Geospatial Biorefinery Siting Model

Biomass Resource Assessment

Prepared by: Richard Nelson, ENERSOL and Ken Skog, U.S. Forest Service

Background

Resource assessment and supply analyses are important factors in determining energy inputs and outputs, environmental impacts, and most importantly, the economic feasibility of biomass-related production and utilization scenarios. Quantitative assessment and cost of delivery associated with each individual and applicable biomass resource within a set distance of a conversion facility is critical to optimizing and maximizing the energy returns, environmental enhancement, and economic feasibility.

Potential National Biomass Resources

Biomass is defined as organic material derived from plant and animal growth. The biomass resource is diverse and includes forestry and primary and secondary wood processing wastes, animal manures, waste greases, animal fats, dedicated energy crops such as switchgrass and poplar trees, and agricultural crop residues such as corn stover and small-grain straws. These biomass resources can potentially be utilized for generation of alternate energy such as bioethanol, biodiesel, and/or electricity.

What quantity of resource is potentially available for use as feedstocks for alternate energy production depends upon a number of energy, environmental, and economic factors. These include policy implications such as the 2007 Energy Independence and Security Act (EISA) that mandates set levels of certain biomass-based liquid fuels, the possible implementation of a national renewable electricity standard that would include a set amount from renewable resources including biomass, the price of both petroleum and coal that these resources would compete against, alternate markets for their use such as in the food sector for grains and some animal fats, and environmental concerns such as ‘cap-and-trade’ scenarios that would impact biomass resource production and competition. Specifically, the following biomass resources were investigated in this project:

Agricultural sources:

- Biosolids
- Cotton gin waste

- Soybean hulls
- Wheat dust and chaff
- Orchard and vineyard trimmings
- Edible and inedible tallow
- Pork lard and choice white grease
- Urban waste greases (yellow, trap, and sewage)
- Agricultural crop residues
    - corn stover
    - small-grain straws (wheat, barley, oats, rye)
- Herbaceous energy crops (e.g., switchgrass))
- Grain and oilseeds (corn, soy, grain sorghum, and wheat)

Forest based sources:

- Wood biomass from integrated forest harvesting
- Wood from “other” forest removals
- Unused wood and bark from primary wood products mills
- Conventionally sourced wood – separate harvest of pulpwood sized roundwood

Project Objectives

The objectives of performing a national biomass resource assessment were to:

1) provide estimates of quantities of select biomass resources throughout the United States on a regional, county and/or city basis for use as feedstocks for liquid fuel (transportation) production,
2) provide quantities and price/cost data for an integrated GIS analysis.

Quantification and Supply of National Biomass Resources

Following are descriptions of each potential national biomass resource, the amount of resource potentially available from a quantitative point given certain criteria such as sustainability impacts, and price information. Where applicable projections were made to

possible resource levels in 2017; in some cases data for projecting quantities, etc. was not available at the county, state, or national level. All resources were developed at either the county or sub-county level, but not all resources had price information associated with them and in some cases the actual amount of resource generated at sub-county locations was unknown due to proprietary reasons by individual companies.

Agricultural sources

Biosolids

Biosolids are the nutrient-rich organic portion that results from treatment of sewage in wastewater facilities. Biosolids can be recycled and applied as fertilizer to improve and maintain productive soils and stimulate plant growth. Values (tonnages) for biosolids generation (dry basis) at the county level were estimated for all states by using a combination of parameters comprising the expected future design flow, expressed in million gallons per day (MGD), an average national biosolids generation rate of approximately 206 dry tons of material per MGD capacity, and an expected recovery rate of 80%. County-level biosolids generation data was derived from the US Environmental Protection Agency's Clean Watersheds Needs Survey which has future expansion of wastewater facilities embedded in its data[1].

No cost data exist as biosolids use depends upon transportation, bioenergy conversion facility size, and type of technology. For facilities under 0.3 MGD as they were felt to not have the necessary infrastructure to allow the capture of treated waste for energy purposes. Table **BIOSOLID** provides expected state-level data biosolids totals in 2017.

[1] http://www.epa.gov/waters/tmdl/ expert_query_flow_2004.html

Table Biosolids. Total bone-dry tons of biosolid waste by state.

AL	172,869	IN	234,706	NE	36,600	SC	150,779
AK	13,159	IA	126,601	NV	31,324	SD	12,125
AZ	124,449	KS	118,736	NH	33,558	TN	231,472
AR	89,469	KY	125,084	NJ	400,844	TX	550,966
CA	912,000	LA	161,731	NM	22,088	UT	77,509
CO	95,366	ME	47,997	NY	775,352	VT	15,330
CT	106,505	MD	134,019	NC	279,909	VA	220,746
DE	31,887	MA	248,761	ND	7,419	WA	168,059
FL	398,057	MI	421,558	OH	487,372	WV	49,333
GA	247,348	MN	136,096	OK	106,376	WI	228,154
HI	30,175	MS	95,902	OR	184,571	WY	21,346
ID	32,540	MO	263,461	PA	453,392	US	9,667,537
IL	677,350	MT	33,400	RI	43,686		

Cotton gin waste

Cotton gin waste (CGW) is the by-product of the ginning process and most waste is either sold as animal bedding or applied back onto harvested fields as a soil amendment. Cotton in the field is either stripped (~ 350 pounds of waste per bale) or picked (~ 100 pounds of waste per bale) which directly impacts waste at the gin facility. Kansas, New Mexico, Oklahoma, and Texas have stripping operations; all other states are considered picked.. An average moisture content of 10% was used. County-level gin locations for 2009 are published by USDA but the amount of cotton actually ginned at each facility is unknown due to proprietary/disclosure reasons[2]. All waste generation statistics are based on the amount of waste from the number of bales harvested within an individual county. Future cotton gin trash estimates were made utilizing the ratio of average annual national acres of upland cotton harvested between 2004 and 2008 (11.27 million) to those expected in 2017 from USDA's long-term projection values (11.3) which is considered nearly identical therefore the same potential quantity my be generated. State-level projections are not calculated by USDA. Table CGW provides estimated state-level cotton gin waste generation data . County-level data was estimated as the amount of waste (due to stripped or picked) multiplied by the number of bales according to USDA statistics.

[2] http://usda.mannlib.cornell.edu/usda/current/CottGinnSu/CottGinnSu-05-12-2009.pdf

Table CGW. Average annual state-level generation (dry tons per year) of cotton gin waste.

State	2004	2005	2006	2007	2008
AL	36,630	38,160	30,375	18,720	21,105
AZ	32,535	27,675	25,020	23,130	18,225
AR	94,005	99,090	113,625	85,320	58,320
CA	80,550	47,925	35,055	29,250	16,515
FL	4,905	6,075	7,470	5,220	5,580
GA	80,865	96,300	105,030	74,700	72,000
KS	11,135	13,813	18,428	9,009	5,355
LA	39,825	49,410	55,845	31,455	12,645
MS	105,570	96,615	94,815	59,310	30,735
MO	37,350	38,880	44,325	34,380	31,410
NM	17,798	17,010	14,648	14,018	11,183
NC	61,200	64,665	57,825	35,235	33,975
OK	47,723	56,385	31,973	44,258	41,265
SC	17,550	18,450	19,485	7,200	11,070
TN	44,280	50,490	61,560	27,000	23,850
TX	1,219,050	1,329,300	913,500	1,299,375	700,875
VA	7,263	8,235	6,993	4,586	5,108
US	1,938,233	2,058,478	1,635,971	1,802,165	1,099,215

Soybean hulls

Soybean hulls are the by-product of the crushing operation to obtain meal and oil with approximately 4.2 pounds of hulls generated per bushel of soybeans crushed. The geographic location (city) of most individual soybean crushing facilities is known from information provided by the National Oilseed Processors Association, but no actual data exists concerning hull generation at each individual soybean crushing facility due to proprietary information[3]. Prices for soybean hulls between 2004 and 2007 ranged from $49 per ton to over $174 per ton at five different locations throughout the United States (Alabama/Georgia, Central Illinois, Iowa, Minneapolis, and Kansas City), but the amount of hulls actually bought and sold at each of these locations is unknown. The following table presents state-level data (average 1998-2007 production) based on state-level production data from (NASS)[4]. Future estimates for soybean hull generation were calculated to be approximately 6.4 million tons using production (total

[3] www.nopa.org
[4] http://www.nass.usda.gov/QuickStats/Create_County_All.jsp

Table SOYBEAN HULLS. Average Annual (1998-2007) generation of soybean hulls by state.

AL	9,585	IN	518,531	NE	420,354	SC	21,054
AK	0	IA	996,129	NV	0	SD	285,434
AZ	0	KS	170,157	NH	0	TN	75,012
AR	208,003	KY	94,912	NJ	6,353	TX	13,013
CA	0	LA	53,084	NM	0	UT	0
CO	0	ME	0	NY	12,464	VT	0
CT	0	MD	34,057	NC	82,481	VI	0
DE	13,350	MA	0	ND	171,010	VA	31,683
FL	789	MI	154,070	OH	392,910	WA	0
GA	10,448	MN	589,507	OK	12,653	WV	1,087
HI	0	MS	101,794	OR	0	WI	124,798
ID	0	MO	371,390	PA	32,138	WY	0
IL	935,608	MT	0	RI	0	US	5,943,854

bushels) data provided by USDA long-term projections[5]. County level data was determined as the number of bushels multiplied by 4.2 pounds per bushel.

Wheat dust and chaff

Wheat dust/chaff is material generated as wheat is processed through a grain elevator. Typically 1% of the weight of a bushel of wheat (60 pounds per bushel) is designated as wheat dust/chaff which could potentially be used as a cellulosic resource for alternate liquid fuel production. No quantitative data exist concerning amounts generated at each grain elevator as it depends upon elevator capacity, types of commodity crops handled, and actual amounts (bushels) of wheat processed. Data was derived for the total amount of wheat dust generated on a county-level basis for all counties in the United States that produced winter wheat using a factor of 1% of total bushel weight in that county. In addition, prices vary depending upon whether the wheat dust has a potential end-use market (cattle feed or as a supplement) or is disposed of (landfilled). Table WHEAT DUST presents estimates of generation data at the

[5] http://www.ers.usda.gov/publications/oce081/

individual state-level. Estimates for wheat dust and chaff generation in 2017 are expected to increase about 3%[5].

Table WHEAT DUST. Average Annual (1998-2007) generation (dry tons per year) of wheat dust and chaff by state.

