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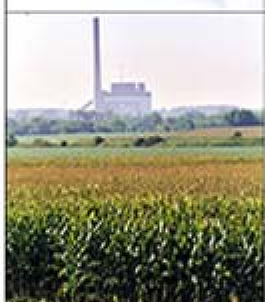


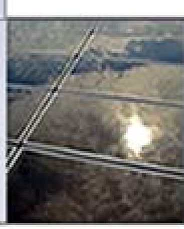
Strategic Assessment of Bioenergy Development in the West

Biomass Resource Assessment and Supply Analysis for the WGA Region

FINAL REPORT

Kansas State University and the U.S. Forest Service

September 1, 2008



Strategic Assessment of Bioenergy Development in the West

In February 2008, the Western Governors' Association adopted a policy reaffirming the governors' strong commitment to enhance and diversify the region's transportation fuels portfolio. The *Strategic Assessment of Bioenergy Development in the West* represents a major step in fulfilling that commitment and expands upon earlier work through WGA's Clean and Diversified Energy Initiative and the Transportation Fuels Initiative. The Bioenergy Assessment Team was formed to examine the potential for future development and to create a comprehensive framework to assess environmental, technical and socioeconomic impacts associated with national, state and regional bioenergy and biomass management policies. This assessment will assist the governors individually and collectively as they develop bioenergy policies. The extensive evaluations conducted by the Assessment Team are contained in the following areas:

- Biomass Resources in the Western States
- Biofuel Conversion Technologies
- Spatial Analysis and Supply Curve Development
- Analyses of Deployment Scenarios and Policy Interactions

While the assessment represents the consensus view of its authors, it is not adopted policy and does not represent the views of WGA or any individual Western Governor. Support for this work was provided by the U.S. Department of Agriculture.

Members of the Western Bioenergy Assessment Team

Western Governors' Association: Gayle Gordon

University of California, Davis: Nathan Parker, Peter Tittmann, Quinn Hart, Mui Lay, Joshua Cunningham and Bryan Jenkins

Kansas State University: Richard Nelson

U.S. Forest Service: Ken Skog, Marcia Patton Mallory, Robert Rummer and R. James Barbour

U.S. Department of the Interior: John Stewart

Antares Group, Inc.: Edward Gray, Anneliese Schmidt and Chris Lindsey

Future Resources Association: Gregg Morris

National Renewable Energy Laboratory: Amelia Milbrandt

Consultants: Jim Kerstetter and Ralph Overend

TABLE OF CONTENTS

List of Figures

List of Tables

1 Introduction

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. This assessment estimates quantities of various biomass resources throughout the WGA region on a county or city basis for use as feedstocks for liquid fuel (transportation) production. The estimates are used to generate potential supply curves, calculate the effect of biomass and crop production on water use and carbon dioxide emissions, and provide quantities and supply curve data for an integrated GIS analysis. And finally, the assessment examines the impact that bioenergy crop production (grain and stover/straw) has on water use and carbon dioxide emissions due to irrigation and emissions of CO_2 from crop planting/establishment, field maintenance, and harvesting.

Biomass resources considered in this project included:

- Agricultural crop residues (corn stover and small-grain straws, including wheat, barley, and oats
- Animal fats and waste greases (beef tallow, yellow grease)
- Forest biomass resources
- Mixed grass species crops (short-rotation woody crops (SRWC) and herbaceous)
- Orchard and vineyard trimmings (apples, almonds, grapes, etc.)
- Biosolids
- Grain and oilseeds (corn, soy, and canola)

2 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[1,2].

A quantitative and economic assessment of corn stover and spring and winter wheat straws on a county-level basis were covered in a previous WGA-sponsored project[3]. An assessment of the amounts and development of county-level supply curves for straw derived from other applicable cereal grains such as barley, oats, and rye was performed in this project since they also possess potential as feedstocks for biofuel production. State-level supply curves expressed in terms of total dry tons available at the field edge at a given price over different price levels ranging from $12.50 to $50.00 per dry ton for each state in the WGA region were derived. These values were estimated utilizing National Agricultural Statistics Service (NASS) corn, spring and winter wheat, barley, oats, and rye production (yield and acreage planted) data for 2000-2003 and employing a procedure developed by Nelson that estimates crop residue retention levels after harvest subject to up to three different field management (tillage) scenarios (conventional tillage (CT); conservation/reduced tillage (RT); and/or no-till (NT)) such that rainfall and/or wind erosion rates did not exceed NRCS soil-specific tolerable soil loss limits[2].

In general, the amount of field crop residue available for bioenergy use in the WGA region, especially from barley, oats, and rye, is small which can be attributed to the following three reasons:

1. Production of barley, oats, and rye is relatively minor due to a number of factors such as climate and markets, therefore significant quantities of residue (on the

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[1] 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.
[2] 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.
[3] Western Governors' Association. 2006. *Clean and Diversified Energy Initiative*. Biomass Task Force Report. http://www.westgov.org/wga/initiatives/cdeac/Biomass-supply.pdf

order of providing feedstock to 25-100 million gallon per year biofuels production facilities) will not be generated,

2. Supply for the WGA region is based primarily on the wind erosion equation (WEQ) which was not specifically developed to analyze residue removal and in utilizing residue retention or removal with WEQ, several agronomic assumptions had to be made which may have undercounted true residue availability, and

3. Residue removal is heavily dependent upon field management (tillage) practices and the tillage “mix” in the 2000-2003 time period in the WGA region is heavily skewed toward conventional (one or more passes of disking and field cultivation) which, due to the large residue burial rates (>50%) associated with disking and heavy field cultivation, leaves little or no residue available for removal.

In select counties, and possibly areas within a county, there are probably "pockets" (small areas) not subject to the county-level “average” tillage mixes as supplied by the Conservation Tillage Information Center, climate conditions, soil erosion, etc. that could potentially produce enough residue for alternative end uses[4]. Also, these numbers do not directly account for any carbon losses or concerns with soil moisture. Appendix A (ACR) provides state-level quantities of each specific agricultural crop residue available for removal at each of five price increments. Supply curves were generated using accepted engineering and economic parameters for machinery that might typically be used to harvest and/or field process, bale, and transport the corn stover or small-grain straw to the field edge. Table 1 presents the economic data used as a function of the amount of both corn stover and small-grain straw that would be harvested at various dry tons per acre increments.

Table 1 - Edge-of-field costs for corn stover and small-grain straw

Yield	Edge-of-Field Cost	
(dt/ac)	Corn	Small-grain
0.1	$350.26	$243.99
0.5	$83.31	$58.65
1.0	$50.95	$35.48
1.5	$41.84	$28.68
2.0	$35.24	$28.28
2.5	$32.92	$25.15
3.0	$34.85	$25.45
4.0	$33.45	$22.20
5.0	$33.50	$20.25

[4] http://www.ctic.purdue.edu/

2.1 Supply Curves for Corn Stover and Small-grain Straws

County-level supply curves based on residue retention rates by individual soil type within a county, cropping rotation, and county-level yields were generated for corn stover and small-grain straws and then these were aggregated into state-level supply curves. Figures 1 through 4 present state-level supply curves for corn stover and straw from winter wheat, barley, and oats in the WGA region based on the soil erosion and residue retention methodology described earlier.

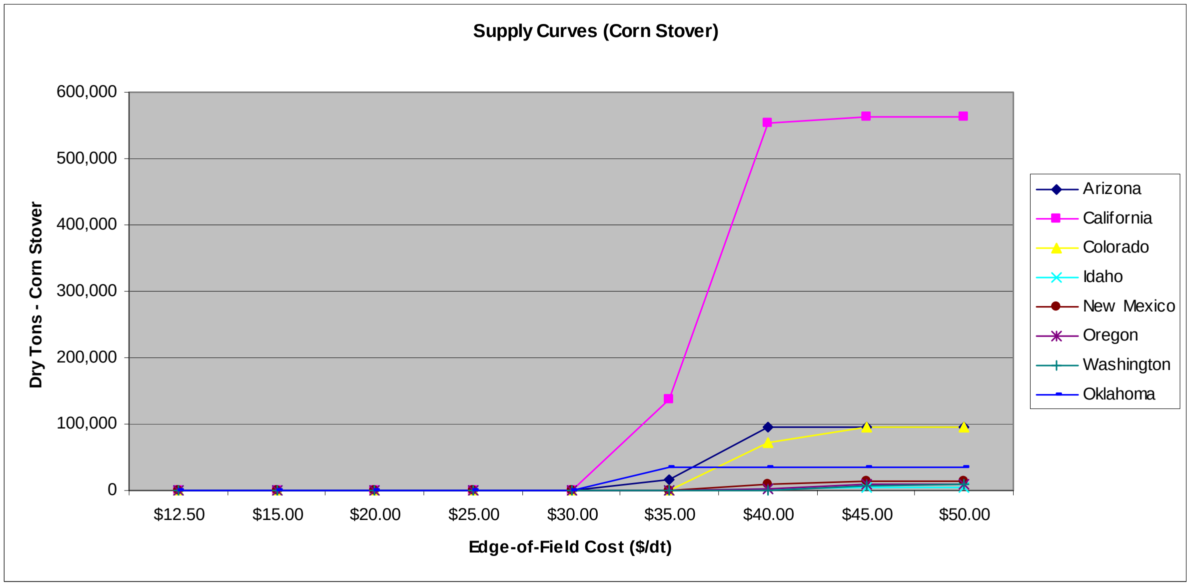

Figure 1 - Supply Curves for Corn Stover in the Western Governors' Association Region

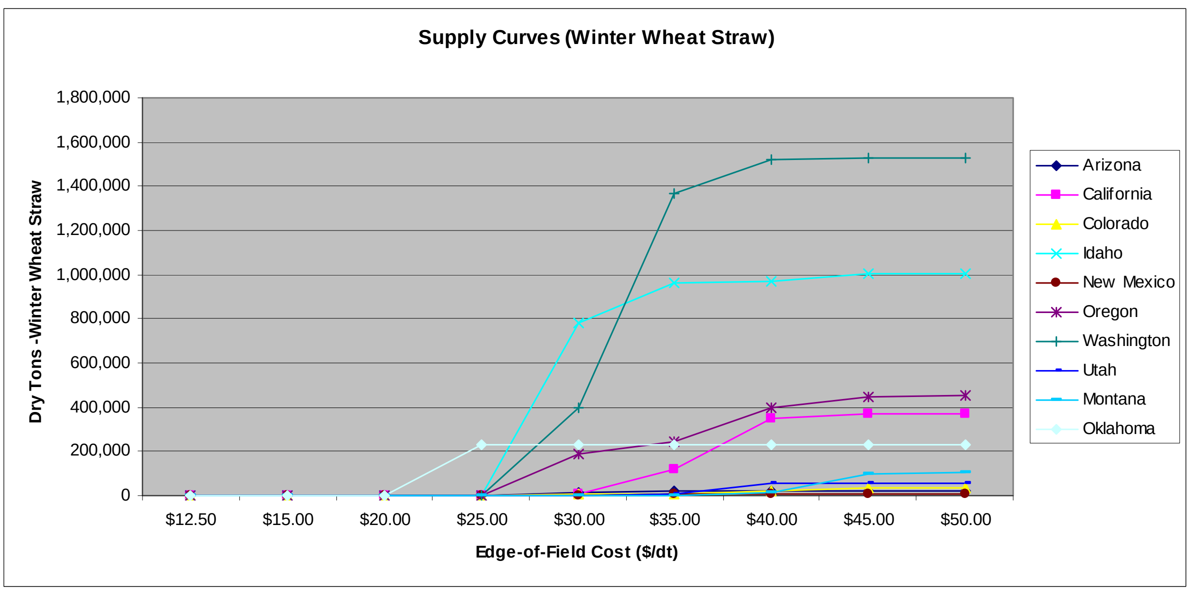

Figure 2 - Supply Curves for Winter Wheat Straw in the Western Governors' Association Region

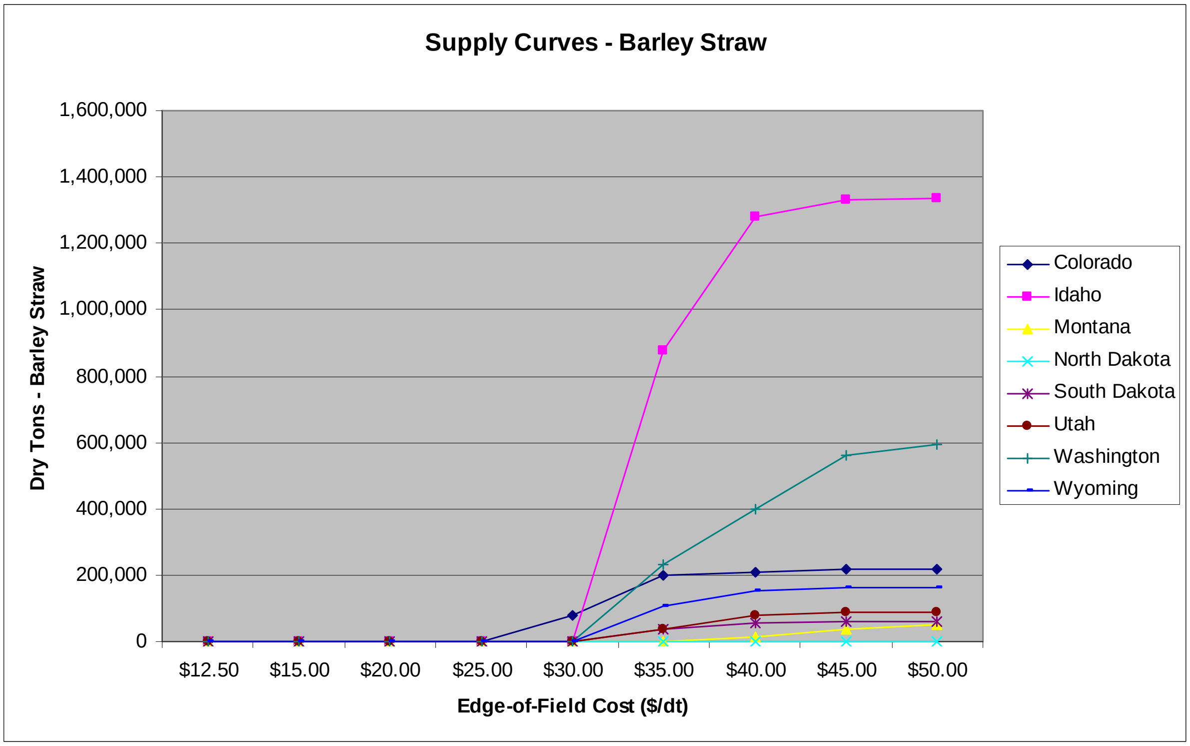

Figure 3 - Supply Curves for Barley Straw in the Western Governors' Association Region

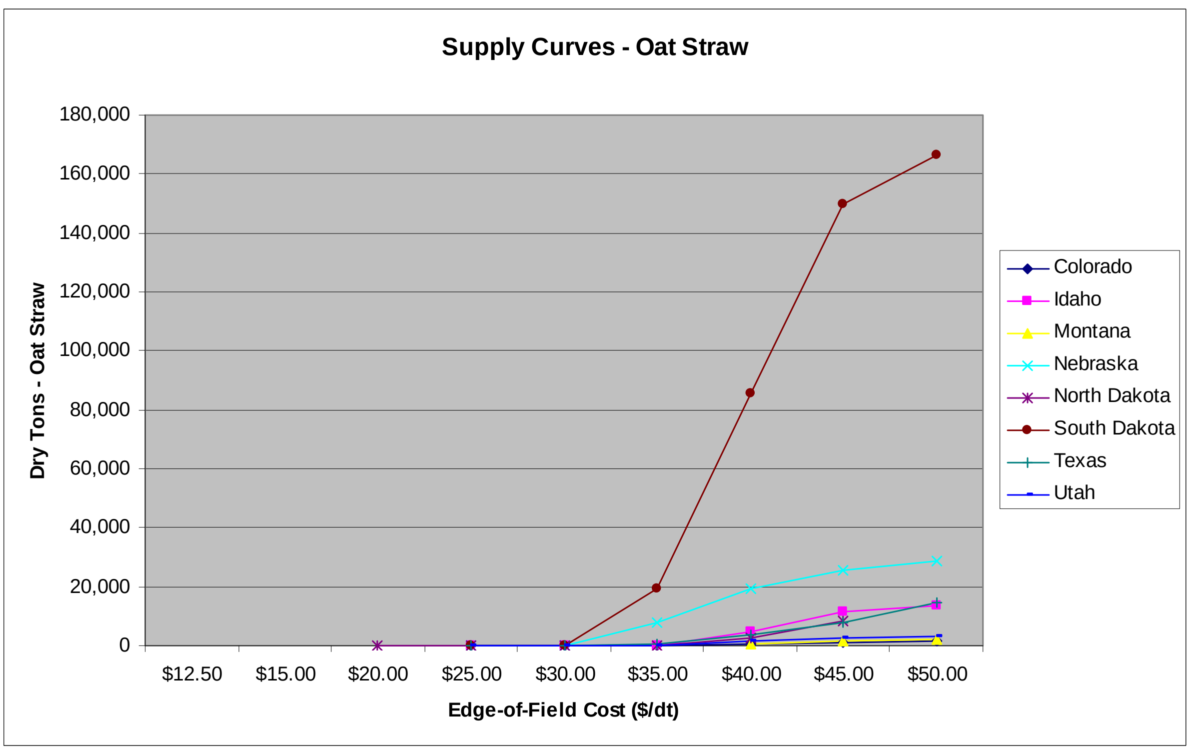

Figure 4 - Supply Curves for Oat Straw in the Western Governors' Association Region

2.2 Water Use in Agricultural Crop Production

Within the WGA region a fair amount of corn, soybeans, wheat, barley, and oats are irrigated. Existing USDA-related databases were utilized to obtain state-wide values for the amount of water consumed per ton of grain and residue produced in each WGA state[5]. Water was allocated between the grain and stover/straw portions of each crop on a mass basis using standard straw (residue)-to-grain ratios which are 1.0, 1.7, 1.3, 1.0, and 2.0 for corn, winter wheat, spring wheat, barley, and oats respectively. Table 2 lists average, state-wide allocations of water between the grain and residue portions for each of the five crops. These values were applied to the supply (on a per ton basis) of corn stover and small-grain straws in each WGA state where applicable.

2.3 Carbon Dioxide (CO_2) Emissions from Crop Production and Allocation to Residues

For all five crops previously examined, carbon dioxide is released through the use of electricity, natural gas, diesel, and/or LP-gas required to pump water for irrigation. The quantity of carbon dioxide generated depends upon 1) water requirements (acre-feet/acre) of each particular crop, 2) type of energy source used and the percentage of that energy source within a state, and 3) depth to water. State-wide average amounts of water, pumping depth, operating pressure, and the number of irrigated acres within each state allocated to electricity, natural gas, and diesel and LP-gas along with accepted state-level CO_2 emission factors for each energy source were combined to estimate a 'composite' CO_2 emissions (tons per tons of grain and residue)[4]. Table 3 provides estimates of CO_2 emissions per ton of crop produced due to energy from electricity, natural gas, diesel, and LP-gas inputs for irrigation for each crop allocated by their individual grain and residue production.

2.4 Estimates of CO_2 Emissions from Corn Stover and Small-grain Straw Harvesting

Removal of corn stover and wheat straw from the field and baling these residues for transport to a conversion facility also requires energy in the form of expended diesel fuel, and CO_2 is produced from these expenditures. Typical operations used in the harvest of corn stover and small-grain straw include flail shredding, baling, and transporting the baled residue to the field edge. Emissions of CO_2 resulting from these operations for average quantities of residue removed in the WGA region is approximately 0.03 tons CO_2 per acre. These emissions were applied to the supply curves for all corn stover and small-grain straw across the WGA region.

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[5] http://www.nass.usda.gov/census/census02/fris/fris03.htm

Table 2 - Average state-wide water consumption (gallons per acre) values for corn, soybeans, winter wheat, barley, and oats and their associated residues

	Corn		Soybeans	Winter Wheat		Barley		Oats	
State	Grain and Oilseed	Stover and Straw	Grain and Oilseed	Grain and Oilseed	Stover and Straw	Grain and Oilseed	Stover and Straw	Stover and Straw	Grain and Oilseed
Arizona	499,447	499,447		400,484	680,823	294,031	441,047		
California	155,858	155,858		271,503	461,556	222,113	333,170	97,741	195,482
Colorado	273,822	273,822	82,103	126,071	214,321	189,374	284,060	108,601	217,203
Idaho	407,652	407,652		195,000	331,500	169,418	254,127	217,203	434,405
Kansas	226,789	226,789	64,509	106,729	181,439	52,129	78,193	43,441	86,881
Montana	471,854	471,854		134,809	229,175	143,354	215,031	152,042	304,084
Nebraska	196,539	196,539	58,645	110,474	187,805			108,601	217,203
Nevada				226,604	385,226				
New Mexico				241,128	409,918				
North Dakota	144,590	144,590	41,051	90,099	153,168	92,789	139,183	119,461	238,923
Oklahoma	244,353	244,353	56,149	120,668	205,136	26,064	39,096	54,301	108,601
Oregon	400,900	400,900		170,752	290,278	168,263	252,395	141,182	282,364
South Dakota	145,749	145,749	45,850	65,819	111,892			130,322	260,643
Texas	252,412	252,412	51,228	118,255	201,033			86,881	173,762
Utah	534,203	534,203		223,871	380,581	236,831	355,247	206,343	412,685
Washington	320,633	320,633		208,900	355,130	211,773	317,659	130,322	260,643
Wyoming	159,715	159,715		110,612	188,041	257,577	386,365		

Table 3 - Average CO2 emissions due to irrigation per ton of crop produced for corn, soybeans, winter wheat, barley, and oats and their associated residues

	Corn		Soybeans		Winter Wheat		Barley		Oats	
	CO_2 from irrigation allocated to grain	CO_2 from irrigation allocated to straw	CO_2 from irrigation allocated to soybean oil	CO_2 from irrigation allocated to straw	CO_2 from irrigation allocated to grain	CO_2 from irrigation allocated to straw	CO_2 from irrigation allocated to grain	CO_2 from irrigation allocated to straw	CO_2 from irrigation allocated to grain	CO_2 from irrigation allocated to straw
Alaska										
Arizona	6,754	6,754			3,055	5,194	2,076	3,114		
California	1,871	1,871			692	1,177	533	799	7,338	14,676
Colorado	2,785	2,785	256.3	n/a	569	967	1,345	2,018	18,171	36,341
Hawaii										
Idaho					0	0				
Kansas	2,402	2,402	212.6	n/a	392	667	251	377	4,277	8,553
Montana	2,420	2,420			409	695	504	756	21,905	43,811
Nebraska	1,903	1,903	180.8	n/a	359	611			29,448	58,896
Nevada					1,735	2,950				
New Mexico					1,122	1,907				
North Dakota	1,178	1,178	93.9	n/a	419	712	447	671	2,530	5,059
Oklahoma	2,417	2,417	168.5	n/a	370	629	126	190	5,613	11,225
Oregon	759	759			185	314	153	230	5,651	11,302
South Dakota	973	973	76.4	n/a	192	326			1,674	3,349
Texas	3,368	3,368	131.1	n/a	445	756			25,069	50,139
Utah	5,534	5,534			1,538	2,614	1,530	2,295	114,025	228,049
Washington	817	817			313	533	131	196	8,033	16,066
Wyoming	2,017	2,017			787	1,339	2,460	3,690		

2.5 N_2O Emissions from Agriculture

N_2O is a potent greenhouse gas with a global warming potential of nearly 300 times that of CO_2. Agriculture accounts for approximately 70% of the anthropogenic emissions of N_2O mostly due to microbial processes associated with gasses emitted through denitrification/nitrification which can be enhanced through use of nitrogen fertilizers. The rate of N_2O emissions from agricultural operations are a function of many factors including soil type, fertilizer type, and cropping rotation. While recognized in this report, it was beyond the scope of this project to attempt to quantify N_2O emissions for the agricultural crops and/or practices used to generate bioenergy resources across the WGA region.

2.6 Criteria Pollutant Emissions Allocation to Biomass Feedstock Production

Calculations were made concerning the amount of select criteria pollutants (CO, PM, SO_2, NO_X) emitted due to use of diesel fuel in agricultural field operations (planting, field maintenance, harvesting) and use of both diesel fuel and electricity in irrigation operations per ton of crop or residue produced. In all cases, these values were considered negligible (< .01% of one ton per ton of crop or residue produced) and therefore were not included in the environmental analysis.

3 Animal Fats and Waste Greases

3.1 Animal Fats (Beef Tallow)

Tallow is a by-product of our meat production and processing system and two types of tallow are generated through the slaughter of beef cattle. These are edible and inedible and each has distinct characteristics and price structure. Edible and inedible tallow are potential biodiesel feedstocks that, due to their highly centralized generation in slaughter/processing facilities, may have energy, environmental, and economic advantages that could be exploited.

Most tallow (edible and inedible) in the United States is currently generated by the meat packing industry. Inedible tallow is most often used as a supplement for animal feed (majority of market share), followed by use in fatty acids, soap, lubricants, and other uses while edible tallow is primarily used as a cooking or baking product. Statistics derived from two independent sources[6, 7] show an average generation of tallow, of about 1.6 billion pounds in the Western Governors' Association area from approximately 50 separate locations in Arizona, California, Colorado, Kansas, Nebraska, Texas, Utah, and Washington. Prices for edible and inedible tallow at various locations throughout the U.S. were obtained from a national source[8] for a period of two years (July 2005 through June 2007) and these were used in conjunction with the resource data in each state and county location to derive 'psuedo' supply curves for producing biodiesel at each geographic location. Table 4 presents average quantitative data on beef tallow generation by state within the WGA region.

3.2 Yellow Grease

Waste grease feedstocks (e.g. restaurant greases) are a secondary, but very accessible and pertinent source of biodiesel feedstocks. Estimates of this resource were made based on methodology developed by Wiltsee (1998)[9] using urban population statistics. Wiltsee estimated an average yellow grease generation of nine (9) pounds yellow grease/capita. These figures may change by 2015 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.

All WGA population centers with greater than 100,000 persons as measured by the 2000 census (latest data available) were included in this analysis. Population expansions were estimated for each WGA city for 2015 using data for state population increases derived from data provided by the US Census Bureau[10]. Within the WGA region, over 50 million gallons per year (MGY) of yellow grease-based biodiesel could potentially be produced in 126 urban centers with individual city plant capacities ranged from 0.14 to greater than

[6] Livestock Marketing Information Center. Lakewood, CO.
[7] Steve Kay. Cattle Buyers Weekly. Petaluma, CA.
[8] http://www.thejacobsen.com/
[9] http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19981001_gen-107.pdf
[10] http://www.census.gov/compendia/statab/population.html

12 MGY. Brown grease was not considered as a serious source due to its high FFA content which would add to pre-processing costs. Table 5 presents data on estimated yellow grease quantities for each WGA state with a projected 2015 population of 100,000 persons or greater.

Table 4 - Average annual tallow generation (pounds) and estimated tallow-based biodiesel

State	Edible and Inedible Tallow Generation (pounds)	Estimated Gallons of Tallow-based Biodiesel
Alaska	0	0
Arizona	30,618,358	4,082,448
California	94,151,452	12,553,527
Colorado	120,483,240	16,064,432
Hawaii	0	0
Idaho	0	0
Kansas	449,477,499	59,930,333
Montana	0	0
Nebraska	445,879,842	59,450,646
Nevada	0	0
New Mexico	0	0
North Dakota	0	0
Oklahoma	0	0
Oregon	0	0
South Dakota	8,802,778	1,173,704
Texas	416,103,489	55,480,465
Utah	36,129,663	4,817,288
Washington	65,217,103	8,695,614
Wyoming	0	0
WGA Region	1,666,863,424	222,248,457

Table 5 - Estimated yellow grease generation and associated biodiesel production

State	Yellow Grease (million pounds) - 2015	Potential Biodiesel Production (MGY)	State	Yellow Grease (million pounds) - 2015	Potential Biodiesel Production (MGY)
Alaska	0	0.0	New Mexico	5	0.6
Arizona	42	5.5	North Dakota	19	2.6
California	167	22.2	Oklahoma	9	1.1
Colorado	18	2.5	Oregon	8	1.1
Hawaii	0	0.0	South Dakota	1	0.2
Idaho	2	0.3	Texas	97	12.9
Kansas	7	1.0	Utah	4	0.6
Montana	0	0.0	Washington	13	1.7
Nebraska	0	0.0	Wyoming	0	0.0
Nevada	6	0.8	WGA Region	397.8	53.0

Table 6 - Estimated yellow grease generation and associated biodiesel production.

State	Yellow Grease (million pounds) - 2015	Potential Biodiesel Production (MGY)	State	Yellow Grease (million pounds) - 2015	Potential Biodiesel Production (MGY)
Alaska	0	0.0	New Mexico	5	0.6
Arizona	42	5.5	North Dakota	19	2.6
California	167	22.2	Oklahoma	9	1.1
Colorado	18	2.5	Oregon	8	1.1
Hawaii	0	0.0	South Dakota	1	0.2
Idaho	2	0.3	Texas	97	12.9
Kansas	7	1.0	Utah	4	0.6
Montana	0	0.0	Washington	13	1.7
Nebraska	0	0.0	Wyoming	0	0.0
Nevada	6	0.8	WGA Region	397.8	53.0

4 Forest Biomass Resources

4.1 Sustainability

Estimates of forest biomass supply were developed for several sources by first identifying sustainability principles to guide their use. Specific guidelines are noted for each source discussed. In general terms sustainability means today's management actions will not degrade the ecological functioning of a natural system[11]. In the context of biomass removal from forests, the question of sustainability requires consideration of a wide range of issues, including: nutrient cycling and soil productivity, maintenance of biodiversity, water quality, and wildlife habitat. These factors, and resulting constraints on forest operations to address concerns, are generally very site-specific. Soil productivity in certain soil types, for example, may be more sensitive to micro-nutrient levels and thus require retention of some level of woody residue. Wildlife habitat requirements may stipulate retention of snags or maintenance of coarse woody debris. Again, ecological factors including wildlife and endangered species need careful site-specific evaluations in determining biomass availability.

Sustainability is explicitly addressed in this analysis through several assumptions. On Federal lands, vegetation management projects are implemented within the framework of environmental analyses and regulations that ensure consideration of ecological effects and sustainability. While less restricted, treatments on private lands are also constrained through various environmental laws and regulations[12]. The potential forest biomass supply that is modeled here is a secondary output of other management objectives. We consider biomass that would be available from forest health treatments, fire hazard reduction work, or treatment of activity fuels after logging where questions of sustainability are addressed in the larger management plan.

The present assessment also assumes ecological considerations and practical limitations would have the effect of reducing the amount of biomass available for removal and utilization. The process used models silvicultural treatments and estimates total available biomass. The total available biomass is then further reduced to reflect material left on site to meet ecological constraints or is otherwise impractical to remove. The reduced amount is the net biomass available for removal. For example, a previous study[13] with limited environmental screens estimated 345 million oven dry tons (odt) of biomass may be available from fire hazard reduction thinnings whereas with our additional screens – for our Base Case – we estimate 114 million odt tons are currently available. For each estimate it is assumed these amounts would be harvested over a period of years.

As a final gross check on sustainability, the net annual growth in western forest types was calculated from Forest Inventory and Analysis (FIA) plot data and compared to the estimated biomass removal volumes. While growth, mortality and removal are not

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[11] Helms, J.A., ed. The Dictionary of Forestry. Society of American Foresters, Bethesda, MD. 210 p. (1998).
[12] Ellefson, P.V., Chen, A.S., Moulton, R.T. "State forest practice regulatory programs: an approach to implementing ecosystem management on private forest lands in the United States." Environmental Forestry 21(3):421-432. (1997).
[13] USFS. 2003. A strategic assessment of forest biomass and fuel reduction treatments in western states. http://www.fs.fed.us/research/infocenter.html

holistic measures of ecological integrity, they provide a benchmark of management intensity and impact. For 2002 the total net annual growth of growing stock on timberland in western states was about 97 million odt per year and of this 43 million odt was removed[14]. Growing stock growth does not include growth in tops and branches or in non growing stock trees. Our Base Case would use about 13 million odt of biomass per year, which is an amount less than 25% of currently unremoved net growth of growing stock (13/ (97-43) = 0.24). The estimated fraction would be less if we included, in the denominator, the growth of tops of growing stock trees and growth of non-growing stock trees.

The key effort is to recognize that forest practice laws and guidelines[15] will place ecological constraints on the impacts biomass removal can have. Our adjustments to attempt to reflect these guidelines are very gross and further evaluations will be needed to determine availability in local areas. However, we estimate that public lands would allow less removal than private lands. For a County Commissioner looking at this report, and if they knew that there were no endangered species in their county and no water quality issues or sensitive soils, the estimates of available biomass from this report would be overly conservative. Similarly, if they were in a county with the only remnant population of an endangered species, the estimates may not be conservative enough.

4.2 Biomass sources

The forest biomass sources used for this report are very similar for those used for the Western Governors Association CDEAC report[16]. In general terms the forest biomass sources for the current report are:

- Thinning of timberland with high fire hazard,
- Logging residue left behind after anticipated logging operations for conventional products,
- Treatment of Pinyon Juniper woodland,
- General thinning of private timberland,
- Precommercial thinning on National Forest land in western OR and WA, and
- Unused mill residue.

Our analysis includes supply of biomass from federal lands. But this supply from federal land may not be a viable since the Energy Independence and Security Act of 2007 would not allow biofuels made using biomass from most federal lands[17] to count toward the

[14] Smith, W. Brad; Miles, Patrick D.; Vissage, John S.; Pugh, Scott A. 2003. Forest Resources of the United States, 2002. Gen. Tech. Rep. NC-241. St. Paul, MN: USDA Forest Service, North Central Research Station. 137 p. See Table 36 – Net growth for ND, SD, all intermountain states, OR, WA, CA is (6.5 billion cu. ft. x 30 lbs/ cf / 2000 lbs/ton =) 97.5 million od tons. Removal of growing stock in 2002 was 2.9 billion cf (= 43 million od tons).
[15] Ellefson, P.V., Chen, A.S., Moulton, R.T. "State forest practice regulatory programs: an approach to implementing ecosystem management on private forest lands in the United States." *Environmental Forestry* 21(3):421-432. (1997).
[16] Western Governors Association. 2006. Forest fuel treatment & thinning biomass – Timberland. In: 2006 Biomass Taskforce Report: Clean and diversified energy initiative – Biomass Task Force Report - Supply Addendum. Denver, CO. p 11-12ff. http://www.westgov.org/wga/initiatives/cdeac/Biomass-supply.pdf
17 Supply would be allowed from tribal lands held in trust by the federal government and from all lands in " the immediate vicinity of buildings and other areas regularly occupied by people, or of public infrastructure, at risk from wildfire."

biofuels RFS (renewable fuels standard). The RFS requires 21 billion gallons of "advanced biofuels" need to be supplied by 2022 and only certain biomass sources may be used in meeting meet this standard. The only one of our sources that would not be notably reduced by this restriction would be the estimated 2.7 to 4.3 million od tons of biomass per year from general thinning on private land.

Biomass supply estimates were made for each county in selected Western states. We make a Base Case supply estimate for each source and for some sources we make a High Case estimate to cover a range of uncertainty about supply from the source. Supply estimates include amounts available at roadside in each county for each of several successively higher costs.

Base Case and High Case estimates of total potential annual supply by source are shown in Table 6. Base Case and High Case estimates of potential annual supply by state and roadside cost are shown in Tables 8 and 9, and in Figures 5 and 6.

4.2.1 Thinning of timberland with high fire hazard

Thinning of timberland with high fire hazard contributes to forest sustainability by reducing the risk of uncharacteristically severe fire. By conducting a thinning, the intent is to move toward a natural fire regime pattern with natural recurrence of less severe fire. Supply was estimated by simulating thinnings on federal and non-federal land using the FTE 3.0 model[18] and Forest Service FIA plot data[19]. It is assumed that timberland with current high fire hazard will be thinned over a period of years with either 1) an uneven aged thinning (where some trees of all size classes may be taken) or 2) an even aged thinning where trees where small diameter trees are taken first followed by successively larger trees until the hazard reduction target is met. A series of screens were applied to identify about 23 million federal and non federal acres that would receive simulated treatment (see Clean and Diversified Energy (CDEAC) Biomass Task Force Exhibit 1-1). One screen excluded from treatment is those forest types where stand replacement fire is the norm (lodgepole pine and spruce-fir). An additional screen excluded treatment of wet climate counties in western Oregon and Washington (see separate source below). These areas were excluded because such treatments would not be consistent with our ecological objectives. These screening steps are the same as those used for the WGA CDEAC report.

For federal lands it is assumed even aged and uneven aged treatments are used equally but for non-federal land it is assumed only uneven aged treatments are used. The WGA CDEAC report assumed all eligible timberland was treated equally by each type of treatment. The change was made to reflect the likelihood that non-federal land would seek higher value and profit by using uneven aged treatments on all treated land.
For this source and sources C, D, and E in Table 6 it was assumed biomass volumes identified would be harvested over a period of years. Over this period of harvest, tree growth and mortality will continue and – depending on these growth and mortality rates – additional material would be available for harvest beyond the estimated harvest period. For the Base Case, for sources A and E, we chose a harvest period of 22 years. This time period was previously chosen for the CDEAC study, and used here, so fire

[18] Miles, Patrick D. Aug-04-2005. Fuel Treatment Evaluator web-application version 3.0. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. [Available only on internet: http://www.ncrs2.fs.fed.us/4801/fiadb/fte_test/fte_testwc.asp]
[19] See http://fia.fs.fed.us/tools-data/

hazard reduction treatments (source A) would be done on about 500,000 acres per year. For sources C and D we chose a harvest period of 30 years to match the harvest period used in the DOE/USDA "Billion ton supply" report[20] for thinning treatments.

For the source A Base Case it is assumed that tops and branches of all trees and main stem of trees up to seven inches diameter at breast height (dbh) are supplied for biofuels and for the High Case trees removed up to nine inches are also supplied for biofuels. Main stem of larger trees not used for biofuels are assumed to be used to make lumber or other higher value products. The cost to remove tops and branches to roadside was assumed to be covered by the cost of removing the whole tree. At roadside there is an assumed $8/dry ton chipping cost. The cost for removing the main stem of trees supplied for biofuels was estimated using the FRCS model[21] for wood removals from each FIA forest plot. It was assumed stumpage cost would be $2/odt on private land and $0 on public land. Using this data wood biomass supply curves were estimated for each county in 12 Western states[22].

4.2.2 Logging residue left behind after anticipated logging operations for conventional products

Wood harvested and left on the ground at harvesting sites (or land clearing sites) may be taken to a certain degree subject to limits including (but not limited to) the need to maintain nutrients on site and to retain habitat. For the Base Case supply estimate we use the allowable removal fractions from the DOE/USDA "Billion-ton-supply" report – 65% for logging residue is available for biofuels from harvest sites and 50% from land clearing sites. The High Case is the same as the Base Case for this source as only a Base Case exists for this source. Data on logging residue and land clearing is from the Forest Service 2002 RPA Timber Product Output data base[23]. To estimate the roadside cost we assume that whole tree removal will be used (where not already used) to bring out tops and branches to roadside. The cost for removing tops and branches to roadside will be covered by the cost of removing the main stem material. That is, the only cost to provide the wood at roadside will be to chip for $8/odt. It is assumed stumpage cost would be $2/odt on private land and $0 on public land. It is recognized logging residues come from current logging operations that provide sawlogs, pulpwood, posts and poles. It is assumed if thinning to reduce fire hazard expands and general thinning on private land expands (including biomass for fuels) then the extent of traditional operations will decrease along with associated logging residue. Given the uncertainty about the degree of displacement - we decrease logging residue use for fuels by one-quarter unit for each unit increase in biomass for fuels coming from new thinnings.

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[20] Perlack, R.D. et al. 2005 Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion ton supply. Oak Ridge National Laboratory, Oak Ridge, TN 60 p. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf

[21] Biesecker, R.L.; Fight, R.D. 2006. My fuel treatment planner: a user guide. Gen. Tech. Rep. PNW-GTR-663. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 31 p. http://www.fs.fed.us/pnw/data/myftp/myftp_home.htm

[22] Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming

[23] See http://ncrs2.fs.fed.us/4801/fiadb/rpa_tpo/wc_rpa_tpo.ASP

4.2.3 Treatment of Pinyon-Juniper woodland

Pinyon-Juniper is a category of woodland forest which produces less than 20 cu. ft. per acre per year. Pinyon-Juniper forest type has expanded extensively beyond its historic range and our ecological objective in treating this area over time is to bring the extent of this forest type closer to its historic range. For the Base Case supply estimate we use allowable removal fractions from the DOE/USDA "Billion-ton-supply" report (table A-6) – 45.9% of wood on these public Pinyon-Juniper lands is available for biofuels and 61.2% of wood on private Pinyon-Juniper lands is available. This study excludes wood supply from other woodland categories in the west because we could not cite an ecological reason for such treatment.

For the Base Case we estimate 1/30 of the total volume would be supplied each year (as assumed in the Billion ton supply report.) We made a general estimate that the average cost of harvest would be $60/odt and roadside chipping would cost $12.60/odt for a total of $72.60/odt. The chipping cost for Pinyon-Juniper trees is estimated to be higher than for tops and branches of other trees based on case studies that indicate chipper throughput is lower for Pinyon-Juniper. This is though to be due in part because of the irregular form of Pinyon-Juniper trees. It was assumed stumpage cost would be $2/odt on private land and $0 on public land. For the High Case we assume that the treatments would occur over 20 years and costs would be subsidized at $20/odt based on proposed legislation.

Note that Figure 5 shows that large quantities of biomass from Pinyon-Juniper land become available in several states when price reaches $72.60. This is because we have a single price estimate for removing this biomass. In reality the supply would increase more gradually over a range of prices we estimate would be centered on a price of $72.60.

4.2.4 General thinning of private timberland

It is presumed that as demand and prices for biomass for fuels increases, there will be an increase in operations to harvest both woody biomass and sawlogs/pulpwood in combined operations on private land. Some private land is excluded from this source because it is already treated under the fire hazard reduction thinnings noted above. This source estimates supply from private land acres that have sufficient stocking to warrant thinning but have lower fire hazard. For the Base Case supply estimate we simulated an unevenaged thinning on private land FIA timberland plots that were not treated by a fire hazard thinning procedure (source A.) The estimation procedure is the same used to estimate biomass from thinning U.S. timberland for the Billion ton supply report (stands with density greater than 30% of maximum stand density index are thinned back to 30%.) Since the thinnings may be heavier than appropriate for lodgepole pine and spruce-fir forest types - they are subject to wind throw if thinned too heavily - we did not treat those forest types. A lighter thinning could have been developed and applied as was done in wildland urban interface areas for the CDEAC report and source A above.

The Base Case supply is assumed to be provided in equal annual amounts over 30 years. The supply costs were estimated in the same way as for the fire hazard reduction thinnings (source A.) For the High Case, trees removed up to nine inches are also supplied for biofuels and the annual supply is assumed to be provided in equal amounts over 20 years. It is assumed stumpage cost would be $2/odt.

4.2.5 Precommercial thinning on National Forest land in western counties in OR and WA

We did not simulate fire hazard reduction thinnings on National Forest[24] timberland in counties west of the Cascade Mountains in Oregon and Washington where the thinning objective would not be focused on reducing fire hazard but on maintaining appropriate stocking and habitat conditions. Instead, for source E, we simulated a precommercial thinning of FIA plots to remove trees five to nine inches dbh in stands up to 40 years old. For the Base Case it is assumed that 1/22 of this volume could be harvested each year (the same as for source A.) The cost to harvest and move wood to roadside was estimated for each treated FIA plot using the FRCS model. Harvest costs for individual plots ranged from a low of $22/odt to about $70/odt for many plots with some plots costing over $500/odt. It is assumed stumpage cost on National Forest land is $0/odt. The High Case supply is the same as the Base Case.

4.2.6 Unused mill residue

Forest Service surveys of wood products mills (e.g. lumber, plywood, pulp) periodically estimate amounts of coarse and fine wood and bark residue generated by county and how much goes for various uses (e.g. fuel, fiber input for pulp or panels.) Source F is the estimate of mill residue that goes unused. We assume this entire unused amount is available to make biofuels. The amount supplied is the same for the Base Case and High Case. It is assumed the cost at the mill is $0/odt.

4.3 Estimates of CO_2 Emissions from Forest Thinnings

Carbon dioxide is also released from the combustion of diesel fuel used to remove forest thinnings. Average numbers indicate roughly 2 gallons of diesel consumed per thousand cubic feet which translates into approximately 1.2 gallons per oven dry ton and nearly 27 pounds of CO_2 emissions per oven dry ton of thinnings[25, 26].

Table 7 - Current potential annual wood biomass supply from selected western states (million oven-dry tons)

Source	Source	Base Case	High Case	WGA CDEAC	BTSR
A	Fire hazard thinning on timberland	5.2	7.5	7.2	

[24] With additional data, estimates could be made for other federal forest land (BLM) in these OR and WA counties.

[25] Johnson, Leonard R., Bruce Lippke, John D. Marshall, and Jeffrey Comnick. 2005. *Life-Cycle Impacts of Forest Resource Activities in the Pacific Northwest and Southeast United States*. Wood and Fiber Science, 37 Corrim Special Issue. pp. 30-46

[26] Robert B. Rummer. USDA Forest Service, Auburn, AL. Personal communication.

B	Logging residue	4.7	4.1	5.3	5.3
C	Treatment of Pinyon Juniper woodland	7.6	11.5		
D	General thin on private timberland	2.7	4.3		
E	Pre-commercial thin on National Forest in western counties of Oregon and Washington	0.3	0.3		
F	Mill residue	0.2	0.2	0.3	0.3
	TOTAL	20.7	27.9		
	Thinning to reduce fire hazard on timberland				10.8
	Thinning on other forest land			9.2	9.2
	TOTAL			22.0	25.6
BTSR = Perlack et al. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply					

Table 8 - Base Case cumulative forest biomass supply (oven dry tons per year) by state and roadside cost.

State	Roadside cost in dollars per oven dry ton						
	$10	$20	$30	$40	$50	$75	$100
Arizona	53,313	154,025	222,599	225,198	228,874	2,092,106	2,094,275
California	1,271,547	3,366,681	3,966,745	4,046,998	4,104,845	4,263,956	4,268,243
Colorado	82,812	193,561	279,369	324,313	341,516	1,542,596	1,552,011
Idaho	778,692	1,005,643	1,478,387	1,592,434	1,669,077	1,803,476	1,824,399
Kansas	8,720	8,720	8,720	8,720	8,720	8,720	8,720
Montana	628,548	1,053,812	1,554,616	1,694,996	1,768,144	1,850,486	1,882,451
Nebraska	4,971	4,971	4,971	4,971	4,971	4,971	4,971
Nevada	4,799	7,043	7,122	7,195	7,195	1,370,524	1,370,524
New Mexico	68,897	135,084	299,745	326,263	352,722	1,675,499	1,680,423
North Dakota	265	265	265	265	265	265	265
Oregon	924,418	1,628,936	1,712,498	1,764,367	1,824,752	1,850,106	1,851,089
South Dakota	95,407	98,503	112,224	112,224	112,224	112,224	112,224
Texas	3,022	3,022	3,022	3,022	3,022	3,022	3,022
Utah	32,670	48,437	101,966	118,102	128,534	1,776,062	1,787,916
Washington	916,029	1,437,920	1,657,948	1,757,994	1,803,262	1,820,173	1,826,722
Wyoming	81,784	123,925	185,505	204,620	211,075	298,320	301,136
Total	4,955,893	9,270,549	11,595,702	12,191,683	12,569,199	20,472,506	20,568,392

Table 9 - High Case cumulative forest biomass supply (oven dry tons per year) by state and roadside cost.

	Roadside cost in dollars per oven dry ton						
	$10	$20	$30	$40	$50	$75	$100
Arizona	96,705	250,019	345,982	368,714	373,112	3,166,477	3,173,163
California	2,168,806	4,102,790	4,665,927	4,830,207	4,869,050	5,129,086	5,154,233
Colorado	102,932	246,115	379,128	436,494	468,969	2,267,626	2,290,743
Idaho	809,109	1,166,217	1,914,282	2,062,528	2,175,302	2,401,380	2,465,831
Kansas	8,720	8,720	8,720	8,720	8,720	8,720	8,720
Montana	652,215	1,216,020	2,027,512	2,387,698	2,474,417	2,628,944	2,676,008
Nebraska	4,971	4,971	4,971	4,971	4,971	4,971	4,971
Nevada	4,697	4,697	4,770	4,843	6,808	2,051,801	2,051,807
New Mexico	82,152	169,769	405,814	472,724	514,633	2,495,484	2,504,444
North Dakota	265	265	265	265	265	265	265
Oregon	1,451,328	1,778,410	1,875,010	1,958,933	2,057,311	2,097,133	2,100,369
South Dakota	95,407	106,298	129,042	129,042	129,042	129,042	129,042
Texas	3,022	3,022	3,022	3,022	3,022	3,022	3,022
Utah	35,852	53,571	141,958	171,528	192,325	2,678,423	2,691,756
Washington	1,144,729	1,624,495	1,855,034	2,052,241	2,120,472	2,175,068	2,188,618
Wyoming	81,340	150,630	263,255	281,884	294,622	429,622	432,318
Total	6,742,251	10,886,012	14,024,691	15,173,815	15,693,041	27,667,065	27,875,310

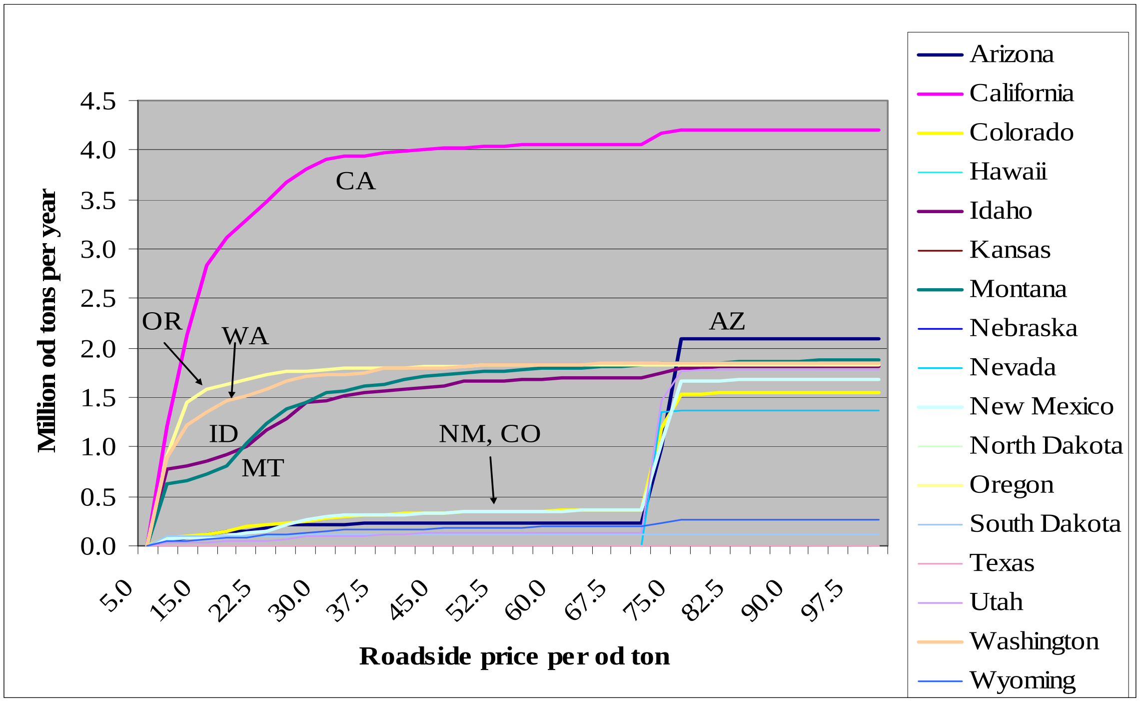

Figure 5 - Base Case forest biomass supply by state

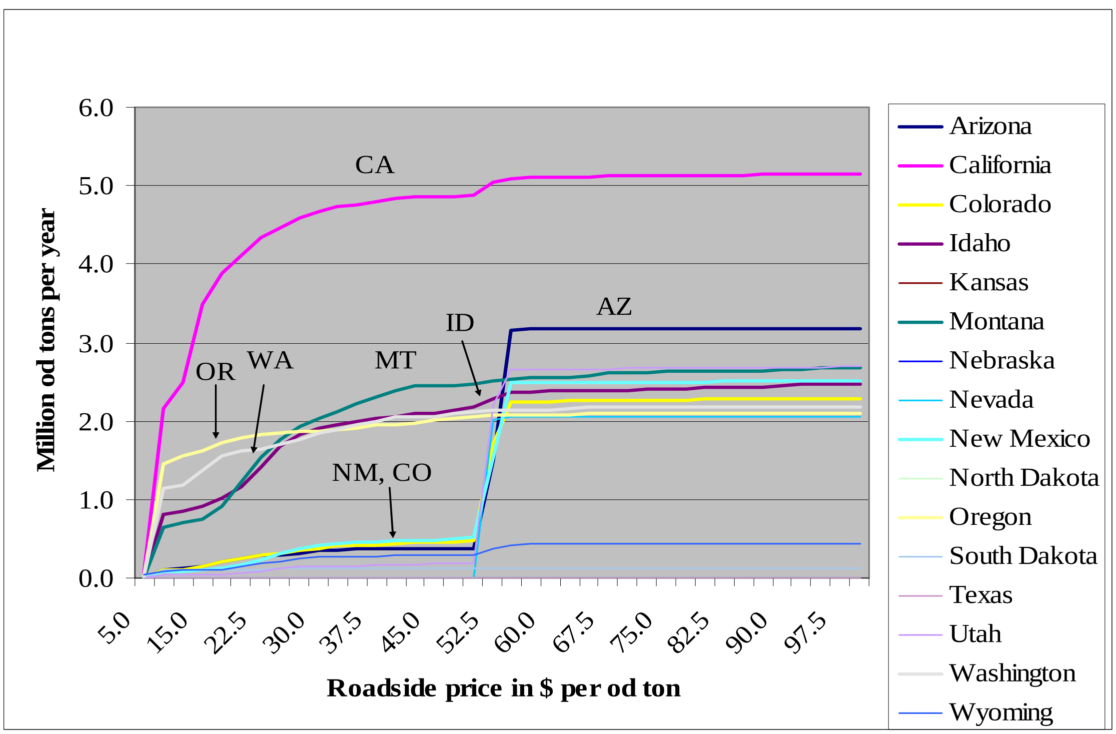

Figure 6 - High Case forest biomass supply by state

5 Dedicated Woody and Herbaceous Crops

Herbaceous and woody crops such as short-rotation poplar and willow and switchgrass and big bluestem have been touted as a means of providing significant quantities of bioenergy feedstock both for electricity and liquid fuels due primarily to their high mass per unit area production. In addition, there appear to be environmental benefits such as enhanced carbon sequestration and water quality benefits associated with crops produced for energy, although these have not been confirmed on a large-scale or over extended periods of time. Because both feedstocks are "agriculturally-based" they must also compete on an economic (opportunity cost) and land availability basis with current pulp and paper, commodity crops, or hay production as well as with the price of the energy resource(s) they would displace.

5.1 Short Rotation Woody Crops (SRWCs) in the WGA Region

SRWCs produced for energy would directly compete with the pulp and paper industry and recent research has shown paper and paperboard production/ consumption will increase approximately 80% within the next 40 years due to increased economic and population growth as well as an expectation that virgin wood fiber demand will also increase[27]. This report also indicated for areas within the WGA region SRWC did not show any significant development between the present and 2025. The literature suggests the total cost of biomass from SRWC in the West would be high due to a number of factors such as land rent and plantation costs as well as harvest and transport costs. In order to impact bioenergy in 2015 these woody plants would already need to be planted because they are not ready for harvest for 7-9 years. The role of short rotation woody crops may be an important part of the feedstock supply of the future in areas where there is adequate short term productivity to justify investments. Therefore, based on these factors, a resource assessment and supply analysis concerning potential quantities of dedicated woody crops for the WGA region was not conducted.

5.2 Herbaceous/Native Grasses in the WGA Region

Data concerning actual large-scale production (hundreds to thousands of acres), environmental benefits of herbaceous/dedicated energy crop production, and economics to the landowner versus production of conventional commodity crop or high-value haying or other operations in the WGA region is not well known with any real degree of certainty at this time. Test plots have been established with different varieties of herbaceous crops, primarily switchgrass, at different geographic locations throughout the United States and mostly at United States Department of Agriculture and university-related agricultural experiment stations, but most of these are small-scale (less than 25 acres) and some considerably less than one (1) acre. Appendix B (SWG) contains detailed data from three relevant sources with respect to possible locations within the WGA region concerning several aspects of switchgrass production[28, 29, 30.]

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[27] Alig, Ralph J., Darius M. Adams, Bruce A. McCarl, Peter J. Ince. 2000. Economic potential for SRWC on agricultural land for pulp fiber production in the United States. Forest Products Journal 50(5): 67-74.

[28] M. R. Schmer, K. P. Vogel, R. B. Mitchell, and R. K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. The National Academy of Sciences of the USA. Vol. 105, No. 2, pp. 464-469.

Plots were established in North and South Dakota, Nebraska, Oklahoma, and Texas and almost all in the eastern one-half of these states where precipitation would be higher. Latitudes ranged from approximately 31 degrees to 48 degrees. In one case, the research plots ranged from approximately 7.5 to 23 acres and herbaceous crop production was managed by the actual landowners over a five year period which reflects a more "real-world" operating cycle. In the other two cases, production areas were 0.0034 to 0.0054 acres and were managed by experiment station personnel over periods of two to four years. In some instances, the plots were either intentionally irrigated or needed irrigation in order to continue the experiment during a year of low rainfall.

These data provide one view of potential herbaceous crop production in the WGA region, but many factors can influence herbaceous crop production such as variety and adaptation, field preparation, soil type, type of planting machinery, fertilizer application rates, and potential need for irrigation. It certainly may be possible to provide higher levels of production through incorporation of a number of measures, e.g., genetic modification, irrigation, etc. both in tonnage as well as energy intensity per unit land area, e.g., MMBtu per acre, which would drastically alter the supply of biomass which in turn will probably have a positive affect on the region's environmental quality. However, at this time, extrapolation of the data presented in these studies to an area as large and climatically and geographically diverse as the WGA region could potentially produce inconsistent results (both greater and less than what might be actual) due to: 1) the limited amount of data, and 2) the small experimental or production areas. In addition, no large-scale computer modeling effort has been performed within the WGA region concerning herbaceous energy crop production across different climate regimes, soils, etc. that could be used to help generate supply curves.

Another factor that could potentially play a role in large-scale production involves acreage competition with conventional commodity crop production. Concerns exist over availability of large-scale amounts of land required to produce and supply feedstock within close proximity to the electric generating or liquid fuel production facilities. As an example of this, for a 50 million gallon per year bioethanol production facility, approximately 200,000 acres (17 square miles) would be required at an average annual yield of three dry tons per acre per year. Current commodity crop yields (bushels per acre) and projections for yields and prices for such as corn, soybeans, grain sorghum, and wheat, and potentially other oilseeds, could mean dedicated/herbaceous energy crops may not be able to readily compete on a net-return basis with these crops and especially on prime farmland unless changes are 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 occurs. Other factors may play a role as well.

One manner of providing estimates of quantities (dry tons per acre) of herbaceous/mixed native grass species that could potentially be produced within the WGA region was obtained from a USDA database which contained native grass species production statistics (dry tons per acre) on individual soil types within each county in the

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[29] K A. Cassida, J. P. Muir, M. A. Hussey, J. C. Read, B. C. Venuto, and W. R. Ocumpaugh. 2005. *Biomass Yield and Stand Characteristics of Switchgrass in South Central U.S. Environments.* Crop Sci. 45:673–681. 677 S. Segoe Rd., Madison, WI 53711 USA.
[30] Bouton, J. 2008. Personal communication. The Samuel Roberts Noble Foundation, Ardmore, OK.

WGA region[31]. These data could possibly serve as a “baseline” or “floor” for future potential energy crop production. The database was populated by NRCS rangeland experts over many years and reflects possible production levels of a large number of herbaceous species, including switchgrass, under “non-managed” conditions, e.g., no fertilizer and/or chemical applications or dedicated field preparation that could potentially increase production.

The WGA region is diverse from a geographic and climatic standpoint with large variations in precipitation, soil type and field topography, and elevation. Consultation with a number of USDA-related personnel with expertise in rangeland grass production revealed that inadequate and inconsistent production could possibly occur at elevations of greater than 4,500 feet; field slopes greater than 15% which relates to proper field preparation, establishment, harvesting, and crop transport to the field edge; and most importantly, in areas where average annual precipitation was less than 20 inches. The precipitation value of 20 inches was deemed the most important factor of the three considered.

Figure 7 provides precipitation data for the United States and details the geographic areas in the WGA region which would not meet the 20 inches per year criteria. Even in some areas within the region that have an average annual precipitation of 20 inches or greater, these areas fall in mountainous areas such as in Wyoming, northern Idaho, and Colorado. The states of South Dakota, Nebraska, Kansas, Oklahoma, Texas, Washington, Oregon, and California were examined in this project. Soil data for Washington state was deemed incomplete and therefore was not used in this analysis.

