Biomass Utilization

for Bioenergy in the Western United States

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Wildfires, hazardous fuel buildups, small-diameter timber, wildland-urban interface zones, biomass. These are some of the terms becoming familiar to communities throughout the Western United States after the record-breaking fire seasons of the past decade. Although small-diameter stems are generally expensive to remove and often have limited utilization options, the need to reduce wildfire hazard has become increasingly important with the expansion of the wildland-urban interface across the Western United States. An estimated 73 million acres of national forest land in western states (397 million acres across all ownerships) have been identified as high-priority treatment areas (USDA Forest Service 2000). Nearly 3,800 communities near federal lands in western states are considered to be at high risk of wildfire (USDA and USDI 2001).

The increased risk of forest fires as a result of overstocked stands has created strong incentives to use biomass material for energy or other purposes, often resulting in thinned stands that can be sustainably managed at lower risk of wildfire. While prescribed burning represents one relatively low-cost option for reducing stem densities, mechanical removals may be preferred when prescribed burning is not a viable option. For example, in forests located near residential areas, prescribed fires could cause unacceptable wildfire risks or create smoky conditions.

Often, mechanically removed stems must be reduced in size or bundled, transported to a market destination, and used within a relatively short period of time. These costs are often several times the final value of any products obtained from biomass. A key challenge for natural resource managers, therefore, is to find markets and products that will recover at least a portion of these costs while providing other benefits such as reducing fire risk. For example, thinning costs typically range from $150 to $550 per acre, and the average thinning on Forest Service land costs about $70 per ovendry ton (ODT) of recovered biomass (LeVan-Green and Livingston 2001). This is roughly twice the market value of biomass for the energy and chip markets, which typically ranges between $25 and $35 per ODT.

Biomass may be used for energy at different scales, including large-scale electrical power generation at stand-alone facilities, cogeneration to produce process steam and electrical power, or smaller scale thermal heating projects at governmental, educational, or other institutions. However, barriers that tend to inhibit bioenergy applications in western states include accessibility, terrain, harvesting costs, and capital costs. The availability of government incentives has the potential to stimulate new technologies and new uses of biomass material when private investors may not be willing to provide investment capital.

National and regional perspectives on bioenergy from woody biomass

Electrical energy generation from wood is based largely on mature technologies, which include direct combustion boilers with steam turbines. Stand-alone wood energy plants average about 20 megawatts (MW) in size, ranging up to about 75 MW (Bain and Overend 2002). However, these plants are relatively inefficient as compared with competing technologies such as hydropower or wind energy, typically resulting in biomass electricity costs of 8 to 12 cents per kilowatt-hour (kWh). Even so, biomass energy production is currently the second most widely used form of renewable energy in the United States (**Table 1**).

Power costs for stand-alone wood energy electrical facilities are approaching a point where they will become competitive with fossil fuel systems (**Table 2**). However, generally declining energy costs in the 1990s as well as loss of state incentives (e.g., in California) and a limited supply of biomass available at low cost have made wood less competitive, resulting in some plant closures. Adoption of new wood-burning technologies, use of wood in cofiring applications, and use of low-grade and/or diverse biomass sources could help create favorable trends for biomass fuels, particularly in light of recent energy cost increases. Nationally, bioenergy use is expected to grow at a slower rate than biobased transportation fuels or biobased products (**Table 3**).

Renewable energy portfolios in western states

Renewable energy standards, or portfolios, are state policies requiring a certain percentage of electrical needs to be met with renewable energy resources by a specified date. Currently, 20 states and the District of Columbia have developed renewable energy standards—collectively accounting for more than 42 percent of U.S. electricity sales (US DOE 2005). Renewable energy electric standards typically include goals of up to about 30 percent of total electrical use, with target dates typically set for about 2020 or sooner (US DOE 2005).

Western Governors' Association

The Western Governors' Association, serving the governors of 19 western states, has adopted a resolution to examine the feasibility of developing 30 gigawatts (GW) of "Clean and Diverse Energy" by 2015, of which half (15 GW) is expected to be obtained from biomass (Western Governors' Association 2006). Energy sources considered include not only biomass, but also advanced coal, natural gas, solar, and wind.

Table 1. — 2002 renewable electricity operating capacity in the United States

Renewable energy source	Electrical generation capacity (MW)
Hydropower	94,335
Biomass	11,869
Geothermal	2,779
Wind*	5,078
Solar-thermal	354
Solar-photovoltaics	60

Source: National Renewable Energy Laboratory (REPiS online)

* Wind generation in 2005 has increased to 9,149 MW installed capacity. (Source: American Wind Energy Association)

Table 2. — Renewable electricity generation costs in the United States

Renewable energy source	Electrical generation cost			
	1980	1990	2000	2010[a]
	Cents per kilowatt-hour[b]			
Biomass	12	10	8	6
Wind	33	10	4	2
Solar-thermal	60	22	10	3
Solar-photovoltaics	94	48	27	14
Geothermal	9	5	3	2.5

[a] Projected for 2010.
[b] Levelized cents per kilowatt-hour in constant 2000 dollars.

Source: National Renewable Energy Laboratory 2002.

Table 3. — Feedstock resource vision goals for energy use in the United States, as established by the Biomass Research Development Technical Advisory Committee.

