining feedstock will need to be stored at other locations.

One option is to store the corn stover at the producer's farm until it is needed by the plant. The producer must allocate space for corn stover storage and provide all-weather access to the stover storage area. The producer is also responsible for maintaining stover quality.

Another stover storage solution is to transport the corn stover to a central or intermediate storage location. Increased costs are incurred when corn stover is stored at a central location because of the additional handling; however, these additional storage costs may be offset if transportation is more convenient for either or both the producer and the plant.

Careful consideration must be given to the moisture content of the stover at the time of storage. The desired moisture content of stover at usage must also be evaluated. Corn stover storage systems must minimize dry matter loss and protect the quality of the corn stover prior to use at a power generating facility (Turhollow et al, 2009).

Stover storage losses will determine the appropriate storage system. Storage losses vary between large round and square bales, inside or outside storage of bales, time in storage, and weather conditions for bales stored outside.

Shinner et al. (2007a) conducted a multi-year analysis of corn stover harvest and storage that details the characteristics of storage losses in Wisconsin (See Exhibit 3.2.1). Dry stover losses averaged 3.3% for bales that were stored inside versus 18.1% for bales stored outside. Square bales were more susceptible to weather damage and were only considered for inside storage. Inside storage was the best method for reducing storage loss. Net wrapped bales were the most appropriate manner to minimize loss when bales were stored outside.

Exhibit 3.2.1 Storage Characteristics of Dry Corn Stover Bales for Seven or Eight Months

Storage Location	Wrap or Bale Type	2002 DM loss (% of total)	2003 DM loss (% of total)
Inside	Large Round	4.9	2.2
	Large Square	4.8	1.1
Outside on Ground (only round bales)	Sisal twine	29.1	38.5
	Plastic twine	14.3	19.0
	Net wrap	10.7	14.2
Outside on pallets (only round bales)	Sisal twine	30.9	36.1
	Plastic twine	32.2	11.0
	Net wrap	23.5	8.2

Source: Shinners et al. (2007a)

Inside storage of corn stover is the preferred way to minimize stover storage losses. Under-roof storage has cost impacts that must be calculated into the corn stover harvest system.

Construction of storage structures, improving land surfaces in stover storage areas, or using tarps to cover stover packages increase storage costs. Exhibits 3.2.2 and 3.2.3 show several different storage systems, estimated costs, and the useful life of these various biomass storage systems.

Exhibit 3.2.2 Typical Storage Systems and Cost

Storage System	Cost per ton
Enclosed structure with crushed rock floor	$10 to $15
Open structure with crush rock floor	$6 to $8
Reusable tarp on crushed rock	$3
Outside unprotected on crushed rock	$1
Outside unprotected on ground	$0

Source: USEPA (2007)

Exhibit 3.2.3 Estimated Investment Costs of Biomass Storage Systems

Storage method	Costs	Useful life
Structures for baled biomass	Pole frame structure, all sides open: $71.37/m^2 ($6.63/ft^2) Pole frame structure, one side open: $99.35/m^2 ($9.23/ft^2) Pole frame structure, enclosed: $111.62/m^2 ($10.37/ft^2) Enclosed shed w/concrete floor & foundation: $169.43/m^2 ($15.74/ft^2)	20 years
Bunker silo	Concrete floor and walls, plastic covering: $150.59/m^2 ($13.99/ft^2)	20 years
Storage pad	Gravel: $11.75/m^2 ($1.09/ft^2) Asphalt: $30.68/m^2 ($2.85/ft^2)	10 years
Hay tarp	$2.91/m^2 ($0.27/ft^2)(of tarp area)	5 years
Plastic wrap	$3.11/bale or $6.71/Mg ($6.09/dry ton)	1 year

Source: Turhollow et al. (2009)

It may be difficult to justify the additional investment costs of covered or improved stover storage systems. The market price of corn stover must be high enough to warrant these additional investment costs. Some producers may have existing storage space that could be utilized with small additional costs.

Data in the above table suggests that the best storage option is to utilize an uncovered round bale system. Other stover storage options may have potential; however, the data suggests that the storage cost be kept as low as possible.

The market for corn stover in Missouri is beginning to evolve. Market prices and the specific physical properties for stover purchase have not been established. The end market for corn stover will have specific product specifications. The choices of stover collection and storage systems will be determined by these specifications. For example, generating plants want corn stover as free as possible of dirt to minimize contamination of a coal boiler unit.

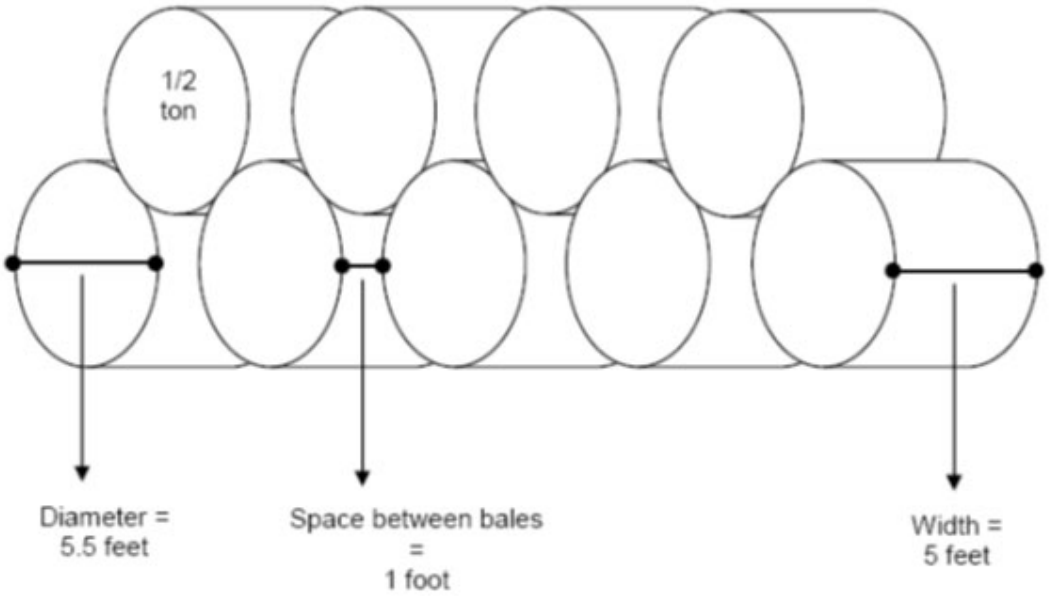
Uncovered bales should be stored on a level surface, in a north-south orientation, butts close together, and three feet between rows at a storage site. These bale storage principles were designed to minimize storage loss and investment by the producer (Morey et al., 2010). These principles for uncovered bales would be suitable for on-farm or centralized bale storage locations.

On-Farm Storage

On-farm storage of stover bales requires that storage areas be accessible to tractor trailers for transport. Long-term in-field storage may result in a reduction in the value of stover from shrinkage and loss of energy content due to deterioration of the stover. Bales must be stored for all weather access and on a relatively level surface.

On-farm storage options of stover bale storage ranges from edge of the field to buildings built specifically for storage of stover. Exhibit 3.2.4 portrays one option for on-farm stover storage (Brechbill and Tyner, 2008). This study determined that a per-bale cost of $2.00 would cover moving bales to the edge of the field. A University of Missouri (Plain et al., 2009) estimates a $3.70 per bale cost to move bales in the field.

Exhibit 3.2.4 Example of Field Storage



Source: Brechbill and Tyner (2008)

Dedicating a facility specifically for corn stover storage is one option that may be viable for some producers. This stover storage might be new building construction or renovation of an existing facility. New construction might be a standard pole frame or steel frame structure.

Renovation of existing facilities might include strengthening buildings to withstand large bale storage or storing stover in bunker silos. Constructing or renovating structures will add to the production cost of stover and should be carefully evaluated.

The Poet cellulosic ethanol plant at Emmetsburg, Iowa reports that most producers are storing the stover on-farm until it is to be delivered by truck to the plant. Poet reports the large round bales are net wrapped with three to five layers of netting. A small percentage of producers selling stover to Poet have utilized storage facilities for stover.

Central Locations

Storing stover and residue at centralized locations offer another option for producers and generating plants. Bales would be hauled to this centralized staging area after harvest. An individual or company would be responsible for handling the stover contracting and logistics to insure the supply of stover to the end user at the times it would be required. The centralized stover storage location should be designed to fit the footprint of biomass volume, have adequate space for maneuvering large equipment and trucks, and separation of facilities to minimize fire hazards (Turhollow et al., 2009).

Centralized storage facilities add land, facility and additional labor cost to the production costs of harvesting corn stover. These costs must be factored into the overall economic evaluation of this business.

Morey et al. (2010) proposed that a centralized storage facility should have at least 200 tons (320 bales at 1,250 lbs) of capacity. This capacity would provide most custom grinding and compacting processors with enough stover to process during one day. The processed corn stover would then be hauled in 25-ton trucks to the generation plant.

3.3 Transportation

Moving and hauling biomass products that have low mass densities are a logistical challenge. Most research has been concentrated on moving bales or processed corn stover within a 50-mile radius of the end destination to minimize transportation costs. Transportation systems and cost to move stover from the field to storage and then to an end use facility will be discussed.

Large bales will need to be moved to the field edge or sent to a central storage facility after stover is baled. There are two viable options for moving bales from the field to storage areas. The first option would use high-speed tractors and bale wagons to move bales (Perlack and Turhollow, 2002). Moving bales with a Highline Bale Mover 1400 pulled with a high speed tractor is one example of a high speed bale moving system. This system has the capacity to move 14 bales at one time. Projected loading time is 7 minutes and unloading time is about 5 minutes. High-speed tractors and bale wagons provide an acceptable bale transportation practice if the storage facility is within three miles of the field location. The second option would be to use trucks with flatbed trailers to move bales from field to storage. This option is more practical if the storage location is greater than three miles from the field location.

Morey et al (2010) estimates that the cost of moving a bale from the field to a storage site with the Highline Bale Mover 1400 to cost approximately $5 per ton. Iowa State (Edwards and Johanns, 2010) estimates the cost of hauling large round bales to storage at an average price of $0.20 per bale per loaded mile. University of Missouri (Plain et al., 2009) estimates the cost of hauling round bales over 20 miles to cost $3.08 per loaded mile.

Transportation costs will vary with the location of the end facility. Some corn stover buyers provide transportation with custom-hired or owned trucks. Local custom operators can be contracted to provide bale transportation or producers may want to haul the stover with existing equipment.

Brechbill and Tyner (2008) reported that custom transportation rates were less per ton than owned transportation for short haul distances; however, owned transportation costs less per ton for longer haul distances. Exhibit 3.3.1 and 3.3.2 show the hauling cost structure with custom equipment and owned equipment. Exhibit 3.3.2 incorporates varied corn acreage, direct baling of corn stover, and the owner having the equipment to transport the stover bales.

Owned equipment assumes the purchase of a semi "road" tractor for hauling corn stover. Farms with larger corn acreage can spread these fixed costs over more acres and have an advantage of owning the equipment. This road tractor might also be used for grain.

Hauling more tons of corn stover will decrease the equipment ownership costs per ton. An additional cost of $1.15 per ton would be needed for loading and unloading at the plant.

Exhibit 3.3.1 Transportation Cost per Ton with Custom Equipment

Miles Traveled	Transportation Cost (per Ton)
5 miles	$2.53
10 miles	$3.92
15 miles	$5.30
20 miles	$6.69
25 miles	$8.07
30 miles	$9.46
35 miles	$10.84
40 miles	$12.23
45 miles	$13.61
50 miles	$15.00

Source: Brechbill and Tyner (2008)

Exhibit 3.3.2 Transportation Costs per Ton with Owned Equipment

Miles Traveled	500 acres	1,000 acres	1,500 acres	2,000 acres
5 miles	$5.51	$3.85	$3.30	$3.02
10 miles	$6.18	$4.52	$3.97	$3.69
15 miles	$6.85	$5.19	$4.64	$4.36
20 miles	$7.52	$5.86	$5.31	$5.03
25 miles	$8.19	$6.53	$5.98	$5.70
30 miles	$8.86	$7.20	$6.65	$6.37
35 miles	$9.53	$7.87	$7.32	$7.04
40 miles	$10.20	$8.54	$7.99	$7.71
45 miles	$10.87	$9.21	$8.66	$8.38
50 miles	$11.54	$9.88	$9.33	$9.05

Source: Brechbill and Tyner (2008)

Round bales can be transported with a truck and flatbed trailer. A bale loading configuration used to deliver large round bale corn stover is illustrated in Exhibit 3.3.3. The configuration of the bales on the 53 foot trailer is normally 30 bales. The bale loading configuration is a double bottom row of 16 bales and a double top row of 14 bales. The total weight of the loaded bales will be approximately 18 tons per load. Exhibit 3.3.3 shows a trailer with 34 bales. The basic loading configuration (two double rows) is the same as this analysis presents.

Exhibit 3.3.3 Example Configuration of Round Bales in Transit

Photo Courtesy of Show Me Energy Cooperative

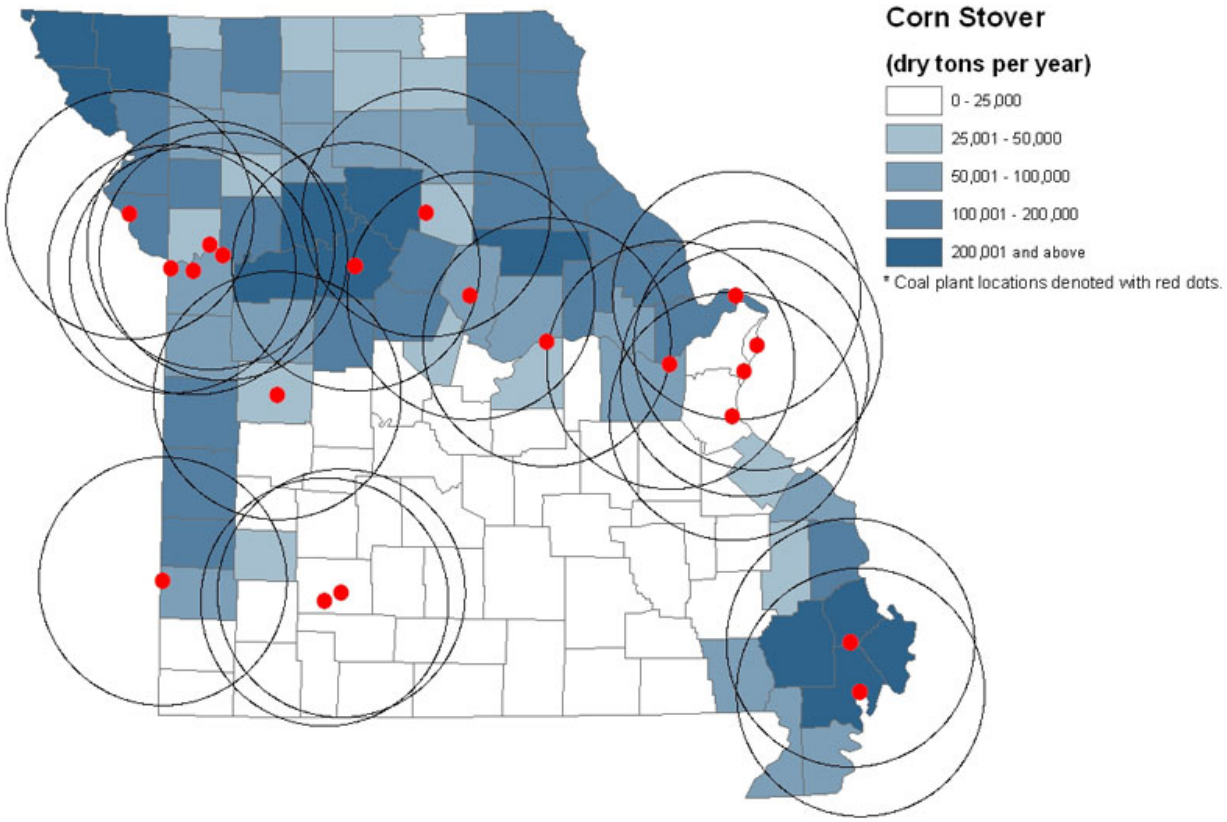
Square bales could also be moved on a 53-foot flatbed trailer. This 53-foot trailer would transport 39 bales (3 x 4 x 8 ft) or 26 bales (4 x 4 x 8 ft). A 48 foot trailer could be used as well (Hess et al., 2009). Hess's research suggests that that transportation and handling costs for the 53-foot system for a round trip distance of 37.8 miles would range from $10.68 to $13.18 per dry ton.

Some end markets require a sized and densified corn stover product. Densification may be done prior to delivery of the product or done at the point of use depending on the purchasing agreement.

Densification processing might involve the use of a tub grinding unit, roll press compaction and/or other processes. Transporting densified stover would probably be done with a 25-ton box unit truck. Transportation costs for moving the densified corn stover would be approximately $7.53 per dry ton for a round-trip distance of 52 miles (Morey et al, 2010).

Coal fired electrical generating power plants are one of the potential markets for corn stover. The location of these plants is shown in Exhibit 3.3.4. Each Missouri power plant location has a 50 mile radius drawn around the plant. Another data layer shows total corn stover production within that 50-mile radius circle. No stover production reductions are made for areas where environmental or soil sustainability restrictions may limit corn stover harvest. Coal plants just outside of Missouri's state borders could also be a potential market, but are not shown on the exhibit. Coal plant locations close to corn stover production areas where stover removal can be sustained would have an advantage in minimizing transportation expenses.

Exhibit 3.3.4 Missouri Stover Production and Coal Plants, with 50 mile radius



3.4 Densification

The densification of biomass involves changing the consistency of the biomass material into a different or denser form. The denser material is more efficient to transport and store. Grinding biomass ensures a more consistent and uniform particle size. Biomass can also be pelletized or cubed by applying mechanical force to compact the ground material into a smaller more dense product.

Biomass materials can also be gasified. The gasification process converts the biomass into a renewable gas that can replace natural gas as an energy fuel.

A biomass feasibility study prepared by Broekema (2009) with Great River Energy recommends "some level of densification of biomass to overcome bulk handling and fuel feeding issues in biomass storage and feed." The technical analysis was developed to investigate the feasibility of direct co-firing 10% of various feedstocks at a North Dakota coal facility (Spiritwood CHP). This study looked at various feedstocks and identified the top five resources as corn cobs, corn stover, switchgrass, wheat straw, and sugar beet foliage. The densification options investigated were: grinding, pelletizing/cubing, and gasification. The densification cost comparison analysis for the Spiritwood CHP Facility is shown in Exhibit 3.4.1.

Exhibit 3.4.1 Densification Cost Comparison for the Spiritwood CHP Facility

Processing for 10 megawatts	Grinding (5,000 Btu/lb.)	Grinding and pelletizing (10,000 Btu/lb)	Gasification (5,000 Btu/ft^3)
Estimated capital	$625,000	$900,000	$22,600,000
Annual O&M	$245,000	$1,925,000	$8,700,000
Levelized cost	$300,000	$2,000,000	$10,000,000
Added cost per ton	$4.25	$30	$150
Cost per MMBtu	$0.43	$1.50	

Source: Broekema (2009)

Grinding was the only biomass densification method recommended by Great River Energy's feasibility study for the Spiritwood CHP Facility. Electric stationary grinders were deemed the most economical equipment for grinding. Grinding biomass had an average cost of $4.25 per ton in this study. Delivery of ground corn stover was estimated to cost $3.80 per MMBtu and ground corncobs estimated to cost $3.60 per MMBtu (Exhibit 3.4.2).

Pellets and cubes are easier to store and handle as a feedstock and tend to provide a more consistent quality of biomass fuel. Pelletizing biomass can increase the density level by as much as four times from 8 lb/ft^3 to 31 lb/ft^3 (Sokhansanj et al, 2004). Equipment and operational costs for pelletizing and cubing are more expensive than grinding however. Great River Energy's study estimates pelletizing costs to be about $30 per ton on average. This translates into a total delivery cost of about $5.70 per MMBtu for pelletized corn stover and about $5.40 per MMBtu for pelletized corn cobs (Exhibit 3.4.2).

Show Me Energy, a Missouri based producer cooperative, manufacture biomass energy pellets and sells their pellets for approximately $150 per ton. Show-Me Energy has become one of the leaders in the market for pelletized biomass.

Show Me Energy has developed a proprietary process to remove the silica from the stover prior to pelletizing which reduces glass build up when co-firing. Show Me Energy is currently testing their pellet product for co-firing with coal. These pellets, with the silica removed, may be a product that existing coal-fired plants can more easily use.

Gasification of biomass involves converting eligible biomass into a product called *producer gas* or *syngas*. Producer gas can directly substitute for natural gas. This substitution allows for potential cost savings or energy price stability for gas users. The cost to produce this synthetic gas product is higher than the other two biomass densification methods. Great River Energy's study shows a producer gas energy output of 10.3 MMBtu per ton of biomass. Gasification of biomass costs about $11 per MMBtu. Costs and energy summaries for gasification and other stover densification processes are shown in Exhibit 3.4.2.

Exhibit 3.4.2 Delivered Cost of Densified Biomass

	Grinding (corn stover)	Grinding (corn cobs)	Pelletizing (corn stover)	Pelletizing (corn cobs)	Gasification of biomass
Cost per ton	$50	$49	$75	$74	$114
Energy output (MMBtu per ton)	13.2	13.8	13.2	13.8	10.3
Cost per MMBtu	$3.80	$3.60	$5.70	$5.40	$11.00

Source: Broekema (2009)

Another recent study looked at supplying corn stover to an ethanol plant in three forms; baled, chopped/ground, and pelletized (Sokhansanj et al, 2010). The economics analyses used in this study were modeled with the Integrated Biomass Supply Analysis and Logistics (IBSAL) simulation model. Collection costs refer to picking up the corn stover at the farm, packaging and transporting to a close storage site.

The chopped system pre-processed bales with a mobile grinder unit. The pellet system used a tub grinder, hammer mill and a pellet mill to extrude pellets. Trucks were used to transport the biomass materials to the plant. Large bales were delivered on flatbed trailers. The chopped stover and pellets were delivered in truck boxes.

The total delivered cost of each form of corn stover is shown in Exhibit 3.4.3. Total delivered costs were $66 per ton for large square stover bales, $76 per ton for field chopped stover, and $78 per ton for corn stover pellets. Corn stover pellets was the highest costing system per ton, because of the additional process needed for creating the pellets.

Exhibit 3.4.3 Total delivered cost for different form of biomass up to the biomass burner

	Bale ($ per ton)	Chop ($ per ton)	Pellet ($ per ton)
Collection	$34.48	$34.48	$34.48
Pre-process	$0.00	$7.45	$27.39
Transport	$9.05	$14.81	$4.07
Total delivered cost to the plant	$43.86	$57.07	$65.94
On-site fuel preparation	$22.35	$19.74	$12.52
Total cost	$65.89	$76.48	$78.46

Source: Sokhansanj et al. (2010)

A detailed analysis study by Sokhansanj et al (2010) shows the breakdown (See Exhibit 3.4.4) for each operation and the associated cost of on-site fuel preparation using corn stover in biomass burners. A 30% overhead expense is included as a contingency and to cover any additional labor that is needed.

Baled corn stover had the highest costs for preparing the stover for onsite boiler use at $22.35 per ton. Baled corn stover requires more storage and further processing at this stage that add to these costs.

Exhibit 3.4.4 Estimated cost of receiving, storing, and preparing biomass for boiler use

Operations	Baled stover		Chopped stover		Pelletized stover	
	Explanation	Cost ($/Ton)	Explanation	Cost ($/Ton)	Explanation	Cost ($/Ton)
Receiving	Unload and stack bales	2.01	Front-end loader and piler	1.00	Dump in pit, elevate[a]	0.00
Storing	Enclosed, free standing, stacked bales	4.33	Enclosed reinforced bearing walls for piled stover	6.01	Steel bin with overhead distribution	1.15
Reclaiming biomass	Stacker, belt conveyor, de-stringer, de-balers	3.94	Front-end loader conveyor	1.27	Bin unloader	1.27
Fine grinding	Hammer mill	4.91	Hammer mill	4.91	Hammer mill	4.91
Delivery	Pneumatic airlock blower	2.00	Pneumatic airlock blower	2.00	Pneumatic airlock blower	2.00
Total (+30% overhead)		22.35		19.74		12.14

[a] Use the existing grain pit and elevator.
Source: Sokhansanj et al. (2010)

Morey et al. (2010) looked at corn stover processing before being delivered to a facility. Corn stover would be stored in centralized locations. A custom crew would process the stover with portable equipment that would grind and compact the corn stover. Stover processing would involve tub-grinding and roll-press compaction to densify the stover for delivery to the plant in 25-ton box trucks. The tub grinder would reduce particle size and a roll press compactor would densify the stover particles by compression between its rolls. Expected grinding and compressing costs for bulk processing corn stover bales (including a labor charge) was approximately $14.00 per dry ton.

3.5 Management and Infrastructure

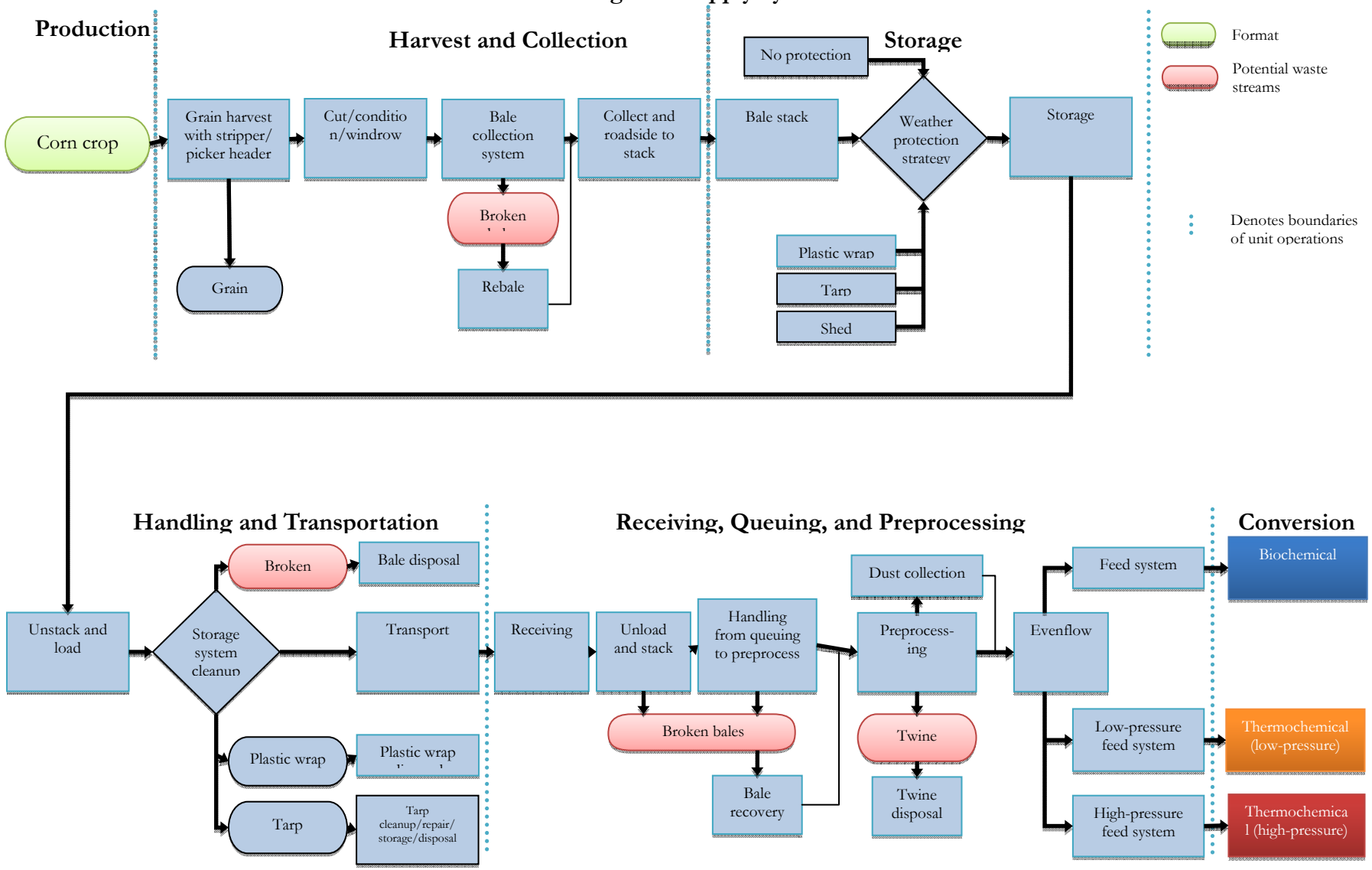
The logistics supply system for a potential corn stover business is important to understand. Exhibit 3.5.1 shows there are a variety of processes within operation stages that must be considered to design a system that is efficient and that works for the participating producers. Many of the processes could be outsourced to custom hire providers if desired. Corn stover business owners must decide how and what services that they wish to provide. Inventorying existing resources, understanding the end market's product needs and learning the farmers' willingness for providing services will dictate how a business should be formed.

Participation Options

Farmers willing to provide corn stover to an end market can choose to participate in two ways. First, they could individually seek an end market for their corn stover and individually develop contracts to provide a certain tonnage amount on a yearly basis. A number of businesses in the US are currently contracting with individual farmers for corn stover. These businesses either pay farmers for corn stover FOB at the plant or pay an access fee and have custom operators harvest the stover. Markets might develop in Missouri if a cellulosic ethanol plant, coal plant or other business decides to secure contracts for corn stover.

A group of producers could take collective action and develop a feedstock supply business. This group could achieve market power with economies of scale by providing a significant amount of biomass feedstock for an end market. Bargaining power with an end market could be gained which would help with upfront negotiations to develop a system that meets the end market's needs.

Exhibit 3.5.1 Conventional Bale Corn Stover Feedstock Logistics Supply System

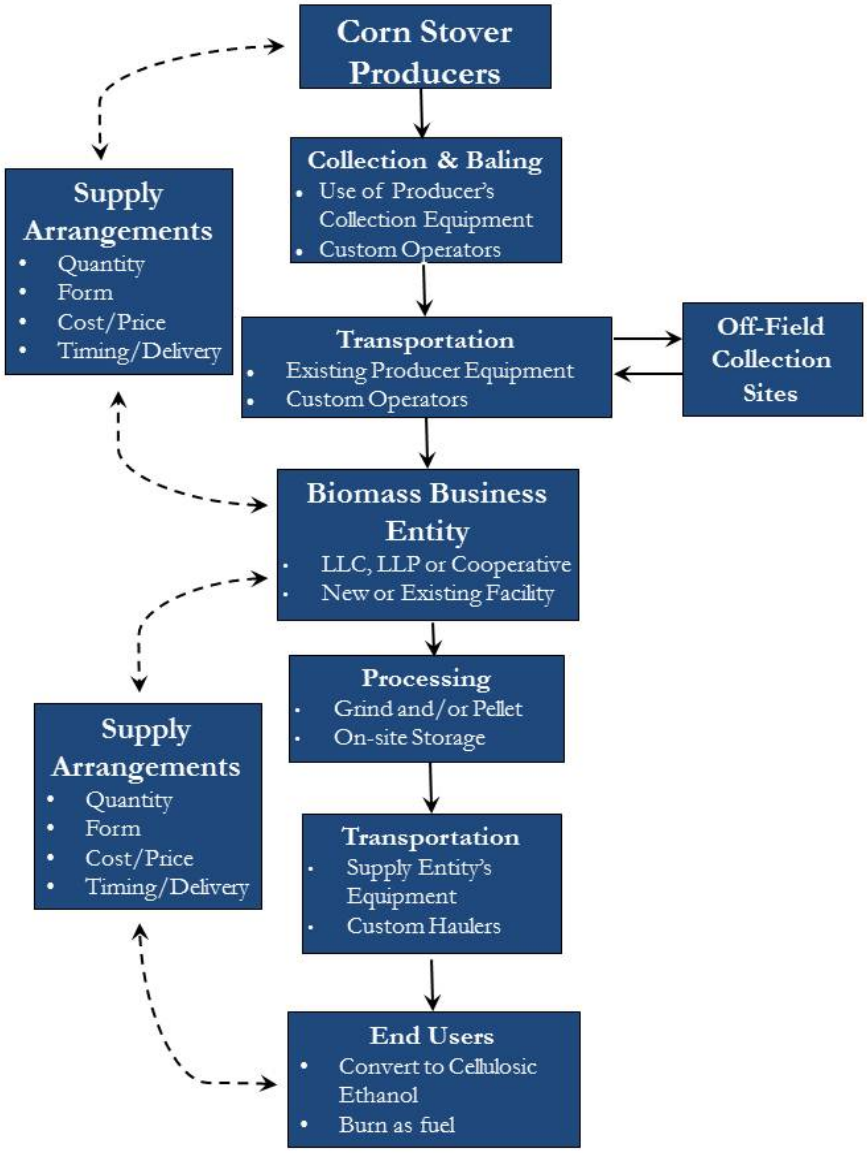


Source: Hess et al. (2009)

Collective action would involve farmers pooling resources and expertise under an organizational structure. Exhibit 3.5.2 shows a potential value chain for a corn stover supply business. Farmers could pool their corn stover supplies and the business would be responsible for coordinating all stover supply arrangements. Business decisions would include what stover product form is provided (round bales, square bales, pellets, etc.) and how to reward farmers for their participation.

Supply and logistics are critical key points in serving an end market. A corn stover business would probably need to be within a certain radius of the end market due to the transportation and handling challenges of baled corn stover. Corn stover densification (i.e. ground/compacted or pelletized) would allow the radius to be larger and the business could serve more distant end markets.

Exhibit 3.5.2 Missouri Corn Stover Value Chain



Source: Adapted from Broekema (2009)

The business personnel structure could be comprised of a manager, the cooperative board, and member-investors. The manager would be responsible for making the day to day business decisions such as coordinating the stover supply and transportation arrangements to a plant. He/she would also have the duties of implementing strategic planning and communicating with the membership. The role of the board would be to develop a strategic plan and provide managerial oversight. The member-investors would be responsible for investing in the company, supplying corn stover, and strategic decision-making for the business.

Ownership Options

Collective or individual participation in a corn stover business will require decisions on equipment ownership to provide corn stover to an end market. Equipment needed would include harvesting, collection, transportation and/or processing equipment. Existing hay collection equipment and/or trucking units owned by farmers may be suitable for collecting and hauling corn stover. This approach would not require additional purchases. Some producers might decide to "share" some of the equipment and reduce ownership expenses.

Another option would be to hire custom operators and outsource the stover business functions. This option allows the producers to focus on their other farm enterprises. An inventory of existing resources and determining willingness of the producers to accept ownership roles will be important in designing a successful business. These business decisions will also play an important role in determining the economics of providing corn stover to a end use facility.

Organizational Structure

Potential business structures that enable collective action include Limited Liability Partnership, Limited Liability Company, corporation, and cooperative. The following paragraphs provide a definition and highlight the general characteristics for each type of potential business structure. The final business structure will be determined by the group(s) pursuing collective action within the industry.

Limited Liability Partnership

The Limited Liability Partnership (LLP) is essentially a general partnership in form, with one important difference. Unlike a general partnership, in which individual partners are liable for the partnership's debts and obligations, an LLP provides each of its individual partner's protection against personal liability for certain partnership liabilities. In Missouri, an LLP has to be registered with the state and the filing requirements have to be met annually. In Missouri, the liabilities that partners are responsible for are limited to the amount that each partner invested. However, there has to be at least one general partner who is responsible for all debts, liabilities, and other obligations of the partnership.

Limited Liability Company
The limited liability company (LLC) is a legal entity that has both the characteristics of a corporation and of a partnership. An LLC provides its owners with corporate-like protection against personal liability. It is, however, treated as a noncorporate business organization for tax purposes. This structure also provides the flexibility in capital and management structure that can be found in a partnership. In Missouri, a person(s) wanting to form an LLC will have to have an operating agreement—a plan on how the business will be operated—and filing Articles of Organization with the Secretary of State's Office.

Corporation
A corporation is a legally created entity with rights, duties, powers and responsibilities in and of itself. The ownership of property, the incurrence of debt, and the performance of services and sales of goods are the responsibility of the corporation rather than the individuals in the corporation. Shareholders contribute capital to the company and are the owners of the corporation. Shareholders are not responsible for the debts or liabilities of the corporation. Advantages of the corporate structure are that shareholder liability is limited to the loss of the shareholder's investment unless a shareholder accepts additional responsibility and the ability to bring other individuals into ownership of the business to raise additional funds. Disadvantages include the costs incurred for incorporating and meeting the requirements (state and federal) for filing reports.

There are four types of corporations—Close Corporation (C Corp), Subchapter S Corporation (S Corp), Not-For-Profit Corporation, and Professional Corporation. This type of venture would not be suitable for a Not-For-Profit or Professional Corporation. The distinguishable characteristics of a C Corp are the options to not have a board of directors, annual meetings, or bylaws if so stated in the article of incorporation. A C Corp is designed to allow the option for a small amount of persons to operate a business as a corporation. An S Corp functions like a general business corporation, but the income or loss of the corporation is passed on to the shareholders for tax purposes.

Cooperative
Generally, cooperatives are corporations. A cooperative corporation, however, is different from an investor-owned corporation in that a cooperative is owned by those who conduct business with it—its purpose is to benefit its owners as investors. An investor-owned corporation's owners do not usually conduct business with the corporation. Two statutes govern the creation and operation of agricultural cooperatives in Missouri. Missouri Statutory Chapter 274 provides for the incorporation and operation of a nonstock cooperative, while Chapter 357 provides for the incorporation and operation of a stock cooperative. For this type of venture, a Chapter 357 (stock) cooperative would not be an option. As with a corporation, Missouri requires that articles of incorporation be prepared and filed by the group wanting to form the cooperative. A minimum of 11 agricultural producers, a majority of whom are Missouri residents, is required in order to form a 274 cooperative.

