A Strategic Assessment of Biofuels Development in the Western States

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Abstract: *The Western Governors' Association assessment of biofuels potential in western states estimated the location and capacity of biofuels plants that could potentially be built for selected gasoline prices in 2015 using a mixed integer programming model. The model included information on forest biomass supply curves by county (developed using Forest Service FIA data), agricultural biomass supply curves, transportation networks, and capital and operating costs of selected conversion technologies. Results indicate biofuels could potentially provide between 5 and 10 percent of projected transportation fuel demand in the region with fuel price between $2.40 and $3.00 per gasoline gallon equivalence (gge) excluding local distribution costs and taxes. At a target price of $2.40/gge, forest biomass could supply an estimated 11 million oven dry tons per year, or about 9 percent of total feedstock supplied.*

Keywords: biofuels, agriculture residues, wood residues, thinnings, grease, herbaceous energy crops, biomass supply estimates, network analysis

Introduction

The technical feasibility of producing biofuels in the western United States is assessed in a set of reports by the Western Governors' Association (2008a–d) using spatially explicit biomass resource supply curves, a detailed transportation network model for the region, and costs for converting biomass to refined biofuels. The study addresses the widespread concern over environmental, geopolitical, and economic effects of U.S. dependence on petroleum. The study is responding to state and federal legislative bodies who are setting goals for reducing consumption of fossil fuels in the transportation sector using targets for the infusion of so-called low-carbon biofuels into the transportation fuel market. The use of biomass from municipal waste streams, forest thinnings, and herbaceous agricultural residues or energy crops for biofuels production can significantly reduce the net life cycle emissions of greenhouse gases in comparison with crude oil; the benefits from grain and other crops are less certain. This report and the accompanying models represent a significant step forward in

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understanding the potential for meeting policy goals based on near-term technological and infrastructure parameters. The report presents biofuel supply curves estimating potential future supplies of liquid fuels from biomass in the western United States as a function of market price. The combined GIS network analysis and biorefinery optimization model was developed to

- spatially resolve biomass resource quantities and distributions throughout the Western Governors' Association region for major feedstock types,
- map supporting transportation and biofuel-handling infrastructure to estimate biorefinery gate feedstock costs and biofuel distribution costs, and
- optimize biorefinery types, sizes, and locations for competing conversion technologies based on the objective of maximizing producer profit under a market price constraint.

Overall, the analysis estimates biofuel supply curves for the year 2015, and biofuels production capacity is estimated at the regional and state levels.

This paper focuses on describing the methods used to estimate forest biomass supply curves and describing selected overall results of the analysis, including information on all forest and agricultural supply sources and maps indicating the estimated location of biofuels plants using cellulosic feedstocks that would include forest biomass feedstocks. Complete results on biomass supply sources, conversion technologies, spatial analysis with construction of biofuels supply curves, and evaluation of alternative scenarios may be found in Western Governors' Association reports (2008a–d).

Methods and Results for Forest Biomass Supply

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 (Helms 1998). 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. Although less restricted, treatments on private lands are also constrained through various environmental laws and regulations (Ellefson et al. 1997). 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 that is otherwise impractical to remove. The reduced amount is the net biomass available for removal. For example, a previous study (USFS 2003) 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 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 (Smith et al. 2003). Growing stock growth does not include growth in tops and branches or in nongrowing 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 nongrowing stock trees.

Biomass Sources

In general terms the forest biomass sources include the following:

- 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 Oregon and Washington
- Unused mill residue

Our analysis includes supply of biomass from federal lands. But this supply from federal land may not be a viable, because the Energy Independence and Security Act of 2007 would not allow biofuels made using biomass from most federal lands to count toward the biofuels RFS (renewable fuels standard). 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." The RFS requires that 21 billion gallons of "advanced biofuels" need to be supplied by 2022 and only certain biomass sources may be used in meeting 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 1. Base Case by state and roadside cost are shown in Table 2 and in Figure 1.

Thinning on 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 (Miles 2005, Skog et al. 2006) and Forest Service FIA plot data (USFS 2008a). 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 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. 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.

For federal lands, it is assumed that even-aged and uneven-aged treatments are used equally, but for non-federal land, it is assumed only uneven-aged treatments

Table 1: Potential annual wood biomass supply from selected western states (million oven-dry tons).

	Source	Base Case	High Case	WGA CDEAC[a]	BTSR[a]
A	Fire hazard thinning on timberland	5.2	7.5	7.2	
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	25.6

[a] BTSR, Perlack et al. (2005); WGA CDEAC, WGA (2006).