Energy source	National energy use			
	2001	2010[a]	2020[a]	2030[a]
	Percentage of total			
Biopower[b]	–	4	5	–
Biobased transportation fuels	0.5	4	10	20
Biobased products	5	12	18	25

[a] Projected energy use.
[b] Includes total industrial and electric generator energy demand.

Source: Perlack et al. 2005.

It has been estimated that 10 GW of electrical energy from biomass could be provided at $0.08 per kWh within the Western United States (Gray 2006). This would require about 72 megatons (MT) of biomass feedstocks per year, broadly defined to include forest resources (generating 50 percent of total), agricultural residues (generating 15 percent of total), and municipal wastes, including biosolids and landfill materials (generating 35 percent of total). The potential electrical generating capacity from forestry biomass in the Western United States is estimated to be 2,230 MW (**Table 4**).

Recent federal initiatives to stimulate biomass utilization

The National Fire Plan — The National Fire Plan (NFP) was developed in August 2000 "with the intent of actively responding to severe wildland fires and their impacts to communities while ensuring sufficient firefighting capacity for the future" (National Fire Plan 2006). A goal of the NFP is to assist at-risk communities to prepare for future wildfire seasons and restore fire-damaged forests. As such, an immediate task is to reduce fuel loads in the immediate vicinity of communities, often characterized by high densities of small stems having little or no value for solid wood products. Five key areas are addressed in the plan:

— firefighting preparedness,
— rehabilitation and restoration of burned areas,
— hazardous fuels reduction,
— community assistance, and
— accountability.

The plan took effect quickly, and between 2002 and 2006 numerous successes have been documented in all five of these project areas (National Fire Plan 2006).

The Healthy Forest Restoration Act of 2003 — The Healthy Forest Restoration Act (HFRA) indicates the national importance being placed on restoring forests and reducing the risk of destructive wildfires. Here, a framework is provided to improve the structure and health of overstocked, small-diameter stands while also reducing the complexity of environmental analysis (Office of the President 2005). Over a four-year period ending in August 2006, fuel treatments had been conducted on more than 5.5 million acres of Department of Interior and USDA Forest Service lands in 11 western states (National Fire Plan 2006). Stewardship contracting projects are playing an increasingly important role in hazardous fuel removals, and 189 such projects had been authorized on Forest Service and Bureau of Land Management lands as of fiscal year 2003 (Office of the President 2005).

The billion ton initiative — The USDA Forest Service and the U.S. Department of Energy have evaluated the potential to sustainably displace 30 percent or more of domestic petroleum consumption with biofuels, a goal that would require utilizing more than 1.3 billion ODT per year (Perlack et al. 2005). Of this amount, forest lands in the continental United States could potentially produce an estimated 368 million ODT per year, broken down into the following categories:

— fuelwood harvested from forests: 52 million ODT
— residues from wood products facilities: 145 million ODT
— urban wood residues: 47 million ODT
— logging and site-clearing residues: 64 million ODT
— fuel treatment operations to reduce fire hazards: 60 million ODT

Available woody biomass resources in western states

Estimated biomass resources

Extensive biomass resources exist throughout the Western United States, and estimates vary depending on land ownership, size distribution of biomass, accessibility of biomass, frequency of harvesting or thinning operations, and what states are included. In the 15 western states, more than 28 million acres of forest could benefit from hazardous fuel removals, yielding an expected 345 million ODT of material from accessible areas to reduce fire risk (Rummer et al. 2003). If this analysis were extended to include all treatable timberland in western states (totaling about 97 million acres), estimates of available biomass would range up to 617 million tons of non-merchantable timber (including limbs, tops, and saplings).

Separately, biomass availability has been estimated at about 270 million ODT for removals from 10.6 million acres (Western Governors' Association 2005). This report assumed treatments only on forests producing at least 300 ft^3 (about 4 ODT) of timber per acre, per year, and considered

Table 4. — Potential electrical generating capacity from forestry biomass in Western United States.

State	Generating capacity from forestry biomass Megawatts (electrical power)
Alaska	114
Arizona	25
California	783
Colorado	60
Hawaii	0
Idaho	277
Kansas	3
Montana	248
Nebraska	7
Nevada	1
New Mexico	42
North Dakota	0
Oregon	204
South Dakota	17
Texas	188
Utah	22
Washington	208
Wyoming	31
Total	2,230

Source: Western Governors' Association 2006.

merchantable removals (including pulpwood, lumber, posts, and poles) separately from biomass removals. Research by Skog et al. (2006) identifies 59.2 million acres of timberland in 12 western states having high risks of stand-replacing fires. In their evaluation, 60 to 70 percent of acres to be treated were in California, Idaho, and Montana, and more than half of the available biomass would be derived from sawlogs (main stems 7 inches in diameter and greater).

An important consideration for using biomass for energy is the need to ensure a steady supply because power plants are often expected to operate at least 20 years. If removals occurred over a 22-year timeframe (Western Governors' Association 2005), a scenario of 6.2 million ODT per year of biomass would be likely from just the 10.6 million acres mentioned earlier. This volume of wood fuel could supply upwards of 12 electrical generation facilities (approximately 50 MW each).

Economic considerations

Regardless of estimates for biomass availability in western states, current market values for biomass fuel generally will not pay for all associated costs of harvesting, collection, size reduction, and transportