On-farm conversion of straw to bioenergy – A value added solution to grass seed residue

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Abstract

Analysis of the geospatial distribution of straw from grass seed and cereal crops across the PNW indicates that optimally-sited bioenergy conversion plants of 1 million kg y^{-1} capacity should be able to obtain needed straw from within a radius of a very few km, opening up the possibility of using farm-scale equipment such as forage choppers, wagons, silage blowers, and bunkers to handle the straw from field to syn-gas generator. The economic advantages of not needing to bale and truck the straw long distances will at least partially offset efficiencies of scale likely present in larger plants operating at many times the capacity of farm-scale units.

Perhaps the most contentious aspect of intensive grass seed production systems has been the management of post-harvest residues. Conflicts over possible adverse effects of smoke from field burning on human health and economic impacts of regulating burning on the grass seed industry have raged in courtrooms, legislatures, elections, and the mass media for decades. Because use of burning to dispose of grass seed and cereal straw throughout the Pacific Northwest (PNW) is now banned or restricted in most areas, agricultural producers have actively sought cost-effective alternatives. In higher rainfall regimes such as Oregon’s Willamette Valley, thorough chopping of the full straw load in the dry, late summer facilitates its decompostion in the wet fall and winter while remaining compatible with high yields of quality seed. Growers using this method view retention of nutrients and building of soil OM as adequate trade-offs for the nuisance of chopping straw and increased problems with slugs and weeds. Other growers bale their residues for domestic use and overseas export as livestock feed, often receiving little more than the cost of baling. In collaboration with partners including the electrical power industry, researchers at the National Forage Seed Production Research Center have built a pilot plant in Spokane for conversion of straw to syn-gas, which can then generate electricity fed back into the regional power grid. The nominal size of the plant is 1 million kg y^{-1}, comparable to straw produced on medium-sized PNW grass seed or cereal farms. Testing of the syn-gas generator is focusing on the impact of operating conditions on CO and H_2 content of the syn-gas and on impurities in it that could damage the diesel engine powering the electrical generator.

Knowledge of the geospatial distribution of straw from grass seed and cereal production in the PNW is vital to the accuracy and reliability of feasibility studies comparing scales of operation of proposed bioenergy conversion plants. Because existing data on straw availability were limited to county-wide summaries, our first step in identifying optimum locations for straw-based bioenergy conversion plants was to map the location of all grass seed and cereal production in the PNW using remote sensing methods. For satellite imagery necessary for remote sensing classification, we used MODIS 16-day composite NDVI, 250 m by 250 m pixels, covering the periods from April 23 through August 29 in 2005, 2006, and 2007. Crop areas and yields per ha within counties were obtained from yearly USDA-NASS summary statistics for winter, spring, and durum wheat, barley, and oats. Areas and yields per ha for grass seed crops were primarily obtained from OSU Extension Service estimates within Oregon and USDA-NASS summaries in Idaho and Washington. Ground-truth data for the remote sensing classifications of cereals were derived from USDA-NASS National Crop Land Data layers (NLCD) covering southern Idaho in 2005, Washington in 2006, and the entire PNW in 2007. Ground-truth data for grass seed crops were a mixture of our in-house, western Oregon GIS and the NLCD. Maps of crop locations were converted into straw yields by use of county-wide average crop yields and harvest indices, and then subtracting crop-specific estimates of residue requirements to protect soils from erosion. Larger quantities of straw were “left behind in the field” for annual crops such as winter wheat or Italian ryegrass than for perennial grasses whose crowns and roots help protect the undisturbed soil from erosion.

Our estimates of total available cereal and grass seed straw in the PNW were 7.01, 6.27, and 5.63 million metric tons in 2005, 2006, and 2007. We used the individual year estimates and multi-year averages of available straw in procedures that identified the optimal locations for each new bioenergy plant, based on local density of straw and location of all previously sited plants. Each new plant was sited at the position of the maximum straw density over a neighborhood adequate to supply all the straw needed for plants with capacities of 1, 10, and 100 million kg y^{-1}. Straw assigned to each new plant was then removed from the raster and the location of the maximum density of remaining straw recalculated.

Approximately 6,200 farm-scale plants (1 million kg straw y^{-1} capacity) distributed across landscape would be required to convert all the available straw in the PNW into bioenergy. Approximately 620 medium-sized plants (10 times greater capacity than the farm-scale units) would be needed to process all the available straw (Fig. 1). The first 10 million kg y^{-1} plant built could obtain all its straw from within a distance of only 2 km, while the 124th plant (20% of 620) would only need a range of 4 km to meet its needs. Relative to the average distance required to supply straw to the first 10% of plants, a range of twice that distance was sufficient for 70% of the smallest sized plants, and 60% of the medium- and largest-sized ones. The final 10-20% of straw is extremely hard to justify going after for all plant sizes. Locations of the most easily supplied plants clearly show the regions across the PNW where a straw-based bioenergy industry is likely to initially develop. Maps of the 6,200 smallest-sized plants tend to show a more egalitarian distribution of optimal locations across all production areas in the PNW. In contrast, the strongest regional differences in how far straw would have to be transported occurred for the largest-sized plants. Distribution of the 62 largest (100 million kg y^{-1}) capacity plants (Fig. 2) differed somewhat from that of the medium capacity plants (Fig. 1), with the best 20% of sites for the largest plants all occurring in the Willamette Valley, except for a single one in the eastern Snake River Valley of southern Idaho. The next best locations (stars) occur over a broader set of regions, including the Palouse Hills and the Columbia Basin in eastern Washington.

One obvious concern with the methods we used to identify optimal plant locations is that they are based on a single estimate of production. Because the specific crops grown within individual fields often change from year to year, a logical question is what impact this yearly variation has on the efficiency of plant siting. In other words, if plant locations are optimized for crop (and straw) distribution patterns of one year (e.g., 2005), how well would those locations function as centralized collection points for another year (e.g., 2006)? Since the bioenergy conversion plants are unlikely to be mobile, a relatively simple way to evaluate the impact of yearly variation in cropping patterns was to measure how much straw was available around plants whose locations and collection distances were optimized for one year when a second year's straw distribution was assumed. Practical limitations in programming methods used to optimize plant locations caused some variability to exist in amount of straw present within the defined ranges around each plant even when the same year was used to define locations (and collection ranges) and measure straw availability. Using the CV of the straw availability at each plant for the "same year" analysis as the standard, a ratio of the CVs can be calculated showing how much less stable the straw supply would be in some other year compared to the one used to locate the plants. The worst combination we found was when medium-sized plants were located based on 2007 straw distribution and tested using 2005 straw distribution, with a CV ratio of 11.6-fold (Table 2). The smallest CV ratios occurred when the 3-year average straw distribution was used to define plant locations, with ratios for 2005, 2006, and 2007 ranging from 1.7 to 2.2 X for the smallest plants, 2.6 to 3.9 X for the medium sized plants, and 1.5 to 2.2 X for the largest plants. The individual CVs generally followed a pattern of slowly decreasing with increasing plant size, with mean CVs for all combinations of years-defining and year-testing straw availability averaging 50.0, 32.3, and 27.1% for the smallest-, medium-, and largest-sized plants.

In a "young" straw as bioenergy industry, yearly variation in cropping practices and straw yields around individual plants will merely generate small changes in the distance required to supply sufficient straw for plants. In a "mature" bioenergy industry, the yearly variations will likely also impact how close to full capacity the plants can operate and the prices paid for straw. The largest scale straw-to-bioenergy plants currently under development in the Willamette Valley are designed to utilize 150 million kg y^{-1}. Even a plant that large would only need 2.3% of the total available straw in the PNW. As a consequence, there is ample opportunity for market forces to determine how much straw will continue to be exported as livestock feed, how much will be converted into electricity and other energy products, and what mix of small-scale, on-farm and large-scale, industrial park bioenergy projects will operate to convert the straw into bioenergy.

Table 1. Average distances required to provide sufficient straw to supply bioenergy conversion plants for each 10 percentile increment in total straw assigned using 3-year average density.