An additional form of cooperative that has gained in popularity is the New Generation Cooperative. A New Generation Cooperative is used as a term to describe the operations of an agricultural business, including how it is financed and delivery rights. This is a "closed" cooperative, which limits use to member-owners. Capitalization occurs through the initial sale of delivery rights and debt. Per the delivery rights, this requires member-owners to deliver a set unit of a commodity per share. Earnings are distributed in proportion to shares owned. There are four differentiating factors in the bylaws and operating guidelines of a section 274 and section 375 cooperative that justify the title "New Generation Cooperative:"

1. Defined membership, or closed cooperative, where member-owners deliver a set number of units per share. Expansion may allow for increased membership.
2. Delivery rights, an obligation to deliver according to the signed marketing agreement. Signature of marketing agreement requires membership interest, which allows for voting privileges.
3. Upfront equity, producer-owners pay a fee, used to capitalize the business, for delivery rights.
4. Delivery rights are transferable.

Other than these characteristics, a new generation cooperative follows procedures similar to a section 274 or 375 cooperative.

Chapter 4: Economic Analysis of Corn Stover Removal

4.1 Corn Stover

4.1.1 Potential Market Price for Corn Stover

Currently, prices for baled corn stover are limited due to the nature of its undeveloped market. Independent situations have developed regarding buying corn stover on a smaller, more regional scale. The University of Missouri is currently building a new boiler that is designed specifically for biomass burning, and is expected to be finished in 2012. Gregg Coffin, the MU CHP Plant Superintendent, recently gave a presentation that included their current and expected future prices of woody biomass as a replacement for fuel at this plant. Currently, the plant is purchasing delivered woody biomass at a rate between $25 and $35 per ton, and expects the price could rise to between $35 and $60 per ton after MU's new boiler is operational in 2012.

Additionally, Coffin further broke down the biomass price to a preferred measure, price per Btu. This is a better way of valuing a biomass source by looking at the expected energy value. Corn stover generally has a higher heat value compared to most woody biomass. With an estimated Btu rating of 7,487 for each pound of corn stover, this equates to 14.974 MMBtu per ton. Exhibits 4.1.1.1 categorizes current and expected sized and delivered woody biomass prices provided by Coffin (2010). Exhibit 4.1.1.2 expands Coffin's prices based on the Btu rating of corn stover. Based on Exhibit 4.1.1.2 analysis, it would suggest the current market prices for corn stover sized and delivered to an end user similar to MU would be in the $37 to $41 per ton price range. The price expectations of processed and delivered corn stover in the future could be in the $45 to $75 per ton range.

Exhibit 4.1.1.1 Range of Current and Expected Sized and Delivered Biomass Prices

	Cost per ton	Cost per MMBtu
Current Price	$25.00-$35.00	$2.50-$2.75
Expected	$35.00-$60.00	$3.00-$5.00

Source: Coffin (2010)

Exhibit 4.1.1.2 Current and Expected Sized and Delivered Corn Stover Prices

	Current (Low Price)	Current (High Price)	Expected (Low Price)	Expected (High Price)
Btu for one lb. of stover	7,487	7,487	7,487	7,487
Lbs./ton	2,000	2,000	2,000	2,000
Btu Produced/ton	14,974,000	14,974,000	14,974,000	14,974,000
MMBtu produced/ton	14.974	14.974	14.974	14.974
Price per MMBtu	$2.50	$2.75	$3.00	$5.00
Price per ton of stover	**$37.44**	**$41.18**	**$44.92**	**$74.87**

The Poet Corporation, which manages several ethanol facilities, has been conducting research into cellulosic ethanol. Their plant in Emmetsburg, Iowa not only has a traditional ethanol facility, but also a dedicated cellulosic ethanol plant, which is part of its Project Liberty research endeavor. According to a phone conversation with Allen Keller, Poet is currently obtaining corn stover in the form of bales produced by the baling only method (approximately 25% removal rate). The choppers on the combines were disconnected, leaving a windrow that was then baled. The baler used the majority of the time has been the Vermeer Corn Stalk Special. Other round hay balers as well as a Hesston large square baler have been used to produce a third of the bales.

Current contracts for Poet have listed a price of $40.24 per dry ton delivered FOB to the cellulosic ethanol plant in Emmetsburg. The bales have been ranging from 1,200 to 1,300 pounds, with a moisture content of approximately 20%. Keller estimated that 80 percent of the stover delivered to the plant was produced within a 30 mile radius of the plant, with only three producers outside the radius. The Poet plant currently operates with twenty days of storage at the plant.

4.1.2 Cost of Production

There is a variety of research concerning corn stover in the academic community. The cost of production information from various reports that have been conducted over the past twelve years related to corn stover are presented in Exhibit 4.1.2.1. A key point to understand is that each source has varying assumptions within various locations, and no research publication is created alike. It is also important to understand that some of these prices are older costs and not updated to current figures. But this cost of production data does give some idea to what the range of getting corn stover accumulated and delivered should theoretically be. The reality is that the corn stover feedstock market is in its infancy, so there is not a lot of real-life information to support the academic research. The Poet cellulosic plant in Iowa is a corn stover markets that are starting to commercialize. Farmers participating in this market are beginning to realize the approximate cost structure of harvesting and delivering corn stover.

Exhibit 4.1.2.1 Literature Review on Corn Stover Cost of Production

Source/Publication Year	Cost	Units	Notes
Glassner, et al. (1998)	$31.60-$35.70	Per dry ton	Delivered cost
Perlack & Turhollow (2002)	$42.70-$47.10	Per dry ton	Delivered cost
Sokhansanj & Turhollow (2002)	$19.70-$21.40	Per dry ton	Operations up to and including stacking for storage
Sokhansanj, et al. (2002)	$21.00-$41.00	Per dry ton	Delivered cost at distance of 5 miles
Perlack & Turhollow (2002)	$43.10-$51.60	Per dry ton	Delivered cost with producer payment of $10/ton
Brechbill and Tyner (2008)	$36.49-$45.54	Per wet ton (84% DM)	Delivered cost up to 50 miles
Hess, et al. (2009)	$66.34-$76.26	Per dry ton	Delivered feedstock cost, which included preprocessing prior to delivery
Morey, et al. (2010)	$73.75	Per wet ton (85% DM)	Delivered cost, including a farmer participation payment and preprocessing prior to delivery

Source: Original table from Brechbill and Tyner (2008) and expanded with more recent publications

4.1.3 Nutrient Value

The removal rates of key nutrients (nitrogen, phosphorous and potassium) by corn stover harvest have been extensively researched. Morey et al. (2010) compiled Exhibit 4.1.3.1 to portray the results of studies conducted on corn stover removal and nutrients removed.

Exhibit 4.1.3.1 Nutrients per Ton of Corn Stover Harvested

Source/Publication Year	Nitrogen	Phosphorus	Potassium
	(lb./dry ton)		
Sheehan et al. (2004)	17.6	1.2	14.4
Spatari et al. (2005)	15.0	5.8	25.0
Sawyer and Mallarino (2007)	14.8	5.9	25.0
Brechbill and Tyner (2008)	15.9	5.9	30.0
Petrolia (2008)	0.0	6.2	33.0

Source: Morey et al. (2010)

After consulting with the University of Missouri Extension Soil Testing Lab, it was determined that nitrogen removal rates will not play a significant role in the economics of removing corn stover. Soil test recommendations are not changed based on corn stover removal. The MU Extension Soil Lab specialists explained that although stover contains a relatively small amount of nitrogen, that amount does not offer a benefit for the next growing season, so therefore nitrogen replacement rates each season are not affected by stover removal.

Phosphorous and potassium will be included in the cost analysis of corn stover (See Exhibit 4.1.3.2) because the removal of stover from the field will affect the fertility recommendation. Removal rates per ton of stover were used from Sawyer and Mallarino (2008), while prices per pound of nutrient were taken from Carpenter and Brees (2010). It is also important to understand these nutrients may not need to be replaced, which would be determined by looking at soil samples, land characteristics, crop rotation and fertilizer applied in the past.

Exhibit 4.1.3.2 Corn Stover Nutrient Content and Value

Nutrient	Nutrient Composition (Lb./dry ton)	Nutrient value ($/lb.)	Total nutrient cost ($/dry ton)
Phosphorus (P_2O_5)	5.9	$0.47	$2.77
Potassium (K_2O)	25	$0.43	$10.75
Nutrient value per ton of stover removed			**$13.52**

The price of phosphorous and potassium are known to fluctuate over time. In turn, the cost of these nutrients removed per pound of corn stover harvested fluctuates as well. Exhibit 4.1.3.3 shows the effect a ten percent increase and decrease in nutrient prices will have on the per-ton costs associated with nutrient removal in corn stover harvest. It should be noted, however, that prices for each of the nutrients has fluctuated much more than just 10%. This level of change is only used to illustrate the effect on per ton prices.

Exhibit 4.1.3.3 Per-Ton Impact of Fluctuations in Nutrient Values

Nutrient	10% decrease in price	Total nutrient cost	10% increase in price
	($/dry ton)		
Phosphorus (P_2O_5)	$2.50	$2.77	$3.05
Potassium (K_2O)	$9.68	$10.75	$11.83
Cost per ton	**$12.17**	**$13.52**	**$14.88**

4.1.4 Harvesting Costs

The next economic consideration in corn stover removal is the harvesting costs. For this analysis, we will concentrate on two harvest methods; baling only and raking/baling. There can be greater residue removal achieved (by chopping stalks), but we will not demonstrate those economics, due to the Missouri NRCS recommendation that Missouri producers should not be removing greater than 50% of its stover in any field (See Section 1.3 of this report for details).

The first option is baling directly from the windrow produced by grain harvesting. This can be accomplished by disengaging the chopper on the combine when harvesting corn. After conditions become suitable for corn stover harvest, a tractor and baler combination follow to bale up the windrow. This harvest method will result in approximately 30% of the residue being removed from the land.

The second option increases the level of corn stover removal by adding an extra step in raking the corn stover prior to baling (approximately 50% stover removal). This would result in second pass, first with the tractor/rake and second with the tractor/baler.

The harvesting costs per acre are greatly dependent on the amount of stover removed per acre. Higher grain yielding fields will result in greater amounts of stover generated. Corn stover yield per acre (See Exhibit 4.1.4.1) was derived by taking the Missouri five year corn yield average (140 bushels/acre) and using the 1:1 corn/residue ratio used earlier in this report. Based on this calculation, average corn stover production in Missouri would be 3.93 tons per acre (wet basis including 15% moisture). The removal rates of 30% and 50% would result in the removal amounts of 1.18 and 1.96 tons respectively. On a dry matter basis, it would result in a total corn stover yield of 3.33 tons per acre. The removal rates of 30% and 50% on a dry matter basis would result in the removal amounts of 1.00 and 1.67 tons respectively.

Exhibit 4.1.4.1 Corn Stover Tonnage Removed Based on Missouri Averages

Removal rate	Tons per acre (wet basis)	Tons per acre (dry basis)
Total accumulation	3.92	3.33
30% removal rate	1.18	1.00
50% removal rate	1.96	1.67

Note: Assumes a 1:1 corn/residue ratio and 140 bushel yield per acre

Custom Harvesting

Costs for custom harvesting have been derived from looking at university custom rate guides, which are based on custom operator and farmer surveys. Values reported in these surveys are presented on a per-acre and per-ton basis. University of Missouri (Plain et al., 2009) estimates the cost of raking at $4.88 per acre, while Iowa State (Edwards and Johanns, 2010) coming in closely at $5.65 per acre. Corn stalk baling with net wrap was listed at a cost of $12.25 per bale (round or square) for Iowa State, while University of Missouri reported the cost at $10.32 per bale. Baling without wrap essentially lowers the cost of baling by approximately $1 per bale in both surveys. Bales with other wrapping (twine and plastic wrap) would be suitable as well, but net wrap costs were used due to lower storage losses for uncovered corn stover over a long storage period. It is expected that producers will not be hiring custom operators by the ton; rather, they will likely continue to pay for services on a per-bale or per-acre basis for various harvesting activities. But potential market outlets will most likely pay on a dry ton basis and thus are reported in the analysis in this manner.

Based on the University of Missouri custom rates, two sets of harvesting costs, shown in Exhibit 4.1.4.2, were estimated for 30% removal and 50% removal, based on the Missouri average stover yields. Figures were derived based a 1,200 lb bale size, with an average moisture level of 15%. After factoring in the corn stover dry matter basis, the 30% removal rate would result in a $20 cost per ton and the 50% removal rate would result in a $23 per ton cost. While the 50% removal rate would result in a greater amount of corn stover accumulated per acre, it is more costly due to extra pass needed for raking.

Exhibit 4.1.4.2 Missouri Custom Rate Harvesting Costs

Removal method	$ per bale	$ per dry ton	$ per acre
Baling with net wrap (30% removed)	$10.32	$20.24	$20.23
Raking and baling with net wrap (50% removed)	$11.81	$23.16	$38.59

Source: Derived from Plain et al. (2009)

Additionally, the analysis above was based on using a round baler. Some operators are using large rectangular balers to bale corn stover. Based on our discussion with Poet concerning their cellulosic ethanol plant, a majority of their bales were created using a Vermeer Corn Stalk Special round baler. Other round hay balers as well as a Hesston large square baler have been used to produce a third of the bales for this ethanol plant. Farmers will make the decision on what their custom operators currently use and what the existing infrastructure is using to haul bales.

Producer Owned Equipment

Determining the cost for a producer to own specialized equipment for stover harvesting is more complex. Factors weighing into the equation include equipment acquisition costs, labor, fuel, power, repairs, overhead and depreciation. Additionally, the per-ton costs of equipment will vary based on the total amount of acres harvested with the equipment.

Manufacturers have been developing two distinct types of corn stover balers (round and rectangular). Vermeer has developed the Super M Cornstalk Special baler, which is a large round baler designed specifically for use in baling stover. This baler is currently listed at $55,801 and retails for $47,000. Other hay round balers from other manufacturers are acceptable as well.

In addition to large round bales, some producers may opt to utilize a large rectangular baler. The AGCO Corporation has developed a system that includes a Hesston large square baler connected to a Lexion Class VIII combine. Currently, AGCO is not offering their corn stover baler commercially, but may in the future. Other rectangular balers are available and are being used in various capacities for baling corn stover.

In order to better clarify costs that may be associated with corn stover removal, Exhibit 4.1.4.3 demonstrates the acquisition costs, tractor size needed, and total cost per acre related to baling equipment, according to the University of Minnesota (Lazarus and Smale, 2010). The net cost of a new implement assumes no trade-in or sales tax. Total cost per acre includes all use-related and time-related (overhead) costs, both for the power unit (tractor) and implement being used. Total cost per acre will factor in fuel, lubrication, power and equipment repairs and maintenance, labor, and overhead costs including depreciation.

Exhibit 4.1.4.3 Acquisition and Operating Costs of Raking and Baling Equipment

	Tractor size (HP)	Net cost of a new implement	Acres per year	Total cost per acre
Hay rake (hydraulic) 9 ft	40 HP	$7,000	489	$6.00
Hay rake (wheel, 2-16') 30 ft	40 HP	$43,000	2,095	$3.50
Round baler 1000 lb, 20 ft	75 HP	$23,000	2,364	$6.99
Round baler 1500 lb, 20 ft	75 HP	$32,000	2,364	$8.27
Rd baler/wrap 1500lb, 20 ft	75 HP	$35,000	2,364	$8.52
Rd baler/wrap stover 1500lb, 20 ft	105 HP MFWD	$54,000	2,364	$12.70
Large rectangular baler 3x3 20 ft	130 HP MFWD	$87,000	2,909	$10.73
Large rectangular baler 4x3 20 ft	130 HP MFWD	$106,000	2,909	$11.85

Source: Lazarus and Smale (2010)

Various pieces of equipment (tractors, rakes, balers) may not need to be purchased if currently owned. Tractor or baling equipment utilized in other aspects of the farm could be used to lower ownership costs per acre. Additionally, if producers do not reach the optimum level of acreage usage per year, it is expected that costs per acre will increase higher than the levels found in Exhibit 4.1.4.3.

Additionally, other baling expenses would need to be included with producer owned equipment. Depending on the baling method, supplies will be needed for either net wrap, twine and/or plastic wrap. Lazarus and Smale (2010) indicated the cost of net wrap for a round baler would cost $2.63 cost per bale (7,800 ft. x $272 per package). Brechbill and Tyner (2008) indicated the cost for sisal twine would be $0.54 per ton (20,000 ft roll x $20.75 per roll) and for twine/plastic wrap together, it would cost $2.75 per ton.

An estimation for Missouri producer owned equipment can be found in Exhibit 4.1.4.4. It suggests the dry ton costs per method to be $17.86 for 30% removal and $14.88 for 50% removal, based on the Missouri average corn stover yields.

Exhibit 4.1.4.4 Missouri Producer-Owned Equipment Cost

Equipment or supplies	Total cost per acre	30% residue removal cost ($/dry ton)	50% residue removal cost ($/dry ton)
Hay Rake (Wheel, 2-16') 30 ft	$3.50	-	$2.10
Rd Baler/Wrap Stover 1500lb, 20 ft	$12.70	$12.71	$7.62
Net Wrap (7,800 ft. x $272 per package)		$5.15	$5.16
	Total cost	$17.86	$14.88

4.1.5 Transportation, Storage and Processing

After harvest, the next economic consideration is moving the bales, either to the field edge or sent to a local storage area. Bales could be moved via tractor/bale wagons to the end of a field, which would allow for collection by flatbed trucks or hauled with the same tractor/bale wagons if the storage area is in close proximity. With a short harvest time frame for corn stover, it is known that long-term storage will have to be available either through farmers, an intermediary site, or the market outlet to provide consistent product flow to an end user. Size needed for a storage facility will be dictated by the requirements of the market and their ability to store product.

Morey et al. (2010) developed a sound corn stover supply logistics system that details many of the key assumptions and costs for transporting, storage and processing prior to going to a conversion facility. Much of the following sections are summarized from his work.

Bales (round and net wrapped) would be sent to a local storage site. The cost of moving bales from the field to this storage site would cost $5.00 per ton. A Highline Bale Mover 1400 with a tractor would have the capacity for moving 14 bales at a time, with an expected 7 minutes of loading time and 5 minutes of unloading time. The average round trip distance was based on 3.47 miles. At the local storage site, bales would be stored on a level surface, uncovered, in a north-south orientation, butts close together and three feet between rows. Each of these storage principles were designed to minimize storage loss and lower investment cost (building, tarps, etc.) of corn stover bales.

Costs estimates for storage in Morey's analysis included the land required for storage as well as average storage loss. Storage loss will be expected at the local storage area at a rate of 5% loss for round, net-wrapped bales. With this storage loss, there must be that same percentage loss removed on collection, nutrients and farmer compensation since there is less tonnage. Bale storage was assessed at $0.36 per ton, with the assumption of $200 per acre land charge. Storage period for bales was estimated to range from one to eleven months, with an average moisture rate of 15%. Based on these factors, an estimated cost for local storage cost and loss is calculated at $2.94 per ton.

After storage, the next operation of concern would be bale processing for the end user. With each local storage site, it was suggested to have a minimum of 200 tons to ensure a full day's work for a custom processor. A portable processing unit would be used by a custom operator, moving from site to site throughout the year for an estimated 1,800 hours (36 hrs per week, for approximately 50 weeks). End markets will most likely want one to two weeks of supply on hand, in case of interruptions such as weather conditions or late deliveries.

This processing unit would involve using tub-grinding, roll-press compaction, and 25-ton drop trailer trucks. The tub grinder would use cutting force to reduce particle size and a roll press compactor would densify by compression between its rolls. Processed corn stover would then be loaded onto the 25-ton truck. Expected costs for bale to bulk processing corn stover (including a charge for the aggregator) can be found in Exhibit 4.1.5.1, totaling $12.24 per ton (wet basis) and $14.00 (dry basis).

Exhibit 4.1.5.1 Bale to Bulk Processing of Corn Stover by an Aggregator

Operation	Tractor/Power Unit Size (HP)	Machine Capacity (ton/hr)	Diesel Fuel Use (gal/ton)	Lubricant Oil Use (gal/ton)	Cost ($/wet basis ton)	Cost ($/dry ton)
Feeding bales into tub-grinder with a tractor and front-end loader	130	25	0.114	0.0013	$1.89	$2.22
Tub-grinding of bales	540	25	1.08	0.0048	$4.70	$5.53
Roll-press compacting of tub-ground corn stover particles	60	25	0.106	0.0007	$2.25	$2.65
Payment to aggregator	-	-	-	-	$3.40	$4.00
Total	-	-	1.3	0.0068	$12.24	$14.40

Source: Morey et al. (2010)

The compacted, bulk corn stover product would then be ready to ship to the end destination. The use of drop trailers would be expected, as one trailer is being delivered, another is being filled. Average distance that used in this study was a round-trip distance of 52 miles, within a 30 mile distance from the end user. Transportation costs were estimated to be $6.40 per ton (wet basis) and $7.53 per ton (dry basis). A summary of all storage, transportation and processing costs are presented in Exhibit 4.1.5.2.

Exhibit 4.1.5.2 Summary of Storage, Transportation and Processing Costs

Operation	Cost ($/wet basis ton)	Cost ($/dry ton)
Bale moving from field to storage site	$5.00	$5.88
Local storage cost/ local storage loss	$2.94	$3.46
Tub-grinding/roll-press compaction	$12.24	$14.40
Truck transport of compacted corn stover	$6.40	$7.53

Source: Morey et al. (2010)

4.1.6 Other Economic Considerations

There are other economic considerations that should be discussed when making a decision to remove corn stover. Removing corn stover from a field can impact the soil in a negative manner, with some economic consequences if it results in soil loss due to erosion. But it is hard to quantify, as the tillage system, soil characteristics and slope will determine how much the value is. Also, this analysis would need to understand what your current predicted erosion is prior to removal and what would be expected if you remove stover. Iowa Learning Farms (2009) put together a hypothetical example for a northwest Iowa field with Clarion Loam Soil and average slope of 2.6 percent. With 30% residue removal, it was expected to cost $4.21 per acre, with an additional soil loss of 0.69 tons/acre. With 50% removal, it was expected to cost $5.61 per acre, with an additional soil loss of 0.92 tons/acre. Each of these examples valued soil at a cost of $6.10 per ton. While this is an important consideration, it was not included in this overall report analysis as it requires very site-specific analysis to reach a conclusion on this economic cost and would vary considerably from field to field.

Productivity changes in corn grain yield from residue removal are another consideration. University of Nebraska (Wortmann et al., 2008) stated that one study had corn yields decrease by 2 bushels per acre for each ton of corn stover that was removed. Other reports suggest that there may be agronomic benefits to removing corn stover. At the 2010 Illinois Agronomy Day, Nafziger (2010) reported that the University of Illinois conducted a four year study over ten Illinois sites on continuous corn. Based on their results, removing some of the residue could potentially increase corn yields under no-till practices. The University of Missouri is currently conducting a three-year trial (2009-2011) on nutrient management of biofuels (including corn) and may have some findings that will be applicable to Missouri producers on quantifying what the ramifications are for corn yields. Since productivity changes are not well defined in Missouri, there were left outside of our summary analysis in Section 4.1.7.

Lastly, farmers have to gain an economic reward (profit) for making the corn stover removal decision. This would be the payment to a farmer for their participation in serving as a corn stover supplier. If the opportunity cost of not removing corn stover is zero or is very small, farmers will most likely make the decision to not remove corn stover. Most of the academic research has estimated that producer payments must be around the 10-15% of total product cost for their willingness to participate. In our summary analysis in Section 4.1.7, we did not include a value, but farmers interested should look at the total product cost and determine this value in their decision making.

4.1.7 Summary

Based on information presented in the preceding sections, an overall summary for costs of removing corn stover in Missouri can be found in the following exhibits. Exhibit 4.1.7.1 demonstrates the economics of using a custom harvesting business for corn stover removal, while Exhibit 4.1.7.2 shows the potential economics with producer-owned equipment. Values are reported for 30% and 50% removal of corn residues on Missouri average corn production, both for dollars per dry ton and per acre. Based on these findings, it would suggest that corn stover removal would cost $59.67 to $67.96 per dry ton to supply a potential end market. Owning equipment would potentially decrease the cost on a per ton and per acre basis. Per acre costs assumed the Missouri average yields of corn stover (1.00 and 1.67 tons for 30% and 50%, respectively).

Exhibit 4.1.7.1 Summary of Missouri Economics - Custom Hire Harvesting

Nutrient value	$13.52	$13.51	$13.52	$22.52
Harvest	$20.24	$20.23	$23.16	$38.59
Transport to local storage	$5.88	$5.88	$5.88	$9.80
Storage	$3.46	$3.46	$3.46	$5.76
Grinding and compaction	$14.40	$14.39	$14.40	$23.99
Truck transportation	$7.53	$7.53	$7.53	$12.54
Total costs	$65.03	$65.00	$67.96	$113.21

Exhibit 4.1.7.2 Summary of Missouri Economics - Producer Owned Equipment

	30% Residue Removal		50% Residue Removal	
	$ per dry ton	$ per acre	$ per dry ton	$ per acre
Nutrient value	$13.52	$13.51	$13.52	$22.52
Harvest	$17.86	$17.85	$14.88	$24.79
Transport to local storage	$5.88	$5.88	$5.88	$9.80
Storage	$3.46	$3.46	$3.46	$5.76
Grinding and compaction	$14.40	$14.39	$14.40	$23.99
Truck transportation	$7.53	$7.53	$7.53	$12.54
Total costs	$62.65	$62.62	$59.67	$99.41

It is important to understand that various markets may not require all of the stages above to fulfill their product needs. An example may be that a corn stover user may not need grinding and compaction of corn stover, thus the economics would change for that respective market.

Since the potential purchase price for corn stover is not currently well-defined, potential profit (and loss) for varying corn stover purchase prices are illustrated in Exhibit 4.1.7.3. At $70 per ton, farmers would generate a profit for corn stover. Farmers would then need to incorporate what margin that they would need above the breakeven cost for them to decide to sell their corn stover.