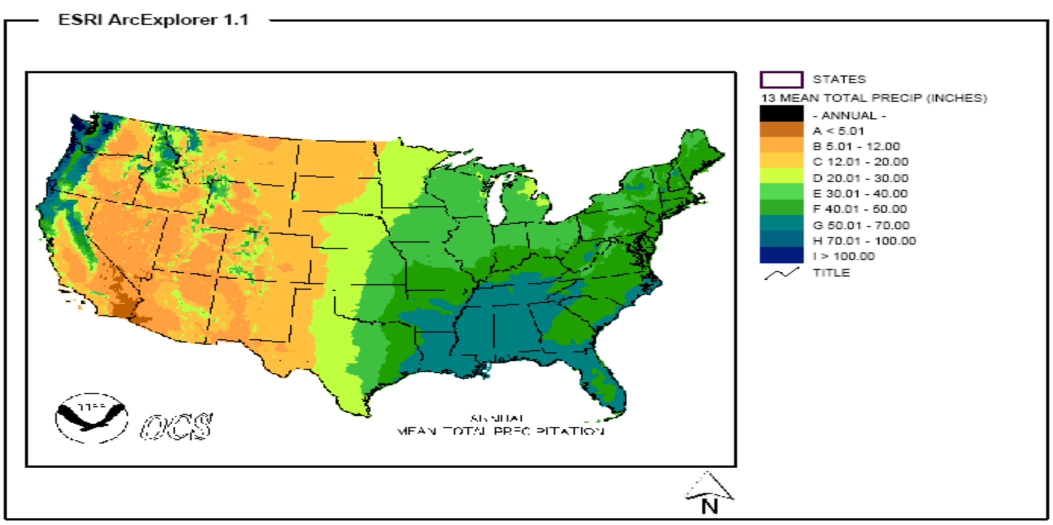

Figure 7 - Average annual precipitation (inches per year)

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31 http://websoilsurvey.nrcs.usda.gov/app/

The database was sorted by the three criteria listed above as well as only examining soil types classified as cropland, rangeland, and grassland designated as land capability class III-VIII. Table 10 provides an example of the type of data used to help estimate potential levels of herbaceous energy crop production in each county of each of the eight WGA states examined. From this individual soil type production data, county-level supply curves were generated using economic and engineering parameters similar to those utilized for corn stover and small-grain baling and harvest.

Table 10 - Example production, field topology, and climatic data from USDA database on native grass species for Allen County, Kansas

Soil Type	acres	% slope	average annual precipitation (in)	elevation (ft)	Production (dry tons)
Osage silty clay, occasionally flooded	3,803	1	40.3	771	3.13
Verdigris silt loam, channeled	14,974	1	39.9	771	3.50
Bates loam, 3 to 7 percent slopes	5,645	6	39.9	1,082	2.38
Bates loam, 3 to 7 percent slopes, eroded	1,118	5	39.9	1,082	2.38
Bates-Collins complex, 3 to 15 percent slopes	94	6	41.9	1,082	2.38
Collins complex, 3 to 15 percent slopes	3	9	40.0	899	1.50

Appendix C (MGP) provides estimates of possible state-level supplies (annual dry tons) derived from the county-level data for native grass species on select soil types throughout the WGA region and under "non-managed" conditions that could possibly reflect a "baseline" condition. Research has been performed that investigated potential yield increases that may occur with application of nitrogen fertilizer in the zones of precipitation applicable to the WGA region and found an average 50% increase in yield may be possible from the application of approximately 67 pounds of nitrogen fertilizer[32]. Given this information, a sensitivity analysis was conducted to investigate the increase/decrease in supply of these grasses that may possibly occur, but also incorporating the cost of nitrogen and an application charge. A nitrogen application charge of $4.20 per acre was used and the cost of nitrogen was set at $453 per ton[33, 34]. The results of this sensitivity case are also presented in appendix MGP. It needs to be noted that although the overall quantity of biomass increased due to the application of nitrogen, there can be ancillary effects associated with the application of large amounts of fertilizer to increase yields. These can include possible promotion of invasive weed species, monocultures in ecological landscapes not typically suited for single-culture grasses, and potential for off-site water quality impacts from runoff as prairie has been subjected to fertilization.

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[32] David. U. Hooper and Loretta Johnson. 1999. *Nitrogen limitation in dryland ecosystems: Responses to geographical and temporal variation in precipitation*. Biogeochemistry46: 247-293.
[33] http://www.nass.usda.gov/Statistics_by_State/Kansas/Publications/Custom_Rates/custom07.pdf
[34] http://www.ers.usda.gov/Data/FertilizerUse/

5.3 Soil Carbon Sequestration with Herbaceous Energy Crop Production

Energy crops such as switchgrass and big bluestem have deep root systems which potentially offer more favorable conditions for sequestering carbon, however the magnitude of sequestration (tons C per acre per year) is dependent upon: 1) net primary production, 2) climatic conditions, 3) soil type and its physical and chemical properties, 4) previous management/use of the land base upon which the energy crops will be produced, and 5) field maintenance practices associated with their use as an alternate energy source.

Several studies indicate the range of variability in magnitude that can exist in sequestering carbon through energy crop production. Liebeg et al examined soil organic carbon (SOC) across the Great Plains on numerous soil types and depths and determined that significant differences exist in SOC rates with depth, with more sequestered at greater depths[35]. Conant et al. reviewed studies of managed grasslands throughout the world and found rates of SOC varied from 0.05 to 1.36 tons ac^{-1} yr^{-1} with an average of 0.24 tons ac^{-1} yr^{-1} and recent publication suggests an annual SOC sequestration rate of 0.49 tons ac^{-1} yr^{-1} [36, 37]. The latter rate was derived from small-scale test plots which have not been duplicated to any real degree on a large-scale.

The Chicago Climate Exchange (CCX) has posted prices ($ per metric ton of carbon) for carbon sequestered for a variety of different land management scenarios including herbaceous energy crop production[38]. In addition, prices for sequestered carbon are offered in futures contracts and these are approximately $4 per metric ton ($3.64 per ton) for 2010 vintage which relates to approximately $3.33 using an inflation rate of 3%. Using the $3.33 target price per ton of carbon sequestered and a sequestration rate of 0.24 tons ac-1 yr-1 yields an annual gross payment of around $0.80 per acre. This presents a conservative estimate of sequestration potential and the price offered for the carbon is low due to no better determination of sequestration rates. For the herbaceous energy crop market to be viable, finer resolutions of those variables that affect sequestration would be required.

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[35] Liebig, M. A., Johnson, H. A., Hanson, J. D., and Frank, A. B. 2005. Soil carbon under switchgrass stands and cultivated cropland. Biomass Bioenergy 28: 347-354.
[36] Conant, R. T., Paustian, K., and Elliott, E. T. 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecol. Appl. 11: 343-355.
[37] Sartori, Fabio, Lal, Rattan, Ebinger, Michael H. and Parrish, David J. (2006) 'Potential Soil Carbon Sequestration and CO2 Offset by Dedicated Energy Crops in the USA', Critical Reviews in Plant Sciences, 25:5, 441 - 472
[38] http://www.chicagoclimatex.com/

6 Orchard and vineyard prunings

Residues (trimmings, dead wood, etc.) are generated from the growth and cultivation of crops produced in the WGA region in orchards and vineyards. Production statistics (acreages and yields) and the average annual quantity of residue by each crop for each crop listed in Table 10 were obtained from the 2002 Census of Agriculture and data from an analysis performed in California by Jenkins et al.[39, 40]. Only quantitative data is presented as supply curves were not generated due to a lack of engineering data concerning residue pick-up and transport to the field edge. There would be a cost associated with the removal and transport of these orchard and vineyard prunings to an end-use facility, but presently this has not been defined. Average annual residue amounts (dry tons per year) on a state-level basis for each orchard and vineyard crop analyzed is presented in Appendix D (O & V P).

Table 11 - Estimated total dry tons per acre per year from orchard and vineyard prunings

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

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

[40] 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)

7 Wastewater treatment plant sludge and biosolids

Biosolids are the nutrient-rich organic portion that results from treatment of sewage in wastewater facilities. After treatment, the biosolids can be recycled and applied as fertilizer to improve and maintain productive soils and stimulate plant growth. Most generated biosolids are land applied and used as fertilizer supplements.

Values (tonnages) for biosolids generation (dry basis) at the county level were available for all states within the WGA region and were estimated 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 conversion rate of 80%[34]. No cost data exist in which to build supply curves as they depend upon transportation, bioenergy conversion facility size, and type of technology. An allowance was made 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. This figure was arrived at in discussions with U.S. EPA and state POTW regulators. Table 12 provides state-level data biosolids totals in 2015.

Table 12 - Projections of total biosolids (tons) for each WGA region state in 2015

Alaska	13,159	New Mexico	22,088
Arizona	124,449	North Dakota	31,324
California	912,000	Oklahoma	287
Colorado	95,366	Oregon	184,571
Hawaii	32,014	South Dakota	12,125
Idaho	32,685	Texas	550,966
Kansas	118,736	Utah	98,742
Montana	33,400	Washington	168,059
Nebraska	7,419	Wyoming	21,346
Nevada	36,600	WGA Region	2,495,336

8 Future Commodity Crop Assessment

Currently, a majority of ethanol in the United States is produced from corn with grain sorghum as another feedstock. Biodiesel produced in this country is derived mainly from soybeans, with the remainder coming from canola, animal fats, and yellow grease. Potential acreages, prices, and production of corn, soybeans, and canola that might potentially occur in all WGA region counties in 2015 were estimated using 2006/2007 crop year planted acres and yield data for corn, soybeans, and canola from USDA's National Agricultural Statistics Service and projections of acreages and yields provided

by the Food and Agricultural Policy Research Institute (FAPRI)[41, 42]. Similar statistics exist from the USDA's Baseline Agricultural analysis[43]. 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.

For each crop, FAPRI and the Baseline Analysis provide annual estimates of potential commodity crop yields and acreages planted for 2007/2008 through 2015/2016. Projected total bushel or pound forecasts for each WGA county in which corn, soybeans, and/or canola were produced were estimated by multiplying the percentage change in yield and planted acres on a national basis for each of the three crops between the 2006/2007 crop year and the average of the 2014/2015 and 2015/2016 crop years. The crop years of 2014/2015 and 2015/2016 were used instead of one single year as decisions concerning 2015 plantings could possibly be made in an earlier year. Yield and acreage projections were 14.5% and 13.6% for corn; -4.2% and 7.9% for soybeans; and 14.9% and 10.6% for canola and these were applied to 2006/2007 crop year statistics. 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.

[41] http://www.nass.usda.gov/
[42] http://www.fapri.iastate.edu/outlook2007/
[43] http://usda.mannlib.cornell.edu/MannUsda/viewStaticPage.do?url=http://usda.mannlib.cornell.edu/usda/ers/94005/./2007/

Appendix A: Agricultural Crop Residues

Supply of Corn Stover at Five Different Price Levels for each WGA State (dry tons)

	$30.00	$35.00	$40.00	$45.00	$50.00
Alaska	0	0	0	0	0
Arizona	0	16,921	95,528	95,528	95,528
California	0	136,097	553,349	562,665	562,665
Colorado	0	0	71,885	95,040	95,040
Hawaii	0	0	0	0	0
Idaho	0	0	1,329	3,675	3,887
Kansas	0	0	0	0	0
Montana	0	0	0	0	0
Nebraska	0	0	0	0	0
Nevada	0	0	0	0	0
New Mexico	0	0	8,525	14,275	14,275
North Dakota	0	0	0	0	0
Oklahoma	0	34,234	34,234	34,234	34,234
Oregon	0	0	2,899	8,458	8,458
South Dakota	0	0	0	0	0
Texas	0	0	0	0	0
Utah	0	0	93	93	93
Washington	0	0	0	6,493	8,228
Wyoming	0	0	0	0	0

Supply of Winter Wheat Straw at Five Different Price Levels for each WGA State (dry tons)

	$30.00	$35.00	$40.00	$45.00	$50.00
Alaska					
Arizona	14,920	19,728	19,728	19,728	19,728
California	3,853	115,907	350,752	368,029	368,096
Colorado	6,392	6,392	22,459	34,118	34,118
Hawaii					
Idaho	783,324	964,661	970,752	1,003,304	1,003,428
Kansas	0	0	0	0	0
Montana	0	2,692	13,182	95,342	105,148
Nebraska	0	0	0	0	0
Nevada	0	0	0	0	0
New Mexico	0	7,976	7,976	9,974	9,974
North Dakota	0	0	0	0	0
Oklahoma	232,706	232,706	232,706	232,706	232,706
Oregon	185,274	241,120	399,520	443,357	453,012
South Dakota	0	0	0	0	0
Texas	0	0	0	0	0
Utah	2,452	5,051	59,222	59,222	59,222
Washington	397,708	1,365,289	1,520,602	1,525,669	1,525,669
Wyoming	0	0	0	287	287

Supply of Spring Wheat Straw at Five Different Price Levels for each WGA State (dry tons)

	$30.00	$35.00	$40.00	$45.00	$50.00
Alaska					
Arizona	0	0	0	0	0
California	0	0	0	0	0
Colorado	0	3,702	4,275	4,275	4,275
Hawaii					
Idaho	0	246,063	336,605	352,787	352,787
Kansas	0	0	0	0	0
Montana	0	0	7,468	8,381	8,460
Nebraska	0	0	0	0	0
Nevada	0	0	0	0	0
New Mexico	0	0	0	0	0
North Dakota	0	0	0	0	0
Oklahoma	0	0	0	0	0
Oregon	0	6,099	18,534	20,355	20,355
South Dakota	0	0	0	0	0
Texas	0	0	0	0	0
Utah	0	0	703	3,568	3,568
Washington	0	0	70,641	143,346	189,890
Wyoming	0	0	0	0	0

Supply of Barley, Oat, and Rye Straw for each WGA State (dry tons)

Barley

	$30.00	$35.00	$40.00	$45.00	$50.00
Colorado	76,609	197,957	210,992	219,736	219,823
Idaho	0	878,628	1,280,994	1,331,533	1,334,041
Montana	0	0	14,676	37,520	50,198
North Dakota	0	827,536	1,490,767	1,652,599	1,688,360
South Dakota	2,306	38,528	53,832	59,285	61,265
Utah	0	35,791	77,992	87,774	87,776
Washington	0	231,369	400,859	560,564	592,785
Wyoming	0	107,805	153,499	160,754	161,230

Oats

	$30.00	$35.00	$40.00	$45.00	$50.00
Colorado	0	0	319	1,211	1,733
Idaho	0	0	4,701	11,654	13,774
Montana	0	0	329	1,385	1,945
Nebraska	0	7,726	19,165	25,398	28.909
North Dakota	0	0	107	2,698	8,491
Oklahoma	249	249	249	249	249
South Dakota	0	19,101	85,777	149,602	166,418
Texas	0	709	3,881	8,069	14,757
Utah	0	4	1,309	2,694	3,140

Rye

	$30.00	$35.00	$40.00	$45.00	$50.00
North Dakota	0	0	0	0	0
Oklahoma	237	237	237	237	237
South Dakota	0	0	0	226	327

Appendix B (SWG):

Data from Schmer et al.

Location	tons/acre			Mean	acres
	harvest year				
	3	4	5		
Lawrence, NE	2.31	3.16	2.76	2.76	18.28
Douglas, NE	1.74	3.92	3.34	2.98	23.47
Atkinson, NE	2.18	2.45	0.00	2.31	7.41
Crofton, NE	2.14	3.20	2.80	2.71	20.01
Ethan, SD	3.56	3.07	2.71	3.12	15.07
Huron, SD	2.94	4.67	2.45	3.34	15.07
Highmore, SD	3.74	3.69	1.65	3.03	15.07
Bristol, SD	4.41	5.07	5.38	4.94	15.07
Streeter, ND	2.23	3.69	2.71	2.89	20.01
Munich, ND	3.65	3.74	3.07	3.47	15.07
Mean				3.16	

Data from Cassida et al.

Variety	College Station TX	Stephenville Texas	Dallas Texas
Alamo	8.78	4.84	8.67
SL931	9.52	5.02	8.47
SL932	8.46	6.07	8.33
SL941	7.70	5.67	7.69
NL931	6.31	4.75	7.87
NL942	7.19	5.42	8.37
Caddo	2.41	2.23	2.69
NU942	2.59	3.15	3.52
SU941	2.93	2.59	4.13
average tons/acre	6.21	4.42	6.64
plot size (acres)	0.0045	0.0045	0.0054

Data from Bouton

	Ardmore, OK	Stillwater, OK	Overton, TX
County	Payne	Carter	Rusk
plot area/acres	150 sq ft/.0034	150 sq ft/.0034	150 sq ft/.0034
yrs production	2	2	2
varieties	NFSG05-1	NFSG05-1	NFSG05-1
	NFGA-991	NFGA-991	NFGA-991
	NFGA-992	NFGA-992	NFGA-992
	NFGA-993	NFGA-993	NFGA-993
	NFGA-001	NFGA-001	NFGA-001
	SHAWNEE	SHAWNEE	SHAWNEE
	TRAILBLAZER	TRAILBLAZER	TRAILBLAZER
	NSL 2001-1	NSL 2001-1	NSL 2001-1
	SL93 2001-1	SL93 2001-1	SL93 2001-1
	ALAMO	ALAMO	ALAMO
	KANLOW	KANLOW	KANLOW
	CIR	CIR	CIR
ave yld of Alamo (lbs/ac)			
2006	3,174	3,419	1,107
tons/acre extrapolated	1.59	1.71	0.55
2007	15,545	13,284	6,543
tons/acre extrapolated	7.77	6.64	3.27
irrigated	yes	yes	no
fertilizer	N-75, P-46	N-75	400lbs 13-13-13

Appendix C: MGP

Estimated Supply Curves (dry tons) for Native Grass Species in the WGA Region Based on Soil Type Characteristics, Annual Precipitation, Field Topology, and Elevation (no N application)

	$10.00	$20.00	$30.00	$40.00	$50.00	$60.00	$70.00
North Dakota	0	0	5,793	20,011	20,608	20,608	20,608
South Dakota	0	2,071	103,224	201,236	224,753	229,177	231,472
Nebraska	0	796	1,664,488	4,973,956	5,977,629	5,987,291	5,997,665
Kansas	0	294,124	6,527,817	12,662,734	13,972,989	14,006,186	14,012,453
Oklahoma	0	107,630	2,210,595	2,876,251	3,783,402	4,004,190	4,073,062
Texas	0	111,746	13,278,807	20,643,588	24,529,912	24,817,909	25,146,188
California	0	0	254	6,591	39,786	39,814	40,032

Estimated Supply Curves (dry tons) for Native Grass Species in the WGA Region Based on Soil Type Characteristics, Annual Precipitation, Field Topology, and Elevation (50% in Yield with 67 pounds nitrogen applied)

	$10.00	$20.00	$30.00	$40.00	$50.00	$60.00	$70.00
North Dakota	0	0	5,462	22,772	22,772	23,624	23,624
South Dakota	0	0	150,248	301,921	335,657	343,766	346,191
Nebraska	0	0	2,409,011	7,460,934	8,962,725	8,980,937	8,982,174
Kansas	0	2,537,211	18,994,100	20,959,484	21,018,680	21,018,680	21,018,680
Oklahoma	0	0	2,702,154	4,314,377	5,148,179	6,006,285	6,066,702
Texas	0	0	18,925,547	30,965,382	35,029,633	37,226,864	37,623,896
California	0	0	381	9,886	50,680	59,721	60,032

Appendix D: Orchard and Vineyard Prunings (O&V P)

Average Annual Generation of Orchard and Vineyard Prunings (Dry Tons)

	AZ	CA	CO	ID	KS	MT	NM	OR	UT	WA
Apples	176	22,700	2,658	4,061	273	435	2,385	8,747	2,191	216,017
Dates	340	3,300	0	0	0	0	0	0	0	0
Grapefruit	1,004	incl. in Oranges	0	0	0	0	0	0	0	0
Grapes	1,503	1,416,900	562	844	55	25	226	14,182	21	73,269
Hazelnuts	0	no data	0	0	0	0	0	20,413	0	80
Lemons	0	incl. in Oranges	0	0	0	0	0	0	0	0
Nectarines	0	incl. in Oranges	0	0	0	0	0	0	0	0
Oranges	10,953	183,700	0	0	0	0	0	0	0	0
Peaches	105	124,000	2,304	928	36	1	153	932	1,646	3,596
Pears	39	15,300	380	239	5	4	85	47,342	109	70,078
Pecans	5,742	2,300	0	0	3,009	0	31,963	0	148	0
Pistachios	1,285	117,800	0	0	0	0	380	0	0	0
Plums and Prunes	8	91,000	21	480	1	5	21	1,853	4	683
Sweet Cherries	0	18,400	0	0	0	0	0	0	0	0
Tangelos	4,388	incl. in Oranges	0	0	0	0	0	0	0	0
Tangerines	1,022	incl. in Oranges	0	0	0	0	0	0	0	0
Walnuts	0	170,100	0	0	0	0	0	1,095	1	29