	Incremental Percentiles of Total Available Straw Assigned to Optimal Plant Site Locations									
State	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10^6 kg y^{-1} capacity	Average Range Required for Adequate Straw to Meet Plant Capacity (km)									
Idaho	1.2	1.5	1.7	1.8	2.0	2.1	2.3	2.9	4.9	31.2
Oregon	0.9	1.2	1.4	1.5	1.7	1.9	2.1	2.4	3.4	19.2
Washington	1.5	1.7	1.8	2.0	2.1	2.4	2.8	4.0	5.9	16.6
entire PNW	1.2	1.4	1.6	1.8	1.9	2.1	2.4	3.0	4.6	23.0
10^7 kg y^{-1} capacity										
Idaho	3.7	4.3	4.8	5.5	6.1	6.9	8.2	11.5	17.6	88.9
Oregon	2.3	2.7	3.1	3.5	4.0	4.9	5.8	7.4	11.1	39.6
Washington	4.6	5.1	5.5	6.0	6.9	8.2	9.9	12.3	18.0	66.5
entire PNW	3.5	4.0	4.4	4.9	5.5	6.6	7.7	10.2	15.4	64.9
10^8 kg y^{-1} capacity										
Idaho	14.0	16.4	17.5	18.1	25.3	27.5	29.0	46.3	98.2	276.5
Oregon	7.9	9.2	10.7	11.7	13.2	14.8	21.8	28.4	47.0	186.4
Washington	14.8	16.2	19.6	20.9	24.7	26.4	32.2	39.5	44.7	296.2
entire PNW	11.7	14.3	15.2	16.2	21.1	23.6	26.0	39.2	68.3	243.5

Table 2. Straw availability at plant site locations optimized for straw source year and nominal plant capacity and evaluated against 2005, 2006, 2007, and 3-year average straw density rasters.
† Same data source used in defining plant site location series and measuring straw availability.

Data source used to define plant site location series		Data source used in measuring straw availability	Straw availability at defined plant site locations			
Year	Nominal plant capacity		Mean	Standard deviation	CV	Ratio of standard deviation to site location data source
	(10^6 kg y^{-1})	(Raster year)	(10^6 kg y^{-1})		(%)	
2005†	1	2005†	1.13	0.29	26.13	1.00
2005	1	2006	1.01	0.77	76.94	2.63
2006	1	2005	1.26	0.87	69.33	3.04
2006†	1	2006†	1.13	0.29	25.51	1.00
2007	1	2005	1.38	1.60	115.87	5.65
2007	1	2006	1.23	1.17	94.55	4.12
2007†	1	2007†	1.11	0.28	25.53	1.00
2007	1	3-y avg.†	1.24	0.88	71.12	3.12
3-y avg.	1	2005	1.21	0.54	44.66	2.09
3-y avg.	1	2006	1.08	0.44	40.61	1.70
3-y avg.	1	2007	0.97	0.58	59.67	2.24
3-y avg.†	1	3-y avg.†	1.09	0.26	23.77	1.00
Mean	1		1.16	0.59	50.00	2.11
2005†	10	2005†	10.81	2.64	24.41	1.00
2005	10	2006	9.60	4.45	46.34	1.69
2006	10	2005	10.97	4.58	41.80	2.71
2006†	10	2006†	9.82	1.69	17.22	1.00
2007	10	2005	11.75	9.03	76.85	11.61
2007	10	2006	10.51	6.37	60.56	8.19
2007†	10	2007†	9.45	0.78	8.23	1.00
2007	10	3-y avg.	10.57	4.96	46.97	6.39
3-y avg.	10	2005	10.60	3.18	29.97	3.64
3-y avg.	10	2006	9.49	2.30	24.20	2.63
3-y avg.	10	2007	8.52	3.44	40.33	3.94
3-y avg.†	10	3-y avg.†	9.54	0.87	9.14	1.00
Mean	10		10.09	3.33	32.31	3.04
2005†	100	2005†	117.75	30.53	25.93	1.00
2005	100	2006	104.63	34.02	32.51	1.11
2006	100	2005	126.67	48.30	38.13	1.53
2006†	100	2006†	113.29	31.65	27.94	1.00
2007	100	2005	122.90	55.86	45.45	5.78
2007	100	2006	109.96	36.74	33.41	3.80
2007†	100	2007†	98.81	9.66	9.78	1.00
2007	100	3-y avg.	110.55	31.03	28.07	3.21
3-y avg.	100	2005	108.91	23.19	21.30	2.23
3-y avg.	100	2006	97.59	16.01	16.41	1.54
3-y avg.	100	2007	87.65	22.50	25.67	2.17
3-y avg.†	100	3-y avg.†	98.04	10.38	10.59	1.00
Mean	100		110.33	30.48	27.08	1.81

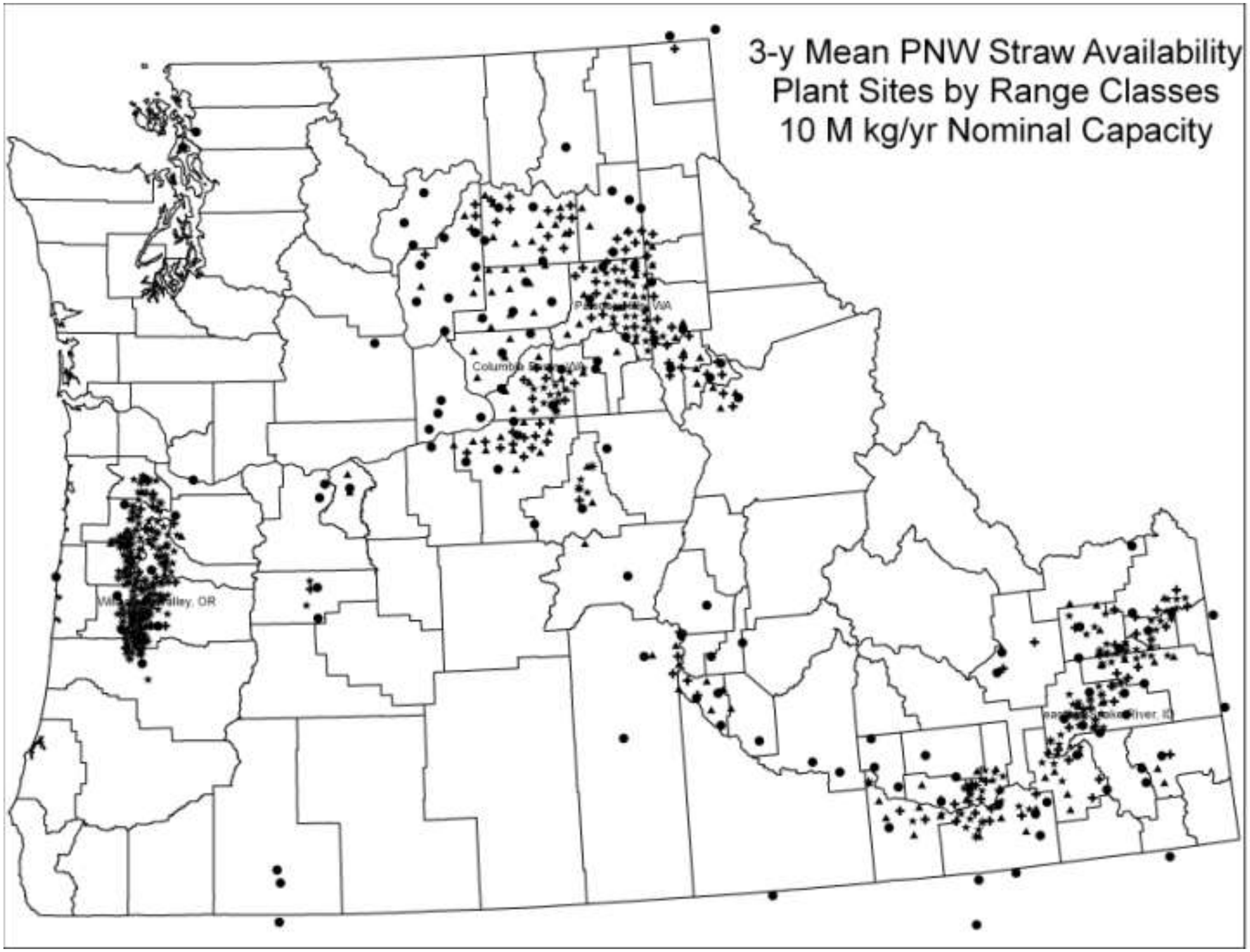

Figure 1. Optimized locations for 10 million kg y^{-1} capacity bioenergy plants based on 3-yr average straw availability. Symbols indicate quantiles of range required to supply straw, with asterisks, stars, crosses, triangles, and circles denoting 2 to 4, 4 to 6, 6 to 7, 7 to 12, and 12 to 600 km miles. County boundaries are outlined.

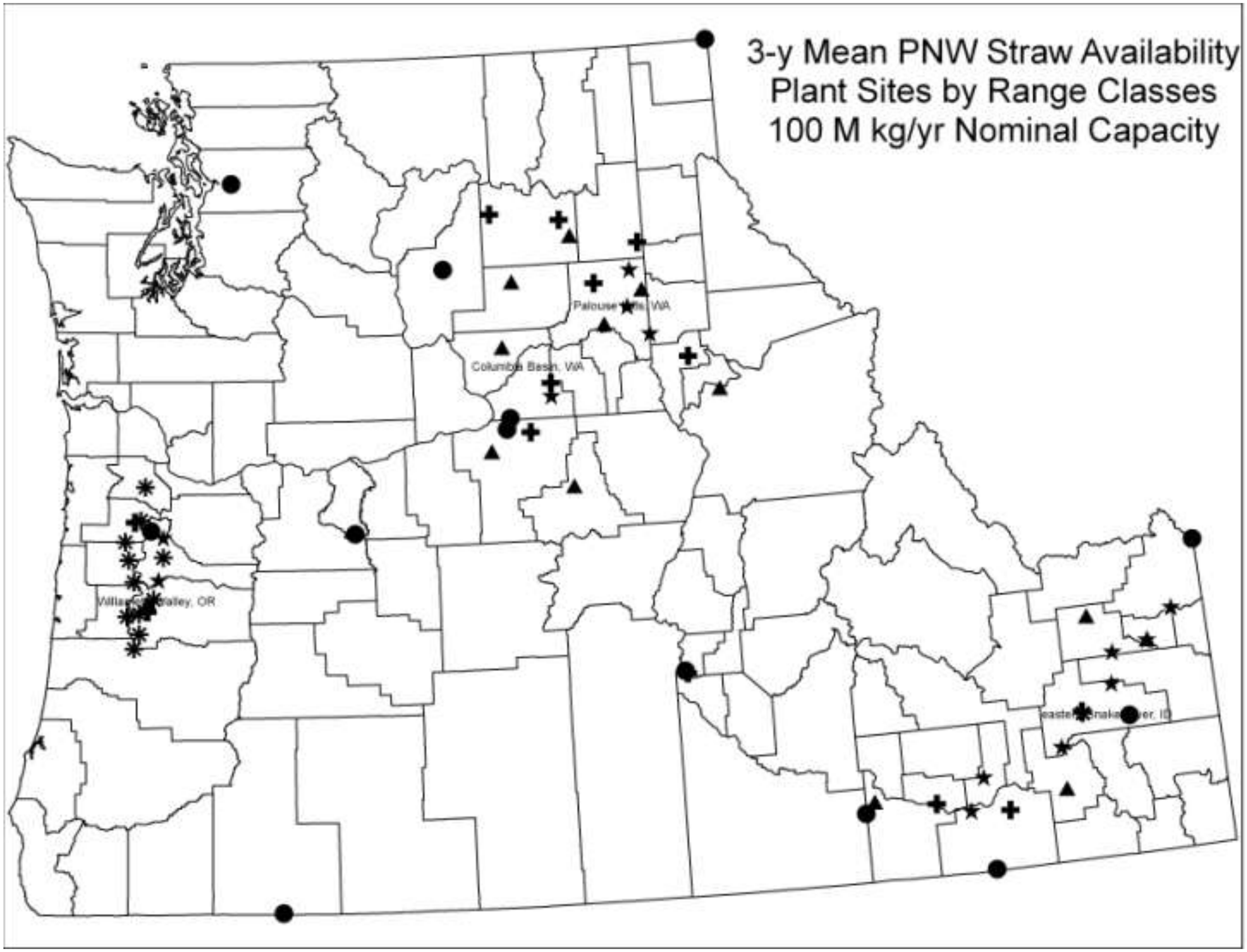

Figure 2. Optimized locations for 100 million kg y^{-1} capacity bioenergy plants based on 3-yr average straw availability. Symbols indicate quantiles of range required to supply straw, with asterisks, stars, crosses, triangles, and circles denoting 8 to 15, 15 to 19, 19 to 28, 28 to 46, and 46 to 488 km. County boundaries are outlined.