Exhibit 4.1.7.3 Corn Stover Profitability (or Loss), Per Dry Ton

Price received per dry ton of corn stover	Custom Hire		Producer Owned	
	30% Removal ($ per dry ton)	50% Removal ($ per dry ton)	30% Removal ($ per dry ton)	50% Removal ($ per dry ton)
$40	($25.03)	($27.96)	($22.65)	($19.67)
$50	($15.03)	($17.96)	($12.65)	($9.67)
$60	($5.03)	($7.96)	($2.65)	$0.33
$70	$4.97	$2.04	$7.35	$10.33
$80	$14.97	$12.04	$17.35	$20.33

4.2 Corn Cobs

Besides corn stover, there is also the opportunity to segregate corn cobs from corn residue. Corn cobs have been used in various gasification, direct co-firing, and cellulosic ethanol applications across the US (Roth and Gustafson, 2010). A limited amount of research has been conducted by companies and universities regarding the economics of corn cob removal.

4.2.1 Potential Market Price for Processed and Delivered Cobs

Corn cobs have a higher Btu rating than that of corn stover, with corn cobs producing approximately 8,000 Btu/lb compared to 7,487 Btu/lb for corn stover. Below is a chart outlining current and expected prices for chopped and sized corn cobs, based on woody biomass prices per Btu the MU CHP plant currently pays or may expect in the future for processed and delivered biomass. Based on this analysis, it would suggest that the future prices for chopped and delivered corn cobs could be in the $48 to $80 range per ton.

Exhibit 4.2.1.1 Current and Expected Corn Cob Prices

	Current (Low)	Current (High)	Expected (Low)	Expected (High)
Btu output of one lb of cobs	8,000	8,000	8,000	8,000
Lbs./ton	2,000	2,000	2,000	2,000
Btu produced/ton	16,000,000	16,000,000	16,000,000	16,000,000
MMBtu produced	16	16	16	16
Price per MMBtu	$2.50	$2.75	$3.00	$5.00
Estimated price of cobs (per ton)	**$40.00**	**$44.00**	**$48.00**	**$80.00**

According to MU Extension (2010), Iowa Agricultural Bio Fibers is currently selling corn cobs in two ways, ground and unground. Price per ton for unground cobs is currently $65 per ton FOB and a selling price of $75 per ton FOB for ground cobs.

4.2.2 Nutrient Value

Removal of cobs from corn fields has a very low impact on the nutrient removal. Corn cobs represent approximately 15-20% of total corn stover left in the field on a dry matter basis. The variation depends on corn yield. Exhibit 4.2.2 is a nutrient replacement example put together by Purdue University, with two different corn yields. Fields with higher corn yields will have slightly increased nutrient replacement costs.

Exhibit 4.2.2 Nutrient Replacement Needed with Corn Cob Removal

	185 Bushel Corn Yield	154 Bushel Corn Yield
Nitrogen ($/acre)	$2.04	$1.70
Phosphorus ($/acre)	$0.93	$0.78
Potassium ($/acre)	$5.65	$4.71
Total Nutrient Replacement (per acre)	**$8.62**	**$7.19**
P and K Nutrient Replacment (per acre)	**$6.58**	**$3.01**

Source: Erickson and Tyner (2010)

4.2.3 Cost of Cob Collection

Erickson and Tyner (2010) have completed the most extensive economic research on corn cob removal. Much of the information presented in this section is summarized from their paper, which includes survey work with producers supplying the Chippewa Valley Ethanol Company in Minnesota and other feedback from 55 farming operations in attendance at the 2009 Top Farmer Crop Workshop at Purdue University.

Wagon rental cost (at the time of Erickson and Tyner's research was $28,000 per season) was based on using the Vermeer CCX770 cob wagon, which is a pull type wagon that is attached on the backside of a combine. Other cob collections systems could be used and current pricing for these systems can be found in Exhibit 4.2.3.1. The cob collection system represents one of the major costs in removing corn cobs.

Exhibit 4.2.3.1 Pricing of Corn Cob Collection Systems

Manufacturer	Product	Type	List price	Retail price	Rental price
Hillco	Separation Attachment	Harvester	$32,485	N/A	N/A
Hillco	Cob Wagon	Cart	$37,900	N/A	N/A
Redekop	H165 Harvester	Harvester	$60,000	N/A	N/A
Redekop	C180 Collection Cart	Cart	$37,500	N/A	N/A
Vermeer	CCX770	Harvester/Cart	$133,000	$120,000	$30,000

Prices as of 10/20/2010

Purdue researchers developed a hypothetical corn farm (686 corn acres) to illustrate the effects of differing harvest working rates and yields on corn cob removal costs (see Exhibit 4.2.3.2). One concern that existing corn cob suppliers in Minnesota had was that corn cob removal tended to slow down harvesting time. Their example used a base scenario of a 10% decrease in harvest working rate and then showed a 5% sensitivity change (increase and decrease) to show the impact on costs. Additionally, they represented two levels of corn yields to show the impact of a corn yield drop (or shock as it is shown in Exhibit 4.2.3.2). The example farm shows a normal corn yield of 185 bushels per acre and a yield reduction of 17% decrease (which lowers corn yield to 154 bushels per acre).

Conclusions from Erickson and Tyner's research show that estimated costs of corn cob removal for this 686 acre farm size to range from $48 to $63 per ton. Expected costs for corn cob removal include nutrient replacement, storage, machinery and rental of a corn cob harvester. Purdue's research does not include any transportation costs for delivery to a market outlet.

Exhibit 4.2.3.2 Purdue University 686 Corn Acre Farm Example

Harvest Working Rate Scenarios	5%	5% (w/Yield Shock)	10%	10% (w/Yield Shock)	15%	15% (w/Yield Shock)
Nitrogen ($/acre)	$2.04	$1.70	$2.04	$1.70	$2.04	$1.70
Phosphorus ($/acre)	$0.93	$0.78	$0.93	$0.78	$0.93	$0.78
Potassium ($/acre)	$5.65	$4.71	$5.65	$4.71	$5.65	$4.71
Storing and Piling ($/acre)	$4.72	$3.94	$4.72	$3.94	$4.72	$3.94
Nutrient Replacement and Storage Total (per acre)	**$13.34**	**$11.13**	**$13.34**	**$11.13**	**$13.34**	**$11.13**
Harvest Working Rate (Total Cost)	$1,138 ($1.66/acre)	$1,138 ($1.66/acre)	$1,593 ($2.32/acre)	$1,593 ($2.32/acre)	$1,972 ($2.88/acre)	$1,972 ($2.88/acre)
Diesel Fuel ($/acre) @ $2.73	$2.00	$2.00	$2.12	$2.12	$2.24	$2.24
Lubrication ($/acre)	$0.30	$0.30	$0.32	$0.32	$0.34	$0.34
Labor ($/acre)	$2.59	$2.59	$2.87	$2.87	$3.17	$3.17
Labor Hours per Machine Hour (Benchmark of 3.5)	$4451 ($6.49/acre)	$4451 ($6.49/acre)	$4451 ($6.49/acre)	$4451 ($6.49/acre)	$4451 ($6.49/acre)	$4451 ($6.49/acre)
Combine Repair and Maintenance ($/acre)	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50
Moving to Field Edge ($/acre)	$4.10	$4.10	$4.10	$4.10	$4.10	$4.10
Moisture Benchmark (40% moisture @ delivery)	20%	20%	20%	20%	20%	20%
Machinery Total (per acre)	**$17.64**	**$17.64**	**$18.72**	**$18.72**	**$19.72**	**$1972**
Total Costs (per acre)	**$30.98**	**$28.77**	**$32.06**	**$29.85**	**$33.06**	**$30.85**
Wagon Rental (Fixed Cost)	**$28,000**	**$28,000**	**$28,000**	**$28,000**	**$28,000**	**$28,000**
Corn Yield	185	154	185	154	185	154
Cob Yield (tons per acre)	1.03	0.86	1.03	0.86	1.03	0.86
Corn + Cob Acres	1,493	1,493	1,287	1,287	1,217	1,217
Cob Production (tons)	1,538	1,284	1,326	1,107	1,254	1,047
Total Cob Variable Cost ($/ton)	$30.08	$33.45	$31.13	$34.71	$32.10	$35.87
Total Cob Fixed Cost ($/ton)	$18.21	$21.81	$21.12	$25.30	$22.34	$26.75
Cost of Collecting Cobs ($/ton)	**$48**	**$55**	**$52**	**$60**	**$54**	**$63**

Source: Erickson and Tyner (2010)

4.2.4 Summary

Current cost of production for corn cobs is a limiting factor in being a feasible option. Cob collection systems represent a significant cost in the harvest of corn cobs. Acreage needed to justify the purchase or rental of a collection system is pretty significant. According to Jay Van Roekel with Vermeer, the CCX770 harvester is designed for custom harvesters or large farms (1,500 to 2,000 acres minimum). Additionally, breakeven prices for cobs will vary depending on farm size, grain yields and production method.

One of the current buyers of corn cobs for gasification, Chippewa Valley Ethanol in Minnesota, recently announced that they were not buying corn cobs during the 2010 season as natural gas were very low ($4.50 per MMBtu) so the economics would not justify the purchase. It would become feasible again once natural gas price reached $5 per MMBtu.

It is challenging to harvest enough biomass to supply a potential outlet. Corn cobs alone are a low yielding product. A corn field that yielded 161 bushels per acre would produce approximately 1,200 pounds of cobs per acre (Roth and Gustafson, 2010). Poet Energy originally was going to use a corn cob product, but realized the tonnage required for their Emmetsburg plant would not be able to meet capacity by this product alone. They are currently utilizing corn stover mix (corn cobs and other stover) in round and square bales to supply their ethanol plant.

Erickson and Tyner (2010) also conducted some additional research to understand the price points when farmers would be interested in the collection of corn cobs. Of the 55 farms surveyed (approximately 100,264 corn acres in the year 2008), none of the farms would supply corn cobs if the wagon rental was $28,000 and cob price was $40 per dry ton. If the price reached $100 per dry ton, they predicted that 22 of the farms would begin to supply corn cobs to a market outlet. A $100 per dry ton market price would represent a $22.57 profit per acre. That price point was what they considered to be able to generally persuade farmers to potentially supply markets. But this price point could be lowered with a lower wagon rental rate and/or other productivity improvements.

While Missouri does not have any current outlets buying corn cobs, it would most likely need a similar price to $100 per dry ton to entice larger farms to purchase equipment and begin supplying corn cobs. MU power plant expects that chopped cobs could be valued at approximately $48 to $80 per ton; however, corn cobs will also compete with other various biomass feedstocks. Detailed farm-specific analysis should be conducted by each farmer that would consider becoming a biomass supplier.

4.3 Financial Assistance and Incentives

Corn stover and corn cob production could be assisted by financial assistance programs and generate incentives for farmers. The Biomass Crop Assistance Program (BCAP) was implemented as part of the 2008 Farm Bill to increase the number of producers contributing to renewable energy production by providing financial assistance. According to the USDA, BCAP provides two types of assistance; matching payments for eligible materials and establishment/annual payments for producers within a BCAP project area.

The matching program for "collection, harvest, storage and transportation (CHST)" is designed to incentivize producers to deliver eligible materials to qualified biomass conversion facilities. The program pays at a rate of $1 for each $1 per dry ton paid by a qualified biomass conversion facility, in an amount up to $45 per dry ton, for a maximum of two years. Qualified biomass conversion facilities can produce heat, power, bio based products or advanced biofuels. Eligible materials are defined by the standards and include corn cobs and corn stover.

The other assistance program starts with the identification of BCAP project areas, designated by the Commodity Credit Corporation (CCC). Establishment and annual payments will be available for producers within these areas. Producers would be eligible for reimbursements up to 75 percent of the cost to establish a bioenergy perennial crop. Annual crops are not eligible for the establishment incentive, but are eligible for annual payments. Producers in the BCAP project area can receive annual payments up to 5 years for herbaceous biomass and up to 15 years for woody biomass. Annual payments will be determined by CCC, by using market-based rental rates, to ensure sufficient participation in that BCAP area. After the sale of the crop, annual payments may be reduced various percentages by the end market served (1% for cellulosic ethanol, 10% for advanced biofuels, 25% for heat/power/biobased products, and 100% for any other uses).

As of October 2010, BCAP has contributed $243 million in CHST payments through 4,275 contracts to participating producers in the years 2009 and 2010. Of these payments, only 15 contracts that paid $61,612 were completed for corn cobs in the U.S. and none for corn stover.

References

American Council on Renewable Energy. (August 2010). "Renewable Energy in Missouri." Accessed at http://www.acore.org/files/pdfs/states/Missouri.pdf. December 5, 2010.

Asrar, G. (2007). "REAP: Renewable Energy Assessment Project." USDA Agricultural Research Service. Presentation for National Academies of Science First Federal Sustainability Research and Development Forum, Biofuels -State of the Art Examples of Sustainable Research and Development. October 17, 2007.

Berndes, G., J. Hansson, et al. (2010). "Strategies for 2nd generation biofuels in EU - Co-firing to stimulate feedstock supply development and process integration to improve energy efficiency and economic competitiveness." *Biomass and Bioenergy* 34(2): 227-236.

Blanco-Canqui, H. and R. Lal. (2007). "Soil and Crop response to Harvesting Corn Residues for Biofuel Production." *Geoderma* 141: 355-362.

Blanco-Canqui, H. and R. Lal. (2009). "Corn Stover Removal for Expanded Uses Reduces Soil Fertility and Structural Stability." *Soil Science Society of America Journal* 72(2): 418-426.

Brechbill, S. and W. Tyner. (2008). "The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electric Utility Facilities". Working Paper #08-03, Department of Agricultural Economics, Purdue University,.

Broekema, S. (June 2009). "Feasibility Study of a Biomass Supply for the Spiritwood Industrial Park." NDIC Contract No R001-003, prepared by Great River Energy pursuant to an agreement with the Industrial Commission of North Dakota.

Carpenter, B. and M. Brees. (2010). "2010-2011 Missouri Dryland Corn Budget." University of Missouri.

Center for Applied Research and Environmental Systems (CARES). (2010). CARES Map Room. Accessed at http://www.cares.missouri.edu/ December 10, 2010. University of Missouri.

Chicago Climate Exchange. (2010). Carbon Credit Data Set. Accessed at http://www.chicagoclimatex.com/ November 11, 2010.

Coffin, G. (2010). "Converting a MU Boiler to Biomass". MU Forestry – Biomass Series Presentation Fall 2010. University of Missouri.

Comis, D. and A. Perry. (2009). "Growing Biofuel Crops Sustainably." *Agricultural Research* September 2009. Assessed at http://www.ars.usda.gov/is/AR/archive/sep09/crops0909.pdf. December 2, 2010.

Cruse, R.M., and C.G. Herndl. (2009). "Balancing Corn Stover Harvest for Biofuels with Soil and Water Conservation." *Journal of Soil and Water Conservation* 64(4): 286-291.

Edwards, W. and A. Johanns. (March 2010). "Iowa Farm Custom Rate Survey." Ag Decision Maker FM 1698, Iowa State Extension.

Environmental Protection Agency. (1998). "Compilation of Air Pollutant Emission Factors – Volume 1: Stationary Point and Area Sources." AP-42 Fifth Edition. Chapter 1, Bituminous and Subbituminous Coal, Supplement E. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency.

Environmental Protection Agency. (2007). "Biomass Combined Heat and Power Catalog of Technologies." US Environmental Protection Agency, Combined Heat and Power Partnership.

Erickson, M. and W. Tyner. (2010). "The Economics of Harvesting Corn Cobs for Energy." Purdue Extension Guide ID-417-W. Accessed at http://www.extension.purdue.edu/extmedia/ID/ID-417-W.pdf. December 26, 2010.

Fronning, B., K. Thelen, and D. Min. (2008). "Use of Manure, Compost, and Cover Crops to Supplant Crop Residue Carbon in Corn Stover Removed Cropping Systems." *Agronomy Journal* 100(6): 1703-1710.

Glassner, D., J. Hettenhaus, and T. Schechinger. (1998). "Corn Stover Collection Project." BioEnergy '98: Expanding BioEnergy Partnerships: 1100-1110.

Gould, K. (2007). "Corn Stover Harvesting." Michigan State University Extension. Accessed at: http://www.beef.msu.edu/Resources/Nutrition/CornStoverHarvesting/tabid/595/Default.aspx. December 5, 2010.

Hay, J. (2010). "Crop Residue Value as a Biofuel." University of Nebraska Extension. Presentation at WJAG Farm Show, Norfolk, Nebraska. 1/14/2010.

Hess, J., K. Kenney, C. Wright, R. Perlack, and A. Turhollow. (2009). "Corn stover availability for biomas conversion: situation analysis." *Cellulose* 16:599-619.

Iowa Learning Farms. (May 2009). "Economics of Residue." Iowa State University Extension. Accessed at http://www.extension.iastate.edu/NR/rdonlyres/E16B8B31-E925-466B-BF37-C2C41D032BF1/135604/Economics_of_residue.pdf. December 17, 2010.

Karkee, M., R. McNaull, S. Birrell, and B. Steward. (2010). "Agricultural Biomass Removal Rate Estimation for Real-time Optimization of Single Pass Crop Grain and Biomass Harvesting System." American Society of Agricultural and Biological Engineers Meeting Presentation.

Lardy, G. and V. Anderson. (2009). "Alternative Feeds for Ruminants." NDSU Extension Service, North Dakota State University. Fargo, North Dakota.

Lazarus, W. and A. Smale. (2010). "Machinery Cost Estimates." University of Minnesota Extension.

Lee, D., V. Owens, A. Boe, and P. Jeranyama. (2007). "Composition of Herbaceous Biomass Feedstocks." North Central Sun Grant Center, South Dakota State University.

Morey, R, N. Kaliyan, D. Tiffany, and D. Schmidt. (2010). "A Corn Stover Supply Logistics System." *Applied Engineering in Agriculture* Vol. 26(3): 455-461.

Myers, D. K. (2010). "Harvesting Corn Residue." Ohio State University Extension, Department of Horticulture and Crop Science. AGF-003-92. Accessed at http://ohioline.osu.edu/agf-fact/0003.html. December 5, 2010.

Nafziger, E. (2010). "Corn Residue: A Resource or a Problem." Agronomy Day 2010 Presentation, Department of Crop Sciences, University of Illinois. Accessed at http://agronomyday.cropsci.illinois.edu/2010/tours/a2corn/. December 10, 2010.

Perlack, R. and A. Turhollow (2002). "Assessment of Options for Collection, Handling and Transport of Corn Stover." Oak Ridge National Laboratory, ORNL/TM-2002/44.

Petrolia, D. R. (2008). "The economics of harvesting and transporting corn stover for conversion to fuel ethanol: A case study for Minnesota." *Biomass and Bioenergy* 32(7): 603-612.

Plain, R., J. White and J. Travlos. (2009). "2009 Custom Rates for Farm Services in Missouri." Agricultural Farm Management Guidesheet G302. University of Missouri Extension.

Prewitt, R., M. Montross, S. Shearer, T. Stombaugh, S. Higgins, S. McNeill and S. Sokhansanj. (2007). "Corn Stover Availability and Collection Efficiency Using Typical Hay Equipment". *American Society of Agricultural and Biological Engineers* 50(3): 713-718.

Pordesimo L.O, B.R. Hames, W.C. Edens, and S. Sokhansanj. 2003. "Variation in Corn Stover Composition and Energy with Crop Maturity." Paper Number: 036085. Presentation for 2003 American Society of Agricultural Engineers Annual Meeting .

Roth, G. and C. Gustafson. (March 15, 2010). "Corn Cobs for Biofuel Production". eXtension. Assessed at http://www.extension.org/pages/Corn_Cobs_for_Biofuel_Production/. December 15, 2010.

Sawyer, J. and A. Mallarino. (2007). "Nutrient Removal When Harvesting Corn Stover." . Iowa State University Extension. Accessed at http://www.ipm.iastate.edu/ipm/icm/node/2579/print. June 29, 2010.

Sawyer, J. and A. Mallarino (2008). "A General Guide for Crop Nutrient and Limestone Recommendations in Iowa." PM 1688, Iowa State University Extension.

Scheching, T. and J. Hettenhaus. (2004). "Corn Stover Harvesting: Grower, Custom Operator, and Processor Issues and Answers: Report on Corn Stover Harvest Experiences in Iowa and Wisconsin for the 1997-98 and 1998-99 Crop Years." Oak Ridge National Laboratory, ORNL/SUB-04-4500008274-01.

Shinners, K., B. Binversie, R. Muck, and P. Weimer. (2007a). "Comparison of wet and dry corn stover harvest and storage." *Biomass and Bioenergy* 31(4): 211-221.

Shinners, K. (2007b). "Options for Harvesting Corn Stover for Supplemental Feed." University of Wisconsin. Presentation for the World Dairy Expo. Madison, Wisconsin. October 2-6, 2007.

Sims, B. (2010). "Rethinking Ag Residue." Biorefining Magazine. Accessed at http://www.biorefiningmagazine.com/articles/150/rethinking-ag-residue November 14, 2010.

Sokhansanj, S., A. Turhollow, J. Cushman, and J. Cundiff. (2002). "Engineering aspects of collecting corn stover for bioenergy." *Biomass and Bioenergy* 23: 347-355.

Sokhansanj, S. and A. Turhollow. (2002). "Baseline Cost for Corn Stover Collection." *Applied Engineering in Agriculture* 18, no. 5: 525-530.

Sokhansanj, S. and A. Turhollow. (2004). "Biomass Densification Cubing Operations and Costs for Corn Stover." *Applied Engineering in Agriculture* Vol. 20(4): 495-499.

Sokhansanj, S., S. Mani, S. Tagore., and A. Turhollow. (2010). "Techno-economic analysis of using corn stover to supply heat and power to a corn ethanol plant—Part 1: Cost of feedstock supply logistics." *Biomass and Bioenergy* 34: 75-81.

Thompson, W., S. Meyer, and P. Westhoff. (2010). "The New Markets for Renewable Identification Numbers." *Applied Economic Perspectives and Policy* Volume 32, Number 4, pp. 588-603

Turhollow, A., E. Wilkerson, and S. Sokhansanj. (2009). "Cost Methodology for Biomass Feedstocks: Herbaceous Crops and Agricultural Residues." Oak Ridge National Laboratory, Oak Ridge, Tennessee for the U.S. Department of Energy under contract DE-AC05-00OR22725.

University of Missouri (MU) Extension. (2010). "Byproduct Listings." Accessed at http://agebb.missouri.edu/dairy/byprod/bpmenu.asp December 10, 2010.

US Department of Agriculture, Economic Research Service. (May 2010). "Next-Generation Biofuels: Near-Term Challenges and Implications for Agriculture." BIO-01-01.

US Energy Information Administration. Various Data Sets. Accessed at http://www.eia.doe.gov/. November 15, 2010.

Wilhelm, W., J. Johnson, D. Karlen, and D. Lightle. (2007). "Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply." *Agronomy Journal* 99: 1665-1667.

World Bank. (2010). "State and Trends of the Carbon Market 2010". Carbon Finance at the World Bank. Washington D.C.

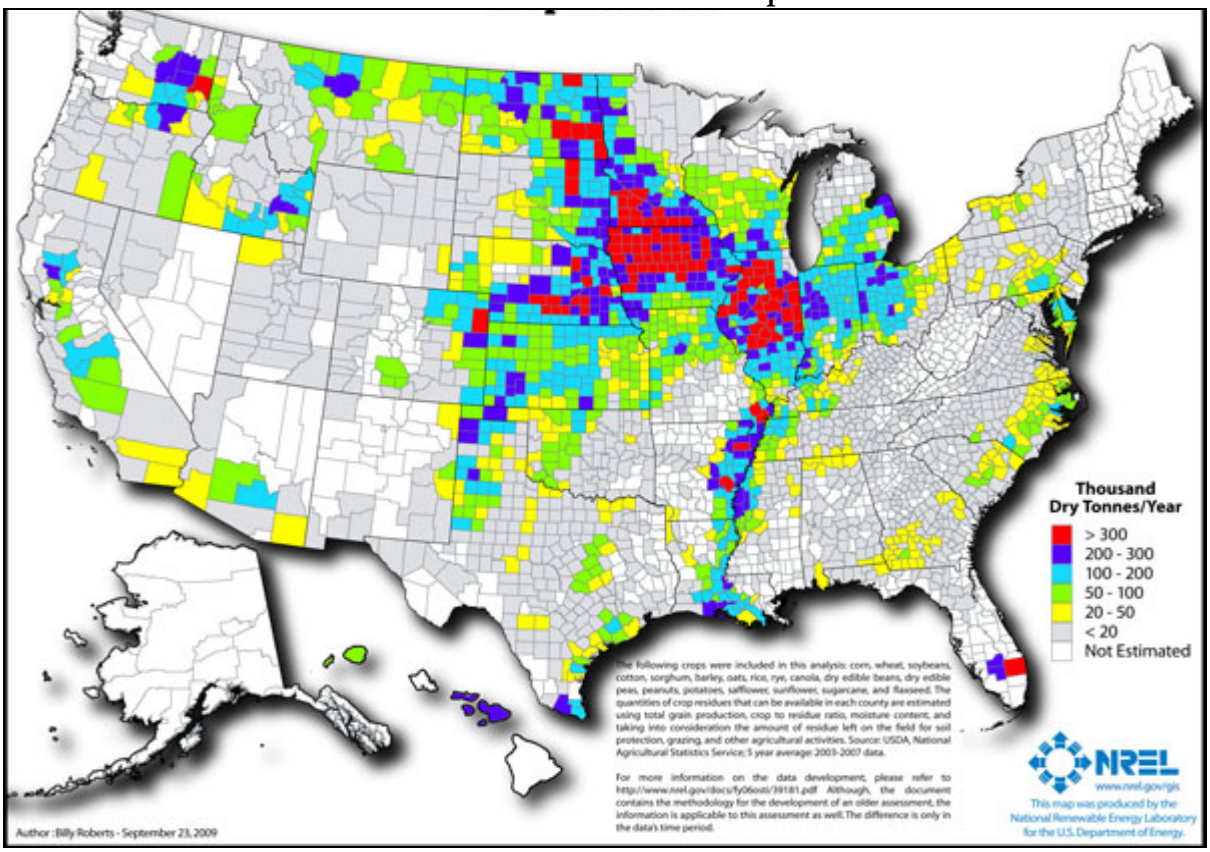
Wortmann, C., R. Klein, W. Willhelm, and C. Shapiro. (May 2008). "Harvesting Crop Residues." NebGuide G1846. University of Nebraska-Lincoln Extension.

Wright, L., B. Boundy, P. Badger, B. Perlack and S. Davis. (2009). "Biomass Energy Data Book." 2nd Edition. Oak Ridge National Laboratory. ORNL/TM-2009/098.

Appendix

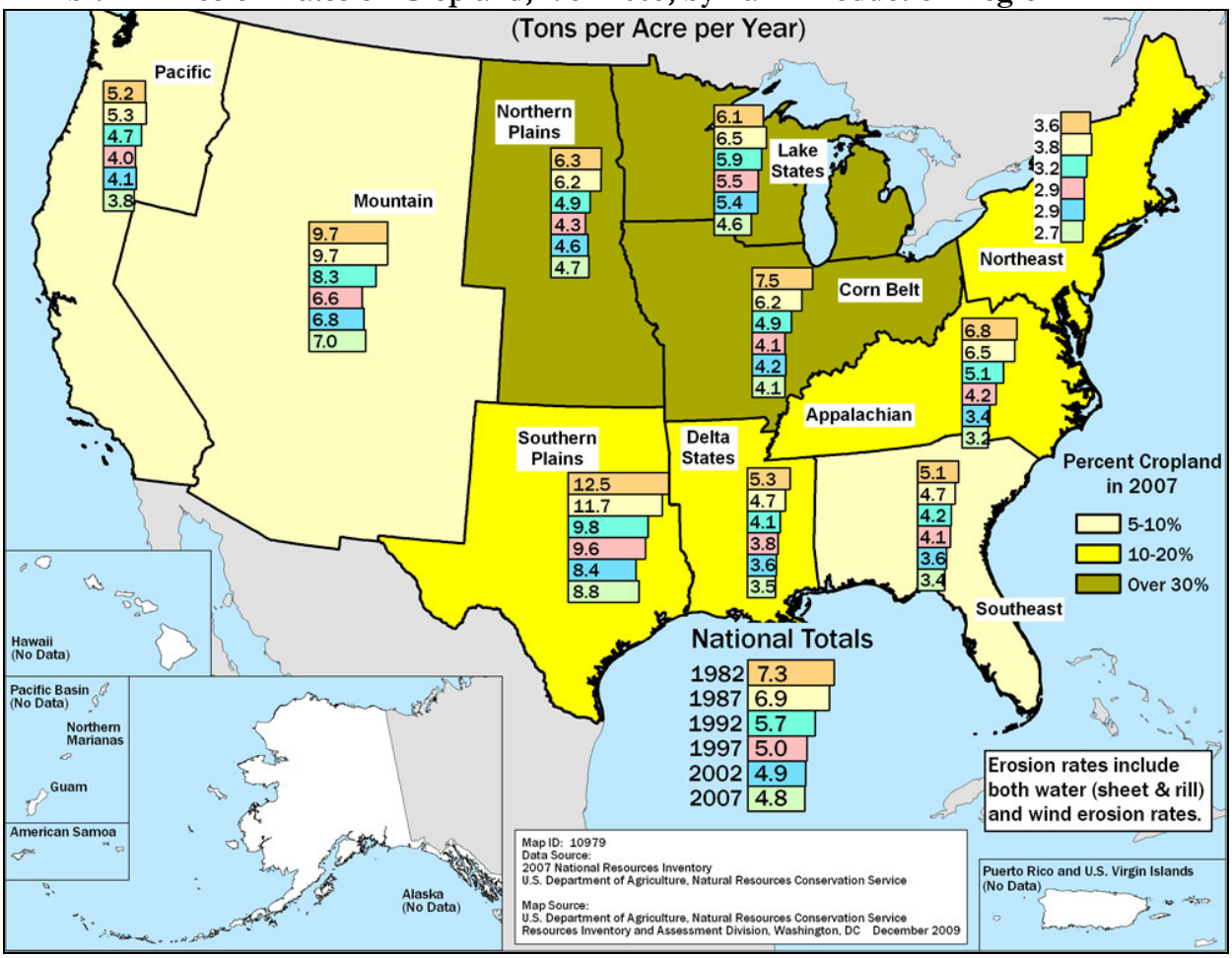
Exhibits A1 to A4 have been included in the appendix of the report because they provide some additional perspectives related to biomass supply and environmental constraints discussed in preceding sections.

Exhibit A1 Biomass Resources of the United States: Crop Residues



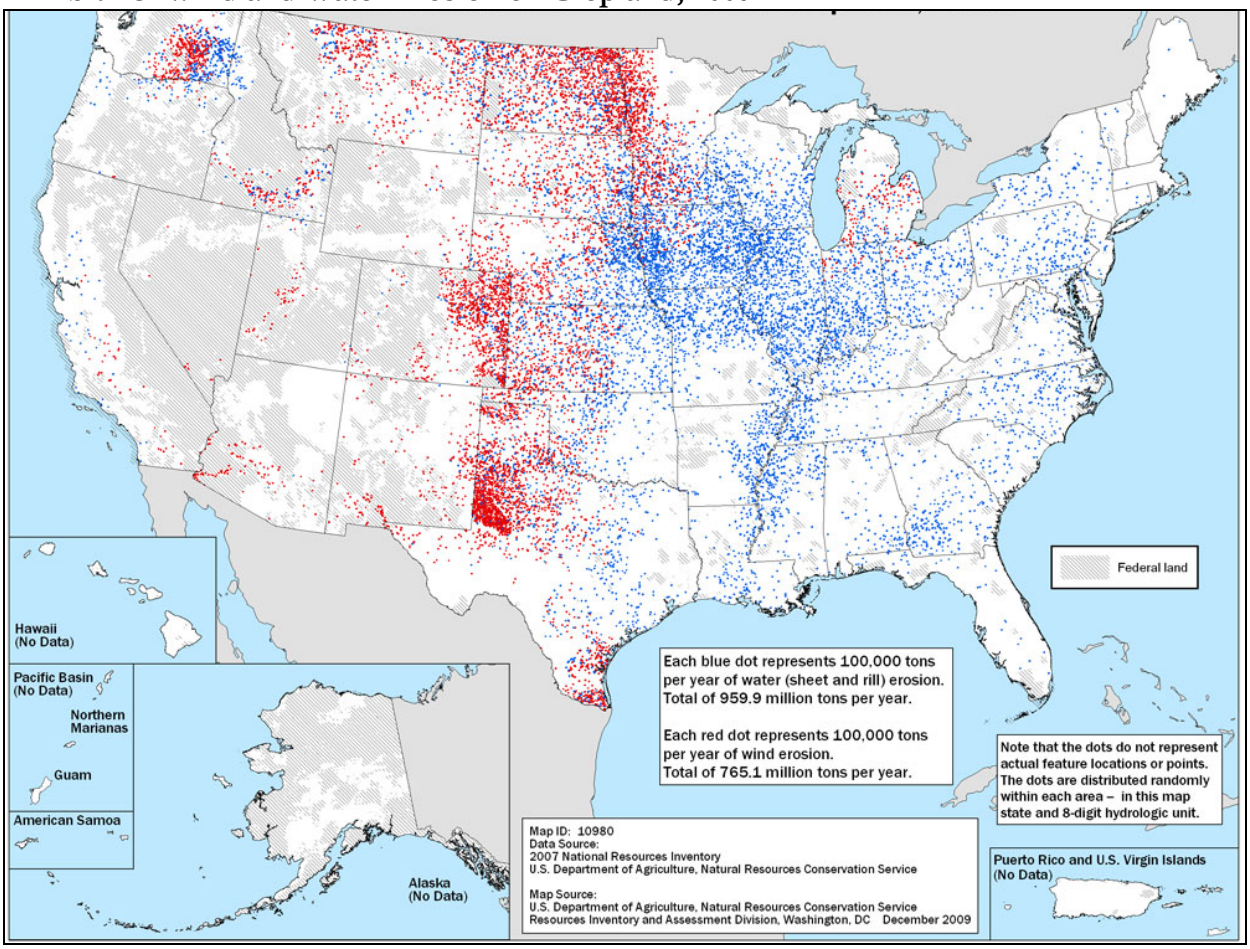
Source: National Renewable Energy Laboratory

Exhibit A2 Erosion Rates on Cropland, 1982-2007, by Farm Production Region



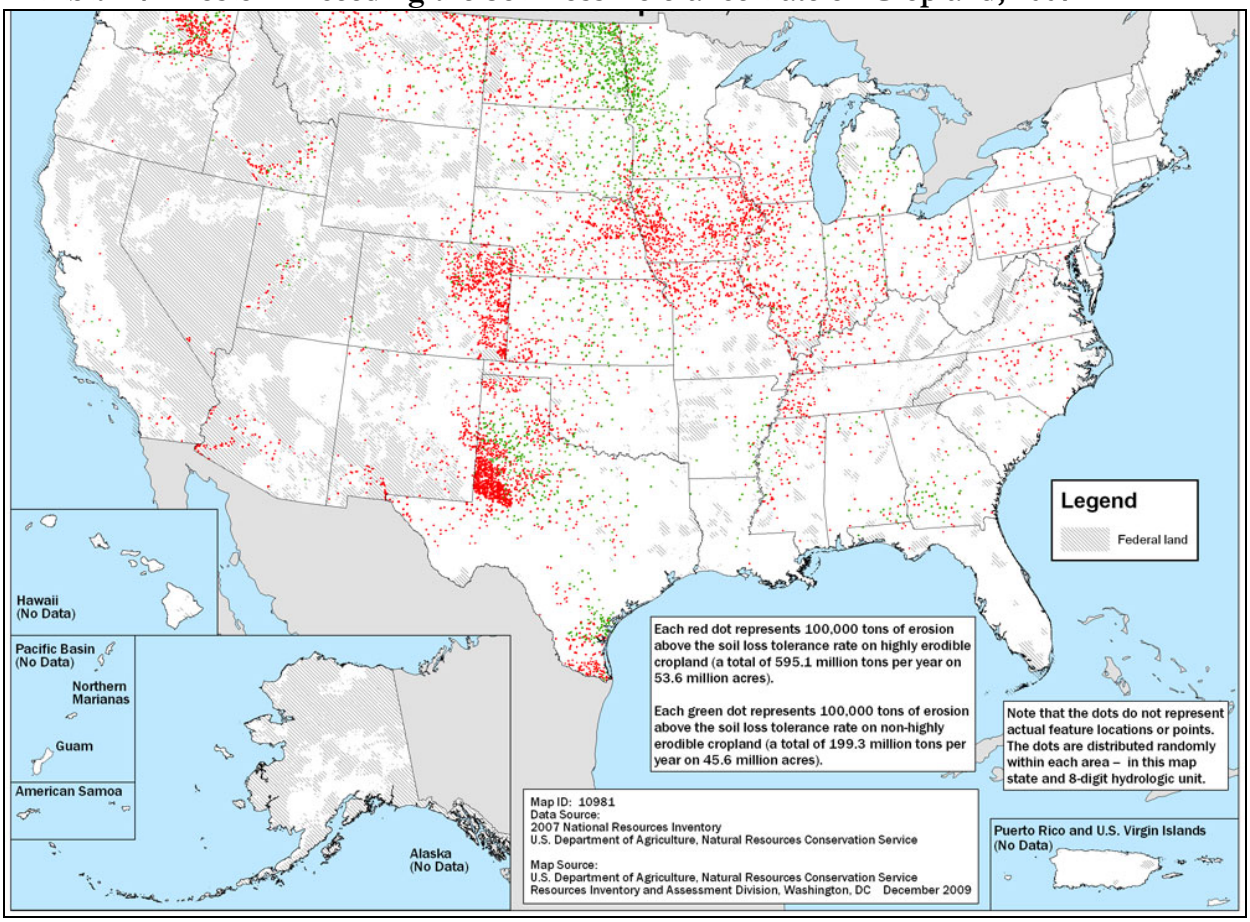
Source: USDA – National Resources Conservation Service

Exhibit A3 Wind and Water Erosion on Cropland, 2007



Source: USDA – National Resources Conservation Service

Exhibit A4 Erosion Exceeding the Soil Loss Tolerance Rate on Cropland, 2007



Source: USDA – National Resources Conservation Service