Table 2: Base Case cumulative forest biomass supply by state and roadside cost

	Biomass supply (oven dry tons/year) at various roadside costs (in $/oven dry ton)						
State	**$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

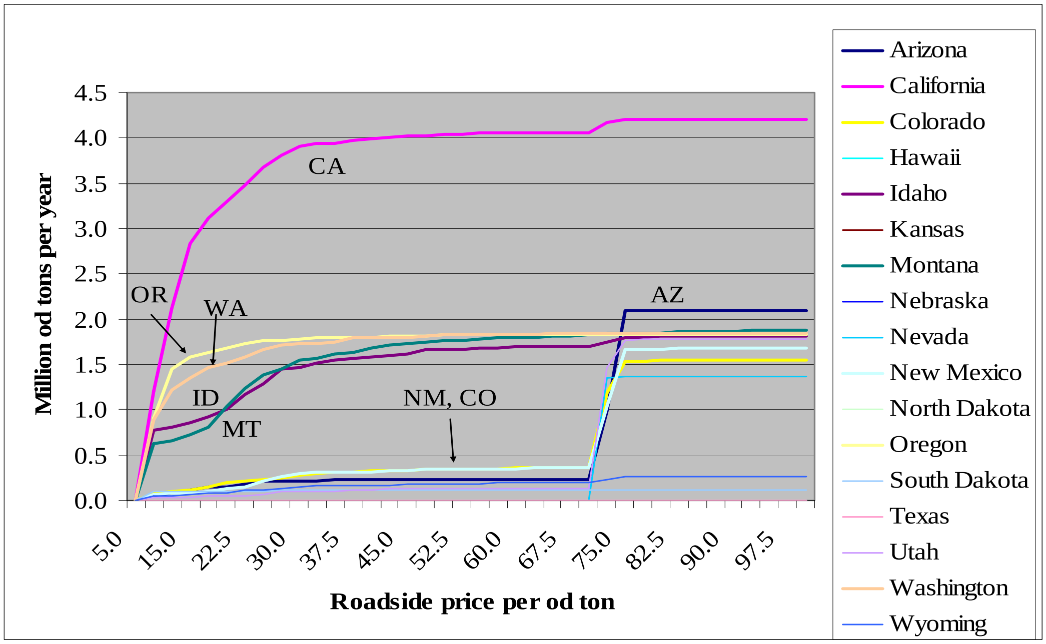

Figure 1: Base Case forest biomass supply by state.

are used. For this source and sources C, D, and E in Table 1, 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 so fire 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 (Perlack et al. 2005) 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 7 inches diameter at breast height (dbh) are supplied for biofuels, and for the High Case, trees removed up to 9 inches are also supplied for biofuels. Main stems 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 (Biesecker and Fight 2006) 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 these data, wood biomass supply curves were estimated for each county in 12 Western states—Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming.

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 because only a Base Case exists for this source. Data on logging residue and land clearing are from the Forest Service 2002 RPA Timber Product Output data base (USFS 2008b). 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.

Treatment of Pinyon-Juniper Woodland

Pinyon-juniper is a category of woodland forest that produces less than 20 ft^3 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 thought to be due in part to 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 1 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.

General Thinning on Private Land

It is presumed that as demand and prices for biomass for fuels increase, 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 uneven-aged 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%). Because 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.

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 9 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.

Precommercial Thinning on National Forest Land in Western Counties in Oregon and Washington

We did not simulate fire hazard reduction thinnings on National Forest 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 9 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.

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.

Additional Results and Discussion

The WGA Biofuels Assessment reports used the forest biomass supply curves, supply curves for additional lignocellulosic biomass sources, supply curves for grease and tallow, information on transportation networks, and costs for conversion technologies in a mixed integer programming model to identify the location for biofuels plants given different offered prices for biofuels at fuel terminals.

Additional sources of lignocellulosic feedstocks include corn stover, straw, herbaceous energy crops (e.g., switchgrass), orchard and vineyard waste, and several types of municipal solid waste. Supply curves for lignocellulosic biomass sources are shown in Figure 2. Table 3 shows amounts of all feedstocks supplied when the offered price for biofuels is $2.40/gge at terminals. The types of biofuels produced include ethanol and biodiesel. At $2.40/gge, forest biomass contributes 11.4 million odt of feedstock per year, or about 9% out of a total supply of 130 million odt.

At $2.40/gge, the 130 million odt of feedstocks would produce 7.6 billion gge/year (Figure 3). If each ton of feedstock produces about the same amount of biofuel, then forest biomass would produce 0.6 to 0.7 billion gge of biofuels. The conversion efficiency varies by feedstock, so this is a rough estimate.

The locations of the biofuels plants using lignocellulosic feedstocks are shown in Figure 4. Biomass supply curves in Figure 1 indicate that forest biomass would be supplying plants that are located in California, Oregon, Washington, Idaho, and Montana.

The modeling framework developed for this assessment constitutes a comprehensive framework for spatially explicit integrated analysis of the entire biofuel supply chain. As with any model, its foremost limitation is in the quality of the input data. The results of this modeling effort indicate that there is significant potential to expand biofuels production in the West. Exclusive of resource competition from other energy and product markets, there is the potential

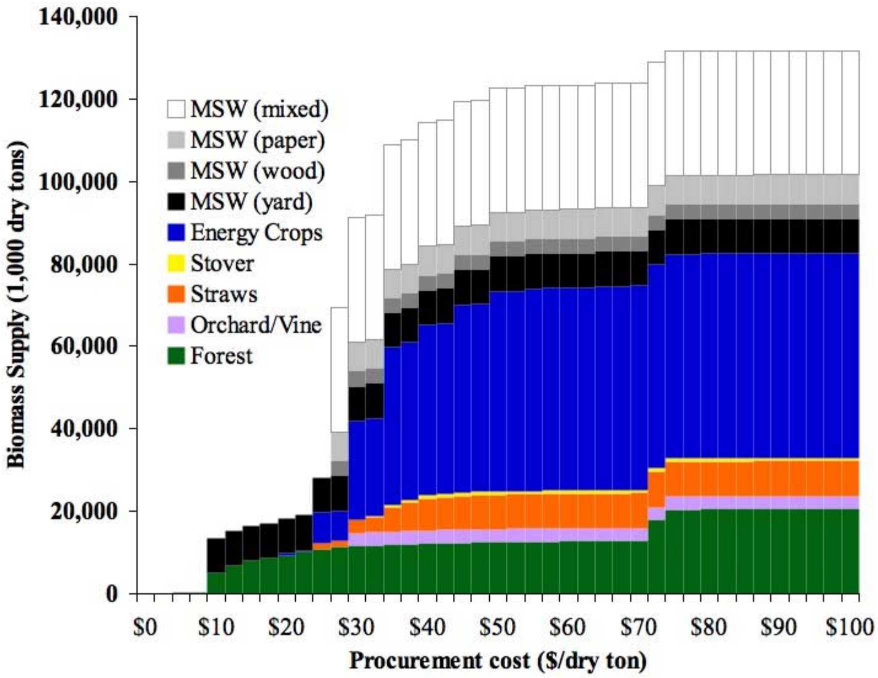

Figure 2. Lignocellulosic biomass feedstock supply by roadside or farm gate cost.

Table 3: Feedstock consumed (million odt) at a biofuels target price of $2.40/gge

Feedstock	**Feedstock consumption**	**Percentage of total**
Corn	43.9	33.8
Herbaceous energy crops	43.1	33.2
Municipal solid waste	19	14.6
Forest biomass	11.2	8.6
Straw (wheat, barley, rye, oats)	7.9	6.1
Orchard and vineyard waste	2.9	2.2
Tallow	0.9	0.7
Corn stover	0.8	0.6
Waste grease	0.2	0.2
Total	130	

for the West to supply substantial fractions of renewable fuels under the new federal Renewable Fuel Standard. The WGA Assessment report suggests several key conclusions concerning land use, and transportation infrastructure that will affect biofuels potential:

- Land use policies will have a significant impact on the availability of feedstock.
- Land use policies will affect expansion of herbaceous energy crop production on marginal lands that will be influenced by sustainability standards or research findings.

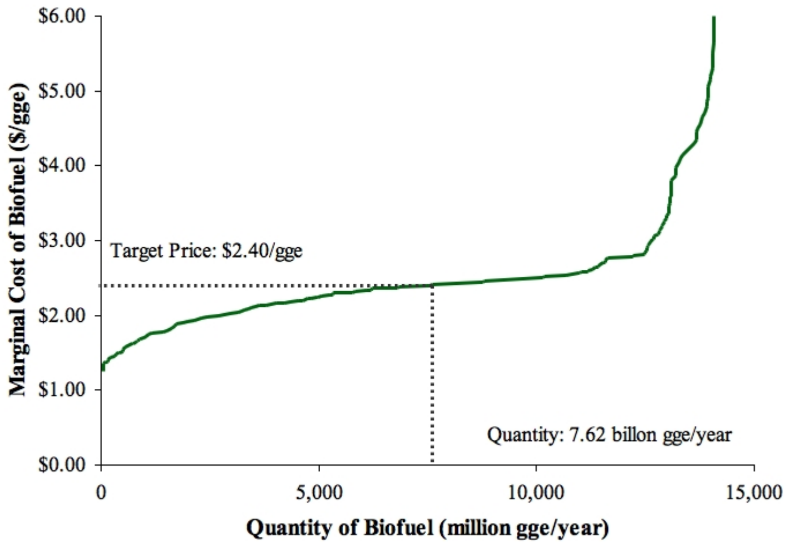

Figure 3: Westwide biofuels supply by delivered cost at fuel terminals.

- Land use policy formulation should carefully explore the possibility of meeting GHG reduction targets under the federal RFS through more sustainable energy crop substitution on lands currently producing corn and other high input crops at low relative yields.
- A more detailed analysis is needed on the capacity of existing transportation infrastructure to meet demands of the biofuel supply chain.
- A spatially explicit analysis should be conducted of the potential for new transportation infrastructure to improve supply chain economics for biofuels production.

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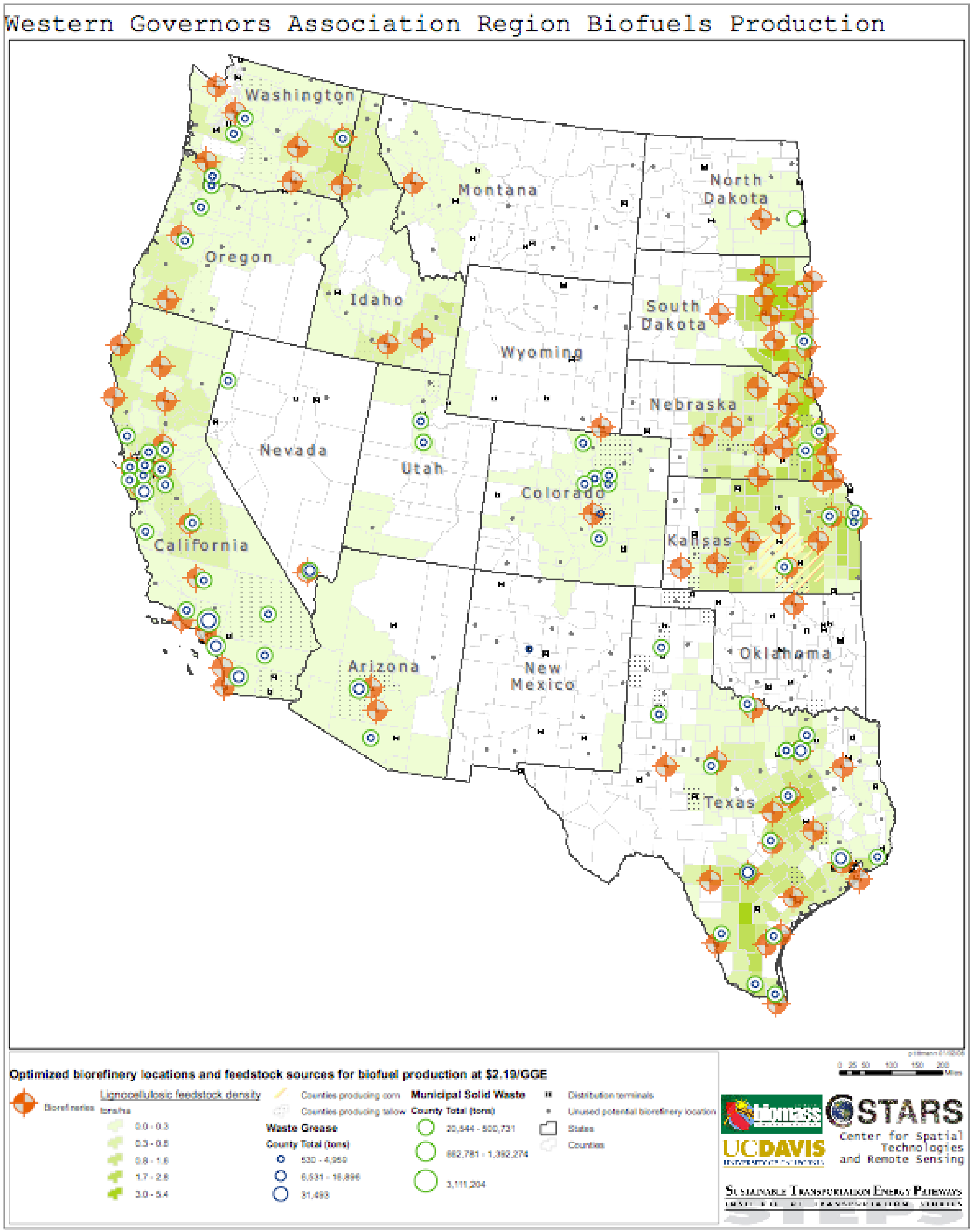

Figure 4: Potential location of lignocellulosic biofuels plants in the West (orange circle markers).

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