AL	623.2	LA	1,766.6	OH	16,402.2
AK	0.0	ME	0.0	OK	36,023.8
AZ	173.5	MD	2,595.8	OR	10,615.5
AR	10,491.2	MA	0.0	PA	2,259.0
CA	6,161.7	MI	9,701.3	RI	0.0
CO	14,797.7	MN	154.1	SC	1,963.7
CT	0.0	MS	2,074.9	SD	13,567.3
DE	893.4	MO	11,633.6	TN	3,770.1
FL	0.0	MT	14,660.4	TX	25,777.8
GA	2,233.7	NE	18,134.3	UT	1,545.9
HI	0.0	NV	131.3	VT	0.0
ID	15,522.7	NH	0.0	VA	2,789.0
IL	12,917.6	NJ	391.2	WA	30,170.6
IN	6,576.4	NM	1,721.5	WV	86.2
IA	158.2	NY	1,617.8	WI	2,938.4
KS	95,109.0	NC	5,873.2	WY	977.0
KY	5,442.2	ND	1,817.6	US	392,260.7

Orchard and vineyard trimmings

Residues (trimmings, dead wood, etc.) are generated from the growth and cultivation of orchard and vineyard crops produced. Candidate orchard and vineyard crops are listed below along with their estimated average annual residue generation by acre. Average annual quantities of residue by each crop for each crop were obtained from the 2002 Census of Agriculture and data from an analysis performed in California by Jenkins et al.[6, 7]. Only quantitative data is presented as supply curves were not generated due to a lack of engineering and cost data concerning residue pick-up and transport to the field edge. Average residue amounts (dry tons per year) ranging for greater than one year in each state analyzed is presented in the following

[6] http://www.agcensus.usda.gov

[7] Jenkins, B.M. (ed.). 2005. Biomass resources in California: preliminary 2005 Assessment, PIER Collaborative Report, California Energy Commission Contract 500-01-016, Sacramento, CA, (http://faculty.engineering.ucdavis.edu/jenkins/CBC/UpdateFiles/ResourceUpdate.html)

table. County level data was estimated as the total tonnage of each orchard and vineyard crop multiplied by its corresponding residue generation factor.

Table O&V Residue Rates. Estimated total dry tons per acre from orchard and vineyard prunings[7]

All Citrus	0.65	Dates	0.39	Limes	1.30	Pecans	1.04
Almonds	0.85	Figs	1.43	Nectarines	1.04	Persimmons	1.04
Apples	1.43	Grapes	1.30	Olives	0.98	Pistachios	0.65
Apricots	1.30	Hazelnuts	0.65	Oranges	1.95	Plums & Prunes	0.98
Avocados	0.98	Kiwifruit	1.30	Peaches	1.30	Pomegranates	1.04
Cherries	0.26	Lemons	1.30	Pears	1.50	Walnuts	0.65

Table O&V TRIM. State level quantities (dry tons) for each orchard and vineyard trimming.

AL	55,183	IN	8,938	NE	1,117	SC	61,594
AK	9	IA	3,600	NV	382	SD	184
AZ	191,421	KS	21,653	NH	8,060	TN	5,320
AR	39,868	KY	6,856	NJ	33,494	TX	797,710
CA	8,942,721	LA	51,643	NM	182,105	UT	12,028
CO	15,777	ME	12,567	NY	291,737	VT	9,619
CT	9,476	MD	13,042	NC	35,266	VA	66,144
DE	360	MA	16,861	ND	0	WA	871,453
FL	3,141,440	MI	225,798	OH	33,148	WV	26,165
GA	602,352	MN	8,780	OK	248,192	WI	19,676
HI	1,781	MS	50,700	OR	255,056	WY	0
ID	17,579	MO	48,467	PA	140,466		
IL	15,951	MT	1,859	RI	1,096	US	16,604,695

<u>Edible and inedible tallow and pork lard and choice white grease</u>

Tallow, lard, and choice white grease are all by-products of the beef and pork meat production and processing system and each has its own distinct physical characteristics and

price structure. All are potential biodiesel feedstocks, but each also competes in other markets such as edible food market, soap, lubricants, and resins and plastics[8].

Most edible and inedible tallow in the United States is currently generated by the beef slaughter and processing industry while pork lard and choice white grease are derived from pork slaughter. Edible tallow markets include baking or frying fats and margarine as well as certain inedible products. Inedible tallow is most often used as a supplement for animal feed (majority of market share), followed by use in fatty acids, soap, methyl esters (biodiesel), lubricants, and other uses. Statistics derived from two independent sources[9, 10] show an average generation of edible and inedible tallow of about 5.8 billion pounds from approximately 70 separate locations across the United States, primarily in Kansas, Nebraska, Texas, and Colorado which if utilized for biodiesel production would equate to almost 800 million gallons. Over 1.8 billion pounds of both pork lard and choice white grease are generated in approximately 70 separate locations that could potentially supply up to 255 million gallons of biodiesel. Prices for edible and inedible tallow and pork lard and choice white grease obtained from a reputable national source have varied considerably between 2003 and mid-2009 ($0.11 to $0.48 per pound) and feedstock price greatly effects the end price of biodiesel as feedstock price can account for up to 80% of the total biodiesel cost[11]. Table ANFATS presents state-level quantitative data on each feedstock and amounts of biodiesel generation.

[8] http://www.census.gov/cir/www/311/m311k.html
[9] Livestock Marketing Information Center. Lakewood, CO.
[10] Steve Kay. Cattle Buyers Weekly. Petaluma, CA.
[11] http://www.thejacobsen.com/

Table ANFATS. Average annual generation of edible and inedible tallow and lard and choice white grease and associated biodiesel production.

	Million pounds - edible tallow	Potential million gallons per year biodiesel - edible tallow	Million pounds - inedible tallow	Potential million gallons per year biodiesel - inedible tallow	Million pounds - lard	Potential million gallons per year biodiesel - edible lard	Million pounds - choice white grease	Potential million gallons per year biodiesel - choice white grease
AL	0	0.0	0	0.0	481,545	0.1	561,803	0.1
AK	0	0.0	0	0.0	0	0.0	0	0.0
AZ	45,151,075	6.2	42,774,702	5.9	0	0.0	0	0.0
AR	0	0.0	0	0.0	2,140,200	0.3	2,496,900	0.3
CA	138,839,554	19.0	131,532,209	18.0	18,833,760	2.6	21,972,720	3.0
CO	177,669,479	24.3	168,318,453	23.1	0	0.0	0	0.0
CT	0	0.0	0	0.0	0	0.0	0	0.0
DE	0	0.0	0	0.0	0	0.0	0	0.0
DC	0	0.0	0	0.0	0	0.0	0	0.0
FL	11,287,769	1.5	10,693,676	1.5	0	0.0	0	0.0
GA	33,863,306	4.6	32,081,027	4.4	749,070	0.1	873,915	0.1
GU	0	0.0	0	0.0	0	0.0	0	0.0
HI	0	0.0	0	0.0	0	0.0	0	0.0
ID	25,397,479	3.5	24,060,770	3.3	1,391,130	0.2	1,622,985	0.2
IL	14,222,589	1.9	13,474,031	1.8	81,060,075	11.1	94,570,088	13.0
IN	0	0.0	0	0.0	63,349,920	8.7	73,908,240	10.1
IA	59,825,174	8.2	56,676,480	7.8	236,064,060	32.3	275,408,070	37.7
KS	662,817,775	90.8	627,932,629	86.0	1,284,120	0.2	1,498,140	0.2
KY	0	0.0	0	0.0	23,114,160	3.2	26,966,520	3.7
LA	0	0.0	0	0.0	0	0.0	0	0.0
ME	0	0.0	0	0.0	0	0.0	0	0.0
MD	2,257,554	0.3	2,138,735	0.3	0	0.0	0	0.0
MA	0	0.0	0	0.0	0	0.0	0	0.0
MI	39,507,190	5.4	37,427,864	5.1	642,060	0.1	749,070	0.1
MN	51,923,736	7.1	49,190,908	6.7	75,977,100	10.4	88,639,950	12.1
MS	0	0.0	0	0.0	278,226	0.0	324,597	0.0
MO	0	0.0	0	0.0	49,866,660	6.8	58,177,770	8.0
MT	0	0.0	0	0.0	0	0.0	0	0.0
NE	657,512,524	90.1	622,906,602	85.3	60,781,680	8.3	70,911,960	9.7
NV	0	0.0	0	0.0	0	0.0	0	0.0
NH	0	0.0	0	0.0	0	0.0	0	0.0
NJ	0	0.0	0	0.0	0	0.0	0	0.0
NM	0	0.0	0	0.0	0	0.0	0	0.0
NY	0	0.0	0	0.0	0	0.0	0	0.0
NC	21,446,760	2.9	20,317,984	2.8	94,275,810	12.9	109,988,445	15.1
ND	0	0.0	0	0.0	1,968,984	0.3	2,297,148	0.3
OH	0	0.0	0	0.0	10,058,940	1.4	11,735,430	1.6
OK	0	0.0	0	0.0	35,099,280	4.8	40,949,160	5.6
OR	0	0.0	0	0.0	2,193,705	0.3	2,559,323	0.4
PA	97,074,810	13.3	91,965,610	12.6	29,106,720	4.0	33,957,840	4.7
PR	0	0.0	0	0.0	0	0.0	0	0.0
RI	0	0.0	0	0.0	0	0.0	0	0.0
SC	12,416,546	1.7	11,763,043	1.6	6,420,600	0.9	7,490,700	1.0
SD	12,980,934	1.8	12,297,727	1.7	36,383,400	5.0	42,447,300	5.8
TN	0	0.0	0	0.0	428,040	0.1	499,380	0.1
TX	613,603,104	84.1	581,308,204	79.6	5,564,520	0.8	6,491,940	0.9
UT	53,278,268	7.3	50,474,149	6.9	0	0.0	0	0.0
VT	0	0.0	0	0.0	0	0.0	0	0.0
VI	0	0.0	0	0.0	0	0.0	0	0.0
VA	0	0.0	0	0.0	23,328,180	3.2	27,216,210	3.7
WA	96,171,789	13.2	91,110,116	12.5	0	0.0	0	0.0
WV	0	0.0	0	0.0	0	0.0	0	0.0
WI	155,319,697	21.3	147,144,976	20.2	4,922,460	0.7	5,742,870	0.8
WY	0	0.0	0	0.0	0	0.0	0	0.0
US	2,982,567,111	409	2,825,589,894	387	865,764,405	119	1,010,058,473	138

Urban waste greases (yellow, trap, and sewage)

Waste grease feedstocks such as restaurant grease or yellow grease, sewage, and trap grease are a secondary resource, but have served as a possible biodiesel feedstock resource. Estimates were made based for each on methodology developed by Wiltsee (1998)[12] and values by Tyson and using urban population statistics. Wiltsee estimated an average yellow grease generation of approximately nine (9) pounds yellow grease/capita and Tyson has per capita generation rates for sewage grease between 3 and 3.59 and trap grease between 0.7 and 0.83 pounds. These figures may change in the future due to a variety of factors such as an increased focus on health, especially heart-related matters, and waste disposal regulations, but due to a lack of better data, they were employed in this analysis.

National population centers (e.g., cities) with greater than 50,000 persons as measured by the 2000 census (latest data available) were included in this analysis. Population expansions were estimated for each city for 2017 using data for state population increases derived from data provided by the US Census Bureau[13]. Nationally, over 140 million gallons per year (MGY) of yellow grease-based biodiesel could potentially be produced in over 600 population centers. Table WST GRSE presents data on estimated yellow (YG), and sewage and trap (S&T) grease quantities for each state with a projected 2017 population of 50,000 persons or greater.

[12] http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19981001_gen-107.pdf
[13] http://www.census.gov/compendia/statab/population.html

Table WST GRSE. Estimated quantities of biodiesel (million gallons per year) by state utilizing yellow (YG) and sewage and trap (S&T) greases for cities with population greater than 50,000.

	YG	S&T		YG	S&T		YG	S&T		YG	S&T
AL	1.33	0.12	IN	2.29	0.21	NE	0.77	0.07	SC	0.49	0.05
AK	0.37	0.03	IA	0.99	0.09	NV	2.06	0.19	SD	0.23	0.02
AZ	6.09	0.57	KS	1.20	0.11	NH	0.28	0.03	TN	2.53	0.24
AR	0.66	0.06	KY	0.74	0.07	NJ	1.80	0.17	TX	16.73	1.57
CA	31.29	2.93	LA	1.60	0.15	NM	0.86	0.08	UT	1.28	0.12
CO	3.06	0.29	ME	0.08	0.01	NY	11.60	1.09	VT	0.00	0.00
CT	1.36	0.13	MD	1.15	0.11	NC	3.32	0.31	VA	2.69	0.25
DE	0.10	0.01	MA	2.76	0.26	ND	0.17	0.02	WA	2.64	0.25
FL	7.86	0.74	MI	3.77	0.35	OH	3.67	0.34	WV	0.13	0.01
GA	2.06	0.19	MN	2.05	0.19	OK	1.65	0.15	WI	2.07	0.19
HI	0.00	0.00	MS	0.39	0.04	OR	1.74	0.16	WY	0.07	0.01
ID	0.53	0.05	MO	1.90	0.18	PA	2.92	0.27	US	141.00	13.20
IL	6.25	0.59	MT	0.27	0.03	RI	0.54	0.05			

Agricultural Crop Residues

Agricultural crop residues are lignocellulosic biomass that remains in the field after the harvest of agricultural crops. The most common residues include stalks and leaves from corn (stover) and straw from wheat, barley, oats, and rye production. Agricultural crop residues play an important role in maintaining/improving soil productivity, protecting the soil surface from water and wind erosion, and helping to maintain nutrient levels. While agricultural crop residue quantities produced are substantial, only a percentage of them can potentially be collected for bioenergy use primarily due to their effect on soil productivity and especially soil erosion. The amount of soil erosion agricultural cropland experiences is a function of many factors: crop rotation, field management practices (tillage), timing of field management operations, physical characteristics of the soil type (soil erodibility), field topology (% slope), localized climate (rainfall, wind, temperature, solar radiation, etc.), and the amount of residue (cover) left on the field from harvest until the next crop planting. Recent analyses demonstrated that under certain conditions, agricultural residue removal can potentially occur without exceeding tolerable soil loss limits[14,15].

A quantitative assessment of corn stover and wheat straw on a county-level basis for Western States were covered in a previous WGA-sponsored project[16]. A more detailed assessment of both corn and sorghum stover and small-grain straws (spring and winter wheat, barley, oats, and rye) at the individual soil type level was performed in this project since they also possess potential as feedstocks for biofuel production.

Agricultural crop residue base

The production of crop residues is significant with the average annual tonnage between 1998-2007 from corn, grain sorghum, winter and spring wheat, barley, oats, and rye exceeding 350 million tons with corn stover comprising about 70% of this total. Residue production is

[14] Nelson, R.G. 2002. "Resource Assessment and Removal Analysis for Corn Stover and Wheat Straw in the Eastern and Midwestern United States – Rainfall and Wind Erosion Methodology." *Biomass & Bioenergy.* Volume 22 pp. 349-363.
[15] Nelson, R.G., Marie E. Walsh, John J. Sheehan, and Robin L. Graham. 2003. "Methodology to Estimate Removable Quantities of Agricultural Residues for Bioenergy and Bioproduct Use." *Applied Biochemistry and Biotechnology* 113 pp. 0013-0026.
[16] Western Governors' Association. 2006. *Clean and Diversified Energy Initiative*. Biomass Task Force Report. http://www.westgov.org/wga/initiatives/cdeac/Biomass-supply.pdf

directly related to yield and projections by USDA indicate yields for corn and wheat will increase approximately 12.5% and 1.7% between the 2008/2009 crop year and 2017/2018 crop year. Residue generation can vary significantly within a county as yields may vary widely due to climate variations, soil type, and previous cropping practices.

The amount of agricultural residue that could potentially be removed from agricultural croplands acres without exceeding the tolerable soil loss limit as imposed by the NRCS as well as causing a change in soil carbon/organic matter to be negative was estimated using the RUSLE2 (Revised Universal Soil Loss Equation) and WEQ (Wind Erosion eQuation) simulation programs which incorporated a soil conditioning index which is related to soil tilth and productivity[17, 18]. In the analysis performed in this study, there was no obvious constraint to removal as it depended upon a number of localized geo-climatic factors.

Cropping Rotations

The USDA-NRCS developed crop management zones (CMZs) which are multi-county and intrastate throughout the United States with similar cropping rotations (e.g., corn-soybean-wheat), and field management practices (e.g., no-till, etc.) that tend to represent the types of agricultural practices that have and currently do occur by farmers/landowners in multi-county areas. Figure CMZ presents CMZs as designated by NRCS and table CMZ provides example rotations. Appendix CR provides all cropping rotations used in this study.

Soil Types

Each cropping rotation in each county was simulated for crop residue removal by both RUSLE2 and WEQ on individual soil types (SSURGO) within that county greater than 1,000 acres and had a land capability class of 1 to 4. The soils database derived from the National Soil Information System (NASIS) populated by inputs from SSURGO (Soil Survey Geographic) contained soil physical properties as well as parameters for field slope, soil erodibility, tolerable soil loss limits, bulk density, etc. needed to estimate erosion and soil carbon enhancement or depletion.

---

[17] http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm
[18] http://www.weru.ksu.edu/nrcs/weq.html

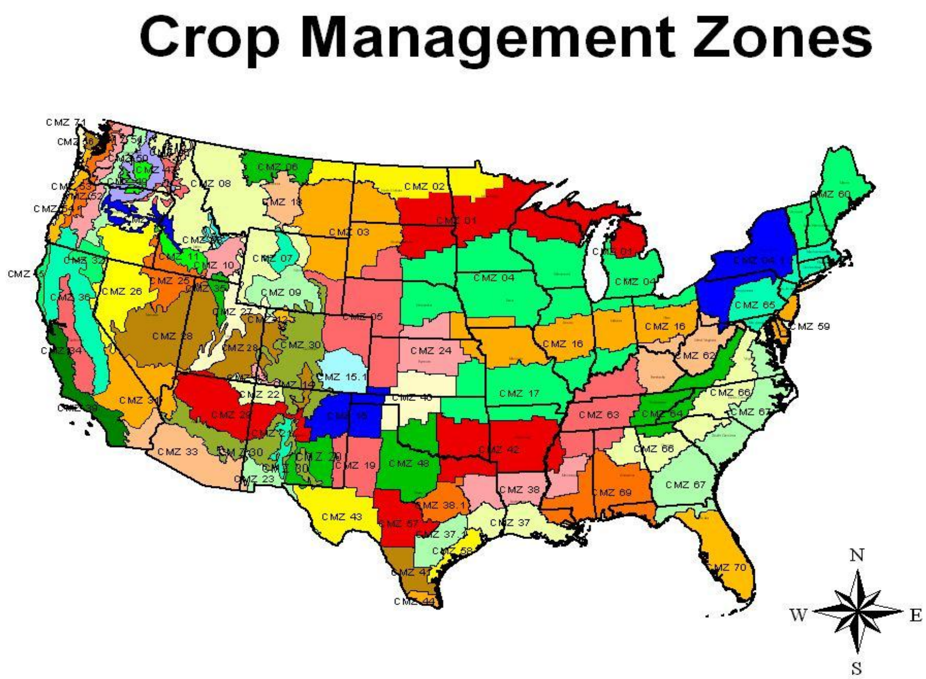

Figure CMZ. Crop Management Zones for the US as designated by NRCS.

Table CMZ. Cropping rotations for three crop management zones.

CMZ	
4	Continuous corn grain;NT no stover harvest
	corn grain;NT, corn grain;NT, Soybean, wr, NTz4
	Corn, grain; NT, SB NT, WW NT CMZ4
	corn grain;NT,anhyd, Soybean, nr, NT Single disk z4
15	Barley,spring, Wheat,winter, Corn,grain, sweepspring, diskspring, irr
	Bean,dry, Corn,grain, ridgetill, irr
	Continuous Corn,grain, RT
	Continuous Corn,grain; NT
	fallow (MT)-wwheat-grain sorghum (NT)
	Wheat, Fallow, Sorghum, NT
	Wheat,1 year fallow; chemical
67	Corn, corn, peanuts, (wheat-soybeans, double cropped), strip tilled, CMZ 67
	Corn, grain, st. till, 100 bu. - (wheat, fall disk, 50 bu. - soybeans, st. till, 30 bu.) (CMZ 67)
	Corn, strip till into winter weeds (115 bu.) - soybeans, strip till into winter weeds (38 bu.), CMZ 67
	Cotton, spring disk, 750 lbs. - Corn, grain, spring disk, 115 bu. (CMZ 67)

Presently, very little data exists regarding acreage or soil types attributable to individual cropping rotations within any certain county and certainly none for the country as a whole. Therefore it was assumed each rotation could potentially be grown on any candidate SSURGO cropland soil as previously defined and based on 1) a percentage of the average annual (1998-2007) NASS crop acres for those crops in each rotation to total candidate SSURGO acres and 2) the number of times a particular crop was produced within all rotations in a county.

Yields

Crop yields (bushels/acre, etc.) utilized were based on acreage-weighted county-level National Agricultural Statistics Service (NASS) data from 1998-2007. For the rotations provided by NRCS in all crop management zones, 13 major commodity crops comprised the rotations. These were corn, grain sorghum, spring and winter wheat, soybeans, canola, sunflowers, beans, cotton (upland), potatoes, barley, oats, and rye.

Removable Residues

Table ACR provides estimated state-level quantities of removable residues comprised of corn and sorghum stover and small-grain straws due to soil erosion and carbon constraints.

Table ACR. Estimated Annual Average Quantities of Stover and Small-grain Straws.

State	Estimated Annual Residue (dry tons)	State	Estimated Annual Residue (dry tons)	State	Estimated Annual Residue (dry tons)
AL	952	LA	247,800	OH	4,134,448
AK	0	ME	0	OK	80,820
AZ	0	MD	410,802	OR	170,115
AR	923,663	MA	0	PA	60,988
CA	348,159	MI	1,783,621	RI	0
CO	73,319	MN	11,754,277	SC	3
CT	0	MS	483,769	SD	2,521,557
DE	254	MO	808,353	TN	44,924
FL	0	MT	0	TX	1,000,233
GA	1,810	NE	4,188,485	UT	0
HI	0	NV	0	VT	0
ID	0	NH	0	VA	126,875
IL	11,464,208	NJ	14,138	WA	853,453
IN	4,010,005	NM	9,350	WV	0
IA	19,056,329	NY	39,247	WI	2,405,392
KS	470,341	NC	5,683	WY	0
KY	18,625	ND	261,296	US	67,773,297

Herbaceous Energy Crops (Switchgrass)

One of the major focus areas concerning the United States meeting its Energy Independence and Security Act (EISA) goals involves production of herbaceous energy crops such as switchgrass for use as a base bioenergy feedstock. Switchgrass is a warm season grass with potential adaptability on marginal acres (lower land capability classes) that has shown in limited field trials to attain high yields (dry tons per acre). The utilization of marginal acreages means alternate fuel sources could be produced within the agricultural sector and possibly not compete with acreages devoted to conventional commodity crops such as corn, grain sorghum, soybeans, and wheat. In addition, large-scale production of switchgrass may provide numerous energy and environmental benefits such as improved water quality and carbon sequestration[19].

Data concerning actual large-scale production (hundreds to thousands of acres) as well as economics to the landowner versus production of conventional commodity crops, high-value haying, or other operations is not known at the national level with any degree of certainty. Test plots have been established with different varieties of herbaceous crops, primarily switchgrass, at different numerous geographic locations throughout the United States, but most of these are small-scale[20].

In addition, no national database exists with simulated yields (dry tons per acre) on a county or sub-county-level basis over a period of time that simulates changes in precipitation, temperature, soil type, and/or other pertinent geoclimatic factors. Individual states have some geoclimatic and temporal-based modeled data for switchgrass production and as mentioned previously individual test plot data does exist, but no real attempt has been made to extrapolate this data in a state or national scale.

Oak Ridge National Laboratory Herbaceous Energy Crop Yield Simulations

Recently, Oak Ridge National Laboratory (ORNL) used localized temperature and precipitation to model possible switchgrass yields at the county level throughout the United States[20]. The ORNL study looked at yields comprised of cultivars that could potentially be

[19] Nelson, R.G., James C. Ascough II , Michael R. Langemeier. 2006. "Environmental and Economic Analysis of Switchgrass Production for Water Quality Improvement in Northeast Kansas." *Journal of Environmental Management*, 79 pp. 336-347.
[20] Gunderson et al. 2008. Exploring Potential US Switchgrass Production for Lignocellulosic Ethanol. Oak Ridge National Laboratory Environmental Sciences Division. ORNL/TM-2007-183. Oak Ridge, Tennessee.

adapted and produced on both upland and lowland soils. The ORNL analysis focused solely on switchgrass and compiled data from numerous field trials (test plot data) from a wide range of locations throughout the United States that included cultivar and crop management information, and geographic location (latitude and longitude) of the field trial. This information was used to obtain temperature and precipitation records from the nearest weather station to help calibrate their model. The study was able to identify major sources of variation in biomass yield and for a given ecotype, temperature, and weather pattern (based on 95th percentile response curves), ORNL developed estimates for both upland and lowland cultivars assuming a choice of optimal cultivars and harvest schedules. For upland ecotype varieties, potential yields were as high as 8 to 9 dry tons per acre and lowland varieties were as high as 10 to 12 dry tons per acre. In the ORNL analysis, yield variation with respect to soil texture, i.e., no real response to sand, silt, or clay at least at the available resolution of soil texture data was apparent. Therefore, given the other factors contributing to variability in the analysis, none of the soil texture variables were able to explain yield differences.

For this analysis, only upland yields were considered due to the high confidence interval selected which provided a more ‘conservative’ estimate and also may reflect possible growth on more ‘marginal’ acreages/soils. Yields at the 95% confidence interval may not be indicative of actual “real-world” production and the analysis does not take into account any year-to-year variation due to a wide variety of other geo-climatic factors (soil type, climate variability, etc.). In addition, a lack of “real-time”, long-term data from numerous geographic locations was another reason for only using the upland yields.

Potential acreages for production

Many factors influence herbaceous crop production such as precipitation, temperature, variety and adaptation, field preparation, soil type, and chemical and fertilizer application rates. Another important factor that could potentially play a role in large-scale production involves acreage competition with conventional commodity crop production which could have possible aspects related to the food versus fuel issue as well as possibly other uses of land (pasture, forest, etc.). Also concerns exist over availability of large-scale amounts of land required to produce and supply feedstock within close proximity to the final end use of the feedstock. Current commodity crop yields (bushels per acre) and projections for yields and prices for such

as corn, soybeans, grain sorghum, and wheat, and others, could possibly mean herbaceous energy crops may not be able to readily compete on a net-return basis and especially on prime farmland. For that to possibly happen, changes would need to be made to 1) the federal commodity crop payment structure, 2) economic allowances are adjusted for the production of dedicated/herbaceous energy crops, and/or 3) an environmental "monetization" of the bioenergy crop production would need to occur. Other factors may play a role as well.

In this project, primarily due to possible competition with conventional commodity crops a set of land bases comprised of 'lesser productive' acreages that included cropland-idle (CI), cropland-pasture (CP), and pastureland (P) were analyzed. These land bases are defined in the 2007 Census of Agriculture were felt to best represent more 'marginal' acreages as well as '1st candidate' land bases for large-scale switchgrass production[21]. Table C of Ag presents national values of each of these for 2002 and 2007 and county-level data can be found on the National Agricultural Statistics (NASS) web site[22]. No other information at the county level is provided concerning these databases such as soil types, field slopes, etc.

Since any one of these land bases could possibly be utilized, but extremely unlikely that only any one of them would be targeted, four separate possible production scenarios were examined based on percentages of each land bases type and using average 2002 and 2007 values. The cases considered are presented in table Land Base Scenarios.

Table C of Ag. Acreage of 2002 and 2007 cropland-idle, cropland-pasture, and pastureland

Year	Data Item	ACRES
2007	AG LAND, CROPLAND (EXCL HARVESTED & PASTURED), IDLE - ACRES	37,968,749
2002	AG LAND, CROPLAND (EXCL HARVESTED & PASTURED), IDLE - ACRES	37,281,096
2007	AG LAND, CROPLAND, PASTURED ONLY - ACRES	35,771,154
2002	AG LAND, CROPLAND, PASTURED ONLY - ACRES	60,557,805
2007	AG LAND, PASTURELAND (EXCL CROPLAND & WOODLAND PASTURED) - ACRES	408,832,116
2002	AG LAND, PASTURELAND (EXCL CROPLAND & WOODLAND PASTURED) - ACRES	395,278,829

[21] http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_US/usappxb.pdf
[22] http://quickstats.nass.usda.gov/

Table Land Base Scenarios. Candidate land bases for herbaceous energy crop production and percentage utilization cases.

	Cropland - idle	Cropland - pastured	Pastureland only
Case #1	25%	25%	0%
Case #2	50%	50%	0%
Case #3	25%	25%	5%
Case #4	50%	50%	10%

Total possible acreages, based on an average of 2002 and 2007 acres of each land base type (cropland-idle, cropland-pasture, and pastureland) and the four land base percentage cases presented above, are shown in the following two tables. US totals for each of the four cases were approximately 21, 42, 43, and 86 million acres, respectively.

Table Total State-level Acres – Cases # 1 and # 2.

	CASE # 1			CASE # 2		
	CI	CP	P	CI	CP	P
ALABAMA	98,433	225,998	0	196,865	451,997	0
ARIZONA	40,199	53,420	0	80,398	106,841	0
ARKANSAS	66,595	303,721	0	133,190	607,442	0
CALIFORNIA	183,420	268,195	0	366,840	536,391	0
COLORADO	466,595	379,961	0	933,190	759,922	0
CONNECTICUT	3,115	4,493	0	6,231	8,986	0
DELAWARE	2,541	1,962	0	5,081	3,923	0
FLORIDA	54,207	209,548	0	108,415	419,095	0
GEORGIA	85,934	181,748	0	171,869	363,495	0
IDAHO	217,410	154,137	0	434,821	308,274	0
ILLINOIS	213,409	104,567	0	426,818	209,134	0
INDIANA	89,318	91,326	0	178,636	182,651	0
IOWA	426,908	273,118	0	853,817	546,236	0
KANSAS	632,538	459,472	0	1,265,076	918,945	0
KENTUCKY	170,980	506,799	0	341,960	1,013,599	0
LOUISIANA	138,177	184,617	0	276,354	369,235	0
MAINE	21,508	10,610	0	43,015	21,220	0
MARYLAND	17,591	26,866	0	35,181	53,732	0
MASSACHUSETTS	3,275	5,760	0	6,550	11,519	0
MICHIGAN	138,240	89,800	0	276,479	179,599	0
MINNESOTA	455,353	181,750	0	910,706	363,499	0
MISSISSIPPI	139,168	204,786	0	278,336	409,571	0
MISSOURI	345,359	754,657	0	690,718	1,509,315	0
MONTANA	887,539	425,483	0	1,775,078	850,966	0
NEBRASKA	298,036	346,676	0	596,072	693,352	0
NEVADA	9,253	62,487	0	18,505	124,974	0
NEW HAMPSHIRE	2,596	4,668	0	5,192	9,337	0
NEW JERSEY	6,659	12,111	0	13,319	24,222	0
NEW MEXICO	138,001	182,603	0	276,001	365,207	0
NEW YORK	74,628	98,873	0	149,257	197,747	0
NORTH CAROLINA	64,817	125,870	0	129,634	251,740	0
NORTH DAKOTA	799,110	262,274	0	1,598,221	524,549	0
OHIO	126,378	130,834	0	252,757	261,667	0
OKLAHOMA	255,136	978,865	0	510,272	1,957,731	0
OREGON	174,912	209,308	0	349,824	418,615	0
PENNSYLVANIA	99,039	123,551	0	198,077	247,101	0
RHODE ISLAND	558	641	0	1,116	1,282	0
SOUTH CAROLINA	62,462	82,387	0	124,924	164,775	0
SOUTH DAKOTA	331,294	451,211	0	662,587	902,422	0
TENNESSEE	115,616	407,115	0	231,231	814,230	0
TEXAS	1,151,533	2,596,361	0	2,303,067	5,192,722	0
UTAH	69,018	125,670	0	138,036	251,341	0
VERMONT	6,557	15,891	0	13,114	31,782	0
VIRGINIA	47,647	219,214	0	95,294	438,428	0
WASHINGTON	343,129	108,782	0	686,259	217,563	0
WEST VIRGINIA	11,899	83,002	0	23,797	166,004	0
WISCONSIN	208,928	144,493	0	417,856	288,985	0
WYOMING	86,805	165,825	0	173,610	331,651	0

Table Total State-level Acres – Cases # 3 and # 4.

	CASE # 3			CASE # 4		
	CI	CP	P	CI	CP	P
ALABAMA	98,433	225,998	117,814	196,865	451,997	235,629
ARIZONA	40,199	53,420	1,158,873	80,398	106,841	2,317,746
ARKANSAS	66,595	303,721	158,011	133,190	607,442	316,023
CALIFORNIA	183,420	268,195	715,204	366,840	536,391	1,430,408
COLORADO	466,595	379,961	924,233	933,190	759,922	1,848,466
CONNECTICUT	3,115	4,493	1,956	6,231	8,986	3,912
DELAWARE	2,541	1,962	504	5,081	3,923	1,008
FLORIDA	54,207	209,548	193,157	108,415	419,095	386,314
GEORGIA	85,934	181,748	84,543	171,869	363,495	169,086
IDAHO	217,410	154,137	246,740	434,821	308,274	493,480
ILLINOIS	213,409	104,567	54,664	426,818	209,134	109,327
INDIANA	89,318	91,326	35,468	178,636	182,651	70,936
IOWA	426,908	273,118	125,138	853,817	546,236	250,275
KANSAS	632,538	459,472	845,961	1,265,076	918,945	1,691,923
KENTUCKY	170,980	506,799	177,671	341,960	1,013,599	355,341
LOUISIANA	138,177	184,617	89,517	276,354	369,235	179,033
MAINE	21,508	10,610	3,771	43,015	21,220	7,542
MARYLAND	17,591	26,866	9,606	35,181	53,732	19,213
MASSACHUSETTS	3,275	5,760	2,731	6,550	11,519	5,463
MICHIGAN	138,240	89,800	26,000	276,479	179,599	51,999
MINNESOTA	455,353	181,750	84,637	910,706	363,499	169,275
MISSISSIPPI	139,168	204,786	98,492	278,336	409,571	196,984
MISSOURI	345,359	754,657	397,435	690,718	1,509,315	794,870
MONTANA	887,539	425,483	1,999,266	1,775,078	850,966	3,998,533
NEBRASKA	298,036	346,676	1,161,055	596,072	693,352	2,322,109
NEVADA	9,253	62,487	253,599	18,505	124,974	507,197
NEW HAMPSHIRE	2,596	4,668	1,832	5,192	9,337	3,663
NEW JERSEY	6,659	12,111	3,812	13,319	24,222	7,625
NEW MEXICO	138,001	182,603	1,938,885	276,001	365,207	3,877,771
NEW YORK	74,628	98,873	44,397	149,257	197,747	88,794
NORTH CAROLINA	64,817	125,870	55,396	129,634	251,740	110,791
NORTH DAKOTA	799,110	262,274	567,224	1,598,221	524,549	1,134,448
OHIO	126,378	130,834	63,514	252,757	261,667	127,028
OKLAHOMA	255,136	978,865	987,406	510,272	1,957,731	1,974,812
OREGON	174,912	209,308	475,032	349,824	418,615	950,065
PENNSYLVANIA	99,039	123,551	46,257	198,077	247,101	92,514
RHODE ISLAND	558	641	354	1,116	1,282	708
SOUTH CAROLINA	62,462	82,387	36,508	124,924	164,775	73,016
SOUTH DAKOTA	331,294	451,211	1,185,087	662,587	902,422	2,370,173
TENNESSEE	115,616	407,115	163,990	231,231	814,230	327,979
TEXAS	1,151,533	2,596,361	4,588,957	2,303,067	5,192,722	9,177,914
UTAH	69,018	125,670	455,294	138,036	251,341	910,588
VERMONT	6,557	15,891	7,668	13,114	31,782	15,335
VIRGINIA	47,647	219,214	120,764	95,294	438,428	241,529
WASHINGTON	343,129	108,782	253,046	686,259	217,563	506,092
WEST VIRGINIA	11,899	83,002	58,291	23,797	166,004	116,582
WISCONSIN	208,928	144,493	65,191	417,856	288,985	130,382
WYOMING	86,805	165,825	1,454,153	173,610	331,651	2,908,306

Future Commodity Crop Assessment

Currently, a majority of ethanol in the United States is produced from corn with grain sorghum as another feedstock. Biodiesel is mainly derived from soybeans, with the remainder coming from other minor oilseeds, animal fats, and waste/yellow grease. The USDA's Baseline Agricultural projections and FAPRI (Food and Agricultural Policy Research Institute) both provide data concerning national yield, acreage, and price estimates of all commodity crops from the present through the 2017/2018 crop year [5, 23]. Both sets of data could develop estimates of national supply curves, but at an extremely aggregated resolution and really only 'valid' for a single year due to potential changes in export potential, agriculture and energy legislation, and recently, alternative fuel demand.

Potential yields and acreages of all commodity crops at the county level that might occur were estimated using an average of 2006/2007 to 2008/2009 crop year harvested yields and acres (USDA Baseline projections only forecast harvested yields and acreages) and then multiplying these values by the national increase/decrease in acreage for each individual crop. Table CC A & Y shows the increase/decrease in acreages for 11 major commodity crops.

Table CC A & Y. Estimated percent increase/decrease in Yields and Acres for 11 Major Commodity Crops by 2017.

Commodity Crop	% increase/decrease (Acres) by 2017	% increase/decrease (Yield) by 2018
Barley	3.3%	15.2%
Canola	16.3%	10.1%
Corn	6.0%	16.2%
Cotton Upland	-25.1%	18.5%
Oats	-5.3%	11.5%
Rye	0.0%	6.7%
Grain Sorghum	0.8%	24.7%
Soybeans	2.8%	8.2%
Winter Wheat	-2.0%	16.8%
Spring Wheat	-2.0%	13.3%
Sunflower	9.2%	12.0%

[23] http://www.fapri.iastate.edu/outlook/

For each of these 11 crops with the exception of rye, FAPRI and the USDA Baseline Analysis provide annual estimates of potential commodity crop yields and acreages for 2007/2008 through 2017/2018. Projected yield forecasts for each crop at the county level were estimated by multiplying the percentage change in yield and harvested acres on a national basis for each crop in 2007/2008 and the average of the 2016/2017 and 2017/2018 crop years. The crop years of 2014/ 2015 and 2015/2016 were used instead of one single year as decisions concerning 2017 plantings, and hence harvested acres, could possibly be made in an earlier year.

Projections of agricultural commodities such as these are tenuous at best as agriculture, energy, and/or environmental legislation, market forces, and the world petroleum situation concerning supply and demand could very quickly render these numbers obsolete and therefore these projections should be evaluated and used with this in mind.

Forest based biomass sources

(Note – These estimates are in the process of being revised based on changes requested by the team preparing the Billion Ton Supply Report. In particular 1) the integrated harvesting estimates may change to a limited degree with new simulated thinnings using updated FIA forest plot data and 2) pulpwood supply estimates will change due to revised estimates in havest costs and distribution of regional supply to the county level.)

Forest based biomass supply curves for all U.S. counties have been estimated for 4 sources:

1. Wood biomass from integrated harvesting estimated as the average of two estimates – a) simulated thinnings tailored to add biomass removals to conventional harvesting from timberland and b) removals of a portion of what is now logging residue from harvesting operations on timberland
2. Wood from “other forest removals” such as urban land clearing and cultural operations (e.g. Precommercial thinning)
3. Unused wood and bark residue from primary wood products mills
4. Conventionally sourced wood – separate harvest operations to provide pulpwood sized roundwood

Estimates are for forest biomass supply in the near term – starting 5 years from now and extending for the following 5-10 years. County level supply curves are estimated for two sub-cases: 1) non-federal forest land alone and 2) all forest land. The non-federal supply case is

provided to approximate possible supply given the restrictions on biomass supply sources for biofuels production indicated in the 2007 Energy Independence and Security Act.

1. Biomass from integrated harvesting - Thinnings/ logging residue - from timberland

It is assumed a major source of lower cost biomass will be wood and bark taken from harvest sites where sawlogs and pulpwood are also taken in integrated harvesting operations. We assume integrated harvesting would take the form of removing whole trees to roadside where tops and branches are removed and chipped for biomass for fuel. Integrated operations would also remove small trees (less than 5 inches) to roadside where they could be chipped.

We use two methods to estimate the possible biomass amounts and roadside costs from these integrated operations. Roadside costs include cost to harvest and move wood to roadside, cost of chipping, and cost for stumpage (cost per ton for biomass in standing trees).

Logging residue base estimates - The first method used to estimate of biomass supply by county is to take a fraction of estimated logging residue from recent harvesting operations from the USDA Forest Service Timber product output database for 2007 (USDA FS 2008a). It is assumed that 65% of logging residue can be moved to roadside from either public or private timberland (Perlack et al. 2005). It is assumed that most of logging residue is moved to roadside as part of whole trees and the only costs will be for chipping at roadside (varies by region, about $13/ odt) and the cost for stumpage. Chipping costs were determined by the FRCS model (Fight et al. 2006) as modified and expanded to cover the U.S. North and South as well as the West by Dykstra and Stokes (2009).

Stumpage cost is assumed to be zero for biomass from federal land. For private land we assume stumpage cost begins at and $4/ odt and increases as supply increases to 90% of pulpwood stumpage price (Table F1) when 100% of available logging residue used. Available logging residue is estimated to be 65% total logging residue generated as noted above.

Thinning simulation based estimates – The second method used to estimate biomass supply by county for integrated operations is to simulate uneven-aged thinning operations on all timberland in the U.S.—as represented by Forest Service forest inventory (FIA) plots on timberland (Smith et al., 2009)—where stand density index is greater than 30% of maximum stand density index for the given forest type (Shepperd, 2007). This simulates thinnings to reduce fire hazard and to improve forest health on overstocked stand. Uneven-aged thinnings are

simulated and estimates are made of the amounts of biomass, poletimber, and sawtimber that are removed. For the West, biomass removals include 1) all wood from trees 1–7 in. diameter at breast height (dbh) and 2) tops and branches of trees greater than 7 in. dbh. For the North and South, biomass removals include 1) all wood from trees 1–5 in. dbh and 2) tops and branches of trees greater than 5 in. dbh.

We assume that all of the small-tree biomass can be extracted to roadside, but that only 80% of the volume in tops and branches of larger tress will make it to roadside because of breakage.

We assume that the only costs for tops and branches will be for chipping at roadside and the cost for stumpage. We assume that the cost to remove small trees will be the total cost for harvesting and hauling them to roadside as estimated by the (FRCS) model (which includes a cost for chipping) plus a cost for stumpage (Fight et al. 2006, Dykstra et al 2009). The Biomass Treatment Evaluator (BTE) [24.], was used to prepare county-level supply curves by 1) estimating biomass and industrial roundwood removals from thinning treatments on FIA plots on timberland, 2) assigning stumpage costs, and 3) assigning harvest and chipping costs using the FRCS model.

The FRCS estimates the cost of providing biomass at roadside by whichever is the least expensive of three alternative harvesting systems—ground-based, whole-tree harvesting with mechanized felling; ground-based, whole-tree harvesting with manual felling; or cable yarding of whole trees that have been manually felled. Cable yarding is used only when the average ground slope exceeds 40%.

We assume that the simulated amounts of biomass supply will be harvested over a 30-year period. This is the same period assumed for thinnings estimates provided in the *Billion Ton Supply* report (Perlack et al., 2005).

Stumpage cost is assumed to be zero for biomass from Federal land and $4/odt to 90% of pulpwood stumpage price for private land. The stumpage price for private land is assumed to increase linearly from $4/odt for the first ton of biomass produced to 90% of pulpwood stumpage

[24] The Biomass Treatment Evaluator (BTE) – a SAS program prepared by Patti Lebow , Forest Service Forest Products Laboratory– was used to prepare county level supply curves by 1) estimating biomass and industrial roundwood removals from thinning treatments on FIA plots on timberland, 2) assigning stumpage costs, and 3) assigning harvest and chipping costs using the FRCS model.

price (Table F1) when the simulated removal of sawlogs plus pulpwood for a state reaches the year 2006 level of total sawlog plus pulpwood harvest. This state-level restriction is to assure that the estimated biomass supply from integrated operations can be supported by the recent (year 2006) level of sawlog and pulpwood harvest in each state.

Table F1. Pulpwood stumpage prices by region, 2007

Hardwoods			
	Delivered price	Stumpage price	Stumpage price
	$/gt		$/odt
North	32.0	7.7	15.4
South	28.8	6.7	13.3
Softwoods			
	Delivered price	Stumpage price	Stumpage price
	$/gt		$/odt
North	33.6	10.4	20.7
South	29.0	7.8	15.7
West	40.3	13.8	27.6

Sources: (RISI 2008) (FRCS model – Fight et al. 2006, Dykstra el al. 2009)

It is assumed that as demand for biomass for bioenergy and biofuels increases, there will be a shift from integrated harvesting operations of a type and location that produce amounts similar to our logging residue estimates, toward integrated operations of the type and location represented by our thinning estimates. For the Base case we assume supply (for each county) will be represented by one half of the logging residue supply estimates and one half of the thinning supply estimates.

2. Wood from "other forest removals" such as urban land clearing and cultural operation

Amounts of other forest removals, by county, are obtained from the TPO database for 2007 (USDA FS 2008a). It is assumed that 50% is available for use (Perlack et al. 2005). It is assumed that 34% of the amount available costs $20/ odt at roadside and the remainder costs $30/ odt at roadside.

3. Wood and bark residue from primary wood products mills

Amounts of wood and bark residue, by county, are obtained from the TPO database for 2007 (USDA FS 2008a). For the Base case it is assumed that only unused mill residue is available. It is assumed the cost for unused residues is up to $10/ odt at mills.

4. Conventionally sourced wood – pulpwood sized roundwood

Supply curves of pulpwood sized roundwood at the county level were developed in several steps using basic concepts about supply curves and demand curves for existing pulpwood markets for each state in the United States. In general we assumed that we can approximate increases in state level pulpwood supply that may be used for bioenergy by starting with recent stumpage prices (Table F1) and supply quantities which are taken to be equal to demand quantities.

Use of Pulpwood Supply and Demand Curves

First we envision there will be additional thinning operations – separate from integrated harvesting operations - that take poletimber size trees and associated biomass in a state. These additional thinning operations – in response to increasing demand for wood for bioenergy - move us up the existing pulpwood supply curve for the state and increase the average stumpage price (Fig F1 - Q2 to Q3 and P1 to P2). Also, as the stumpage price increases, an amount of pulpwood previously demanded and used by other firms is diverted from integrated harvesting operations to bioenergy use. This corresponds to an amount obtained by shifting price upward on the pulpwood demand curve (Fig F1 – P1 to P2 and Q2 to Q1). Note that we make the simplifying assumption that for the time period covered by our supply estimate that there will be little shift in the pulpwood supply curve or in the pulpwood demand curve for pulp or panel production. In reality supply curves may shift with the shifting amount and age composition of timber inventory. Also the demand curve may shift with a number of drivers including level of GDP and strength of the dollar relative to other currencies which will influence demand for exports.

Estimating Pulpwood Supply from Additional Harvest - We start the process of estimating county level pulpwood (and associated biomass) supply curves from additional thinning operations by specifying a new higher state level stumpage price (e.g. 10% higher than the base price, (Fig F1 P1 to P2) and note the quantity obtained as we move up the supply curve (Q2 to Q3). We allocate these state level quantities of pulpwood + biomass (derived from the state level supply curve and state level demand curve) to counties based on the locations were

cost to harvest and transport to roadside is lowest. For each county quantity we assign a roadside cost equal to harvest cost plus the state level stumpage cost. The process is repeated for successive increases in the state level stumpage price to form county level supply curves.

A cornerstone for this method is a set of estimates for elasticity of pulpwood supply quantity and demand quantity with respect to changes in pulpwood stumpage price obtained from a review of literature. The elasticity estimates were made using time series data were variables varied over a certain range and econometric equation forms which limits how we should interpret and apply them. Typically the price and quantity data are annual and the percentage change in prices over the entire time series is less than 50%. Most of the econometric equation forms do not distinguish between elasticity with respect to price in the short term – roughly a year or less - versus quantity response in the long term - more than one year - where capital investments may occur that will influence supply or demand response to pulpwood price change. Given that short term elasticities are generally not estimated the elasticities found in the literature reflect responses to prices that will occur over several years.

Estimated average pulpwood supply elasticity with respect to stumpage price for the U.S. South is suggested to be about 0.35 as indicated by results of 6 studies shown in Table F2. Elasticity estimates from studies that covered the entire South range from 0.23 to 0.49. These are averages for both hardwoods and softwoods for all land where most supply was from private land. While pulpwood supply elasticity estimates are not available explicitly for the North and West, an estimate within this range is consistent with estimates of supply elasticity with respect to stumpage price for all timber from two national studies (Adam and Haynes 1980 and 1996). From these two studies the private timberland area weighted national average supply elasticity for all timber in the North and West is 0.42 to 0.47. In addition, studies for the South suggest a supply elasticity for sawtimber alone of 0.42 to 0.55 (Lao and Zhang 2008; Newman 1987). If elasticity for sawtimber in the North and West is about 0.45 then pulpwood supply elasticity in the North and West would be about 0.3. If the Sawtimber supply elasticity in the North and West were 10% higher or lower the North and West pulpwood supply elasticity could range from 0.16 to 0.44. Given the uncertainties associated with these estimates we have used a pulpwood supply elasticity of 0.35 for all states. Given the uncertainties associated with these estimates it is clear that our estimates of quantity supplied for any a given price at a state level or county level could vary notably from actual supply quantities for the given price. Our estimates are only

intended as an indicator of approximate supply that may aid in determining when more local estimates are warranted.

Given the uncertainty in the supply elasticity estimates and concern about sustainability of increased harvest levels we limit the possible annual pulpwood supply at the state level so that we do not exceed the level of annual timber (growing stock) growth in each state.

Estimating pulpwood supply resulting from a shifting in pulpwood harvest from pulp and panel use to bioenergy use - Estimates of average pulpwood demand elasticity with respect to stumpage price was found in two studies – for the South as a whole (-0.43) and for Texas (-0.41) (Newman 1997, Carter 1992). We use an elasticity of -0.41 for each state. Estimates of potential pulpwood supply were made using backward shifts along the demand curve for successive increments in pulpwood stumpage price (e.g. 10%). In Fig F1 see the shift from Q1 to Q2 for a price shift from P1 to P2. At each price point we allocate the amount to counties according to lowest harvest costs. Resulting county level supply curves indicate the quantity supplied at particular total roadside costs.

Given the uncertainty in the demand elasticity estimate for the nation as a whole and a higher uncertainty for state, we limit the possible degree of over estimate in each state by limiting maximum biomass supply – from displacing current pulpwood uses - to 20% of the about of pulpwood supply reported in 2007 Forest Service Timber Product Output database (USFS 2008a).

5. Total Supply from of All Sources

Table F3 shows total U.S. supply forest biomass supply curves for 3 categories – Wood biomass from integrated harvesting, other removals and unused mill residue where sources except mill residue are either from 1) non federal forest land only or 2) all forest land, and 3) from pulpwood supply for bioenergy.

Pulpwood for bioenergy starts to be supplied at current pulpwood stumpage prices (+ harvest costs) and increases as stumpage and harvest costs increase. Pulpwood either comes from a) additional harvesting operations specifically for pulpwood for bioenergy (possibly more expensive than current integrated harvesting) or from b) a shift in pulpwood use from current users to bioenergy producers.

For 2007 The Forest Service total pulpwood harvest estimate is 4.4 billion cubic feet or about 66 million odt. Supply at $100 per odt is 5.6 million odt, an 8.5% increase. Such an increase would be generated with a stumpage price increase of about 11%[25]. The rest of the price increase is due to increased harvest costs to obtain additional pulpwood supply.

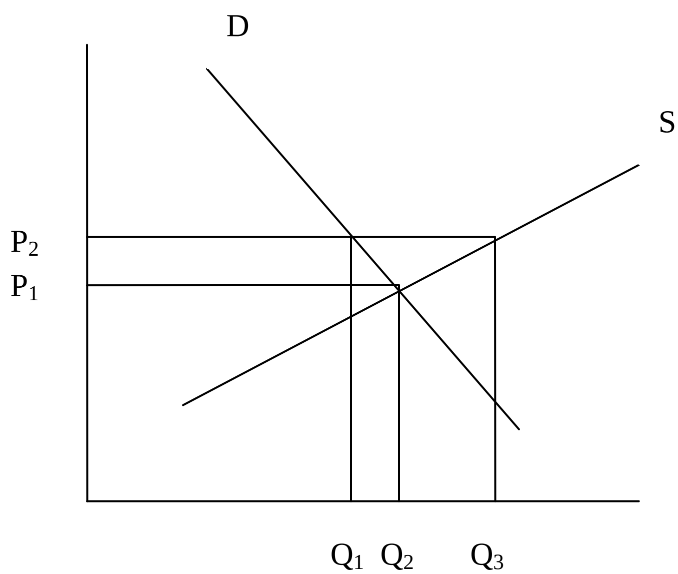

Figure F1 – Pulpwood stumpage supply and demand curves

[25] Percent change in Supply = 0.35 * percent change in stumpage price

References for Forest based biomass estimates

Abt, R.C.; Cubbage, F.W.; Pacheco, G. 2000. Southern forest resource assessment using the Subregional Timber Supply Model (SRTS) Model. Forest Prod. J. 50(4):25-33.

Adams, D.M.; Haynes, R..W. 1996. The 1993 timber assessment market model: structure, projections, and policy simulations. Gen. Tech. Rep. PNW-GTR-368. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 58 p.

Carter, D.R. 1992. Effects of supply and demand determinants on pulpwood stumpage quantity and price in Texas. Forest Science 38(3):652-660.

Dykstra, D., Hartsough, B., & Stokes, B. 2009. Updating FRCS, the Fuel Reduction Cost Simulator for national biomass assessments. 8 p. In: Hartsough, Bruce; Stokes, Bryce, compilers. 2009. Proceedings Environmentally Sound Forest Operations. 32nd Annual Meeting of the Council on Forest Engineering, held June 15–18, 2009 at Kings Beach, California. Proceedings published on CD-ROM by the University of California, Davis, California.

Fight, R.D.; Hartsough, B.R.; Noordijk, P. 2006. Users Guide for FRCS: Fuel Reduction Cost Simulator Software. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Gen. Tech. Rep. PNW-GTR-668. 23 pp.

Lao, X.; and Zhang, Y. 2008. An Econometric analysis of softwood production in the U.S. South: a comparison of industrial and non industrial forest ownerships. Forest Prod. J. 58(11):69-74.

McKeever, D. 2004. Inventories of Woody Residues and Solid Wood Waste in the United States, 2002. Ninth International Conference, Inorganic-Bonded Composite Materials. Vancouver, British Columbia. October 10-13.

Newman, D.H. and Wear, D.N. 1993. Production economics of private forestry: a comparison of industrial and nonindustrial forest owners. Amer. J. of Agr. Econ. 75(August 1993):674-684.

Newman, D.H. 1987. An Econometric analysis of the Southern softwood stumpage market: 1950-1980. Forest Science 33(4):932-945.

Perlack, R.D.; Wright, L.L.; Turhollow, A.F; Graham, R.L.; Stokes, B.J., Erbach, D.C. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The Technical feasibility of a billion-ton annual supply. DOE/GO-102995-2135 or ORNL/TM-2005/66. Oak Ridge National Laboratory, Oak Ridge, TN. 60 pp.

Polyakov, M.; Teeter, L.D.; Jackson, J.D. 2005. Econometric analysis of Alabama’s pulpwood market. Forest Prod. J. 55(1):41-44.

Prestemon, J.P. and Wear, D.N. 2000. Linking harvest choices to timber supply. Forest Science 46(3):377-389.

RISI. 2008. International Wood Fiber Report. San Francisco, CA.

Shepperd, W. D. (2007). SDI-Flex: a new technique of allocating growing stock for developing treatment prescriptions in uneven-aged forest stands. In: Restoring Fire-Adapted Ecosystems: Proceedings of the 2005 National Silviculture Workshop, Robert F. Powers (ed.). Gen. Tech. Rep. PSW–GTR–203, USDA Forest Service, Pacific Southwest Research Station, Albany, CA. http://www.fs.fed.us/psw/publications/documents/psw_gtr203/psw_gtr203_001afm_toc.pdf.

Smith, W.B., Miles, P.D., Perry, C.H., and S.A. Pugh. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: USDA Forest Service, Washington Office. 336 p.

USDA Forest Service. 2008a. Forest inventory and analysis timber product output (TPO) database retrieval system. See http://ncrs2.fs.fed.us/4801/timberproducts/index.htm

USDA Forest Service. 2008b. Forest inventory mapmaker version 3.0. See http://www.ncrs2.fs.fed.us/4801/fiadb/fim30/wcfim30.asp

Table F2 - Elasticity of pulpwood supply quantity with respect to pulpwood stumpage price

	Softwood	Hardwood	Both Softwood and Hardwood			Region	Private Timberland area for region (million acres)
			Private Corporate	Other Private	All Private Land Average	Region	
Newman 1987					0.23	South	179
Carter 1992 (1)	0.59	0.28			0.49	Texas	11
Newman and Wear 1993 (2)			0.58	0.33	0.41	Southeast	73.4
Prestemon and Wear 2000						North Carolina	
Temporary price increase (2)			0.66	0.12	0.29	North Carolina	15.4
Permanent price increase			-0.09	0.08		North Carolina	15.4
Polyakov et al. 2005	0.35	0.35			0.35	Alabama	21.3
Lao and Zhang 2008 (2)			0.9	0.29	0.48	South	179
Estimated average (3)					**0.35**		
(1) Average is weighted by South Pulpwood harvest 2006 (billion cf) (Smith et al. 2009, Table 41)	2.461	1.101					
(2) Average is weighted by South Timberland area 2007 (million acres) (Smith et al. 2009, Table 11)			57	122			
(3) Average is weighted by Private Timberland region area for which estimate was made (Smith et al. 2009, Table 11)							

Table F3 - Forest-based biomass supply for the United States (million oven dry tons per year)

Cost at roadside $/ odt	Wood biomass from Integrated harvesting, other removals, and unused mill residue		Pulpwood supply for bioenergy - extra supply and shift in use from current users (2)
	All Forest Land	Non Federal Forest Land (1)	Total
0	0.0	0.0	0.0
10	1.3	1.3	0.0
20	18.6	16.9	0.0
30	39.4	35.5	0.0
40	42.6	38.1	0.0
50	43.5	38.9	0.0
60	44.2	39.6	0.2
70	44.7	40.1	0.8
80	45.1	40.6	1.9
90	45.6	41.0	3.3
100	46.0	41.4	5.6

(1) Supply if federal lands are excluded from use. The non federal supply amounts would be less than this if federal land is allowed to supply wood for bioenergy.
(2) The pulpwood supply is from two sources – additional supply from treatment on private land only and shift in use from current users to bioenergy producers. For the second source some supply may be from public land.

Appendix CR

CMZ

1 corn grain; soybeans; spring wheat; NT
corn grain; sunflowers; spring wheat; NT, z1
soybeans, nr, NT; Corn, NT, anhyd 2X z1
soybeans, wr, NT Double Disk with Coulters; Corn NT anhyd 2X z1
spring wheat; NT; soybeans NT
Sunflowers NT Spring Wheat NT Z1

2 Barley,Fdisk,FC twist,sdisk;SpWht Fdisk,FC twist,skisk
CAN,SW,SW
Canola FC st pt 3x,sfcult;Barley FC st pt 2x,sfcult 3x; SpWht FC st pt 2x, sfcult 4x
Canola FC st pt, Scult, harrow, SpWht FC st pt, Scult, harrow
SB,FC Sfcult; SB NT; Sp wheat NT
SoyB FC st pt 2x, Scult spike pt, WWht NT
SoyB FC st pts 1x, Scult, harrow, packer,Barley FC st pts 2x, Scult,harrow
SoyB NT,SpWht FC Fcult
Soybean,FC,;WW NT;Canola FC;WW NT
SpWht FCtwist 2x,sfcult; Barley FC twist6 2x,scult; WinWht FC twit 2s, ffcult
Wheat, winter;NT; Canola FC2x, Sfcult

3 Wheat, spring; Corn, silage; Peas, field; NT, Z3
Wheat, spring; Corn, silage; Sunflowers; NT, Z3
Wheat, spring; NT, after chem fallow Z3
Wheat, spring; Wheat, winter; Corn, grain; Sunflowers; NT, Z3
Wheat, winter, after fallow; Corn, grain; Fallow; NT, Z3
Wheat, winter, after fallow; Fallow; NT, Z3
Wheat, winter; Millet; NT, Z3

4 Continuous corn grain;NT no stover harvest
corn grain;NT, corn grain;NT, Soybean, wr, NTz4
Corn, grain; NT, SB NT, WW NT CMZ4
corn grain;NT,anhyd, Soybean, nr, NT Single disk z4

4.1 COG1ntSOY1chisel/ryecover
COG1SOY1wheat1 fp, CMZ 4.1
COG2SOY2sp, CMZ 4.1

5 Bean,dry, Wheat,winter, Corn,grain, ridgetill
corn grain; fallow; winter wheat; NT, z5
corn grain; millet; winter wheat; sunflowers; NT, z5
corn grain; soybeans; NT
corn grain; sunflowers; NT
corn silage; wwheat; sunflower; SC, sweep, fcult
Wheat, winter; fallow; NT

6 wheat,winter-fallow,MT,cm6
wheat.spr-barley-fallow,MT,cm6
wheat.spr-fallow,MT,cm6

7 Barley, Oat hay, graze, irr
Barley, spring, fallow; mulch till
Corn grain, Beans, Barley, irr

8 wheat,spr,MT
wheat,winter-fallow,MT
wheat.spr-barley-fallow,MT

9 Wheat, winter, fallow, no till

10 Canola, spring, fdisk, Fallow, black, fchisel, Wheat, winter, early plant
Wheat, winter, late plant, with fallow, chem

11 Barley, spring, NT
Wheat, winter, late plant, with fallow, chem

12 Barley,spring, notill, irr
Wheat,winter,late, Wheat,spring, chiselfall, sweepspringsummer, chiselspring

13 Wheat, winter, barley, spring, fallow; mulch till
Wheat, winter, fallow; mulch till
Wheat,winter, Bean,dry, chiselfall, fieldcultivatefall

14 Barley,spring, notill, irr
Wheat,winter, notill, irr

15 Barley,spring, Wheat,winter, Corn,grain, sweepspring, diskspring, irr
Bean,dry, Corn,grain, ridgetill, irr
Continuous Corn,grain, RT
Continuous Corn,grain; NT
fallow (MT)-wwheat-grain sorghum (NT)
Wheat, Fallow, Sorghum, NT
Wheat,1 year fallow; chemical

15.1 Barley,spring, Wheat,winter, Corn,grain, sweepspring, diskspring, irr
Bean,dry, Corn,grain, ridgetill, irr
fallow (MT)-wwheat-grain sorghum (NT)

16 Continuous corn grain;NT Fall Strip Till, z16
Continuous corn grain;NT,anhyd, z16
Corn Fall strip till- Soybeans NT Dbl Disk Opener
Corn No Till w NH3 - Soybeans NT Dbl Disk Opener
Corn NT- Corn Spg Disc, Fcult - Soybeans NT drill
Corn NT- Corn Spg Disc, Fcult - Soybeans NT-Wheat NT
Corn NT w/NH3 - Soybeans NT Dbl Disk Openers- Wheat NT
Soybeans NT-Wheat NT

17 Continuous corn grain; NT, Fall NH3 , z17
Corn NT Fall NH3; Soybeans,nr NT
Corn NT; Cotton,NT; Soybeans nr NT
Corn NT; Soybeans,nr NT; Winter Wheat NT
Corn NT-Corn FC, disk, fcult-Soybeans nr NT
Corn NT-Soybeans nr NT-Wheat disk 1X-DC Soybeans nr N
Corn NT-Wheat disc 1x-DC Soybeans nr NT
Cotton, NT; Winter Wheat NT; Soybeans,nr NT
Rice; Sshred, fcult, harrow, land plane; Soybeans,NT, z17
Winter Wheat NT; Soybeans,nr NT

18 barley-barley-fallow,MT,cm18
wheat.spr-barley-fallow,MT,cm18
wheat.spr-wheat,spr-fallow,MT,cm18

19 Corn,Grain;NT,CMZ19
Sorghum,Grain;NT, irr,
Wheat,Fallow;chemical,CMZ1

20 Corn, grain, disk, CT irr CMZ 20
Milo, grain, plow, irr CT CMZ20
WWheat, grain, plow,-Chile, plow-Corn, grain, irr CMZ20

21 WWheat, grain, plow,-Chile, plow-Corn, grain, irr CMZ21
Corn, grain, disk, CT irr CMZ 21

22 Wheat, grain, fall seed, conv till, irr, NM CMZ22
Corn, grain, spring chisel, CT, irr, CMZ22

23 Sorghum, grain, spring disk, CT irr, CMZ 23
Corn, grain, spring disk, CT, irr, CMZ 23

24 Corn No Till w NH3 - Soybeans FC Disk Fld Cult
Corn NTw_NH3_SoyNT DblDsk_WheatNT Z24
Corn NTw_NH3_SunflwNT DblDsk_WheatNT Z24
Dbl_Crop_Corn NT,SoyNT,WheatNT Z24
Dbl_Crop_GrainSorgNT,SoyNT,WheatNT Z24
Dbl_Crop_SoybeanNT,GrainSorNT,CornNT,DblcropWheatNT Z24
Dbl_Crop_SunflowerNT,GrainSorNT,CornNT,DblcropWheatNT
Grain Sorghum No Till w NH3 - Soybeans FC Disk Fld Cult Z2
Wheat, winter; NT14" rows,Sunflower, fallow, Smulch,anhy,fcult Z24

25 Barley, spring, high residue, fchisel, Z25
Wheat, winter, fallow; mulch till, Z25

26 Wheat, winter, fallow; mulch till, Z26

27 Barley, spring, high residue, fchisel, irr Z27

28 Fallow,mulchtill, Wheat,winter, Bean,dry, Wheat,winter, cmz28
Wheat, winter, fallow, mulch till, Z28

29 None

30 None

31 None

32 Wheat, spring; fall chisel, irr Z32
Barley, spring; mulch till, irr, Z32

33 None

34 Corn, grain, Conv Till, irr, CMZ 34

35 Wheat, winter, fallow; no till, Z35
Barley, spring, mulch till, Z35

36 Barley, October seeded, CMZ36

37 Corn, grain; NT, Z37
Cotton, NT; corn, grain, NT, Z37
Sorghum, grain; NT, Z37

37.1 Corn, grain; NT, Z37.1
Cotton, NT, Early, Sorghum-grain, NT, Early, CMZ37.1
Cotton, NT; corn, grain, NT, Z37.1
Sorghum, grain; NT, Z37.1

38 Corn, grain; NT, Z38
Cotton, NT; corn, grain, NT, Z38
Sorghum, grain, NT; CMZ 38
Wheat, grain, Sorghum, grain, NT; CMZ 38
Wheat, grain, Soybean, grain, NT; CMZ3

38.1 Corn, grain; NT, Z38.1
Sorghum, grain, NT; CMZ 38.1
Wheat, grain, Soybean, grain, NT; CMZ38.1
Wheat, grain, Sorghum, grain, NT; CMZ 38.1

39 Wheat, winter; CMZ 39; CA

40 Corn, grain; NT, bale husks and cobs SB NT, WW NT CMZ40
Corn, grain; NT, bale strips SB NT, WW NT CMZ40
Corn, grain; NT, harv res w forage chopper, SB NT, WW NT CMZ4
Corn, grain; NT, SB NT, WW NT CMZ4
Corn, grain; NT, shred and bale all SB NT, WW NT CMZ40
Rye, grain, Sorghum, sweep, disk, change drill CMZ40

41 Corn-grain;NT,Early,CMZ4
Cotton, dry, CT, FD, Bed, Early, 1 yr, Sorghum-grain, CT, FD, Early, 2 yr, CMZ41
Wheat,grain;NT,CMZ41

42 Corn, grain; NT, Z42
Cotton, NT; corn, grain, NT
Sorghum, grain, NT; CMZ 42
Wheat, grain, Sorghum, grain, NT; CMZ 42
Wheat, grain, Soybean, grain, NT; CMZ42

43 Sorghum,grain;NT,CMZ43
Wheat,grain;NT,CMZ43

44 Corn-grain;NT,Early,CMZ44
Cotton, dry, CT, FD, Bed, Early, 1 yr, Sorghum-grain, CT, FD, Early, 2 yr, CMZ4

45 None

46 Wheat, winter, NT, SWheat, fdisk, SBarley, fdisk, Z46
Wheat, winter, high residue, fchisel, irr Z46

47 WWheat, fchisel-SWheat fchisel-WWheat, fchisel-Pea, fchisel, CMZ 47
WWheat, late plant, fchisel-Pea, fchisel Z47
WWheat, early plant, fchisel-SBarley, fchisel Z47

48 Corn, grain; RidgeTill; CMZ 48
Sorghum, grain; RidgeTill; CMZ 48
Wheat w; NoTill; CMZ 48

49 WWheat, CT-Potatoes, CT, irr, Z49
Corn, grain; nt, irr, Z49

50 Wheat, winter; Barley, spring; Fallow; mulch till CMZ50
Wheat, winter; Fallow; early seed, mulch till CMZ50

51 None

52 None

53 Wheat, winter, mulch till; Oats, spring, fall chisel; Z53
Wheat, winter-Clover, annual, seed; fall MT, CMZ53

54 None

55 None

56 None

57 Corn,grain;NT,CMZ57
Sorghum,grainNo;NT,CMZ5
Wheat,grain;NT,CMZ57

58 Corn, grain; NT, Z58
Cotton, NT, Early, Sorghum-grain, NT, Early, CMZ5
Cotton, NT; corn, grain, NT, Z58
Sorghum, grain; NT, Z58

59 corngrain,fctw;soybeans,wr,sctw,z59
corngrain,nt;barley,nt;soybeans,nr,nt,z59
corngrain,sfc;wheat,fdt;soybeans,nr,nt,z59
potato,sctw; rye cover, ftd;corn, nt, wheat grain,nt;soybeans,nr,nt Z59

60 1 yr Corn Grain, mulch till,SC - 1 yr Soybeans, silage, SD, Z60
Corn,grain; No Till, Z60
Potatoes 1yr, SD - Oats 1 yr, FP, Z60

62 Corn FC, Soybean NR FC, Wheat Disk , Intermediate Planting, z62
Early Corn FC, Soybeans NT, Wheat 2X z62
Early Corn NT NH3, Soybeans NT, Wheat NT z62

63 Corn,grain;MT30%,Soybeans,NT, CM63
Corn,grain;NT,Cotton,NT, CMZ 63
Corn,grain;NT,Wheat 1xdisk,Soybeans,NT, CMZ 63
Corn,grain;SP,Wheat,disk2x,Soybeans,SC, CMZ 63

64 Corn, (wheat - soybeans, double cropped), No-Till, CMZ 64
Smallgrain, (wheat), Fall Disk,64
wheat (disk), corn (NT), tobacco (disk), CMZ 64

65 corn gr, sp - soyb, wr; sp, z65
Corn gr; fcst, wheat, fcs, (barley, disk - soybdcnr; nt) z65
corn gr; nt - soyb, nr; nt, z65

66 corn, (wheat, soybeans), Disk, CMZ 66
corn, (wheat, soybeans), NT, CMZ 66
Smallgrain,winter;Fall Disk,66
wheat, soybeans, double cropped, NT, CMZ 66

67 Corn, corn, peanuts, (wheat-soybeans, double cropped), strip tilled, CMZ 67
Corn, grain, st. till, 100 bu. - (wheat, fall disk, 50 bu. - soybeans, st. till, 30 bu.) (CMZ 67)
Corn, strip till into winter weeds (115 bu.) - soybeans, strip till into winter weeds (38 bu.), CMZ 67
Cotton, spring disk, 750 lbs. - Corn, grain, spring disk, 115 bu. (CMZ 67)

68 None

69 Corn (st till),cotton (st till), (soybean (no till) - wheat, disked),CMZ69
Corn,cotton,peanut; strip till into no till rye cover crop, (Wheat - soybeans, no till) CMZ69
corn,cotton; all no till into old crop residue, CMZ69
Corn,cotton; all spring chisel, CMZ69

70 2 yr. Corn, grain, no-till into no-till rye; sorghum, grain, no-till into corn residue; CMZ70
Corn,Grain,125bu; cotton, no till, CMZ70
Corn,Grain;NoTill,125bu; corn, grain,notill; peanuts,strip tillin rye cover crop, CMZ70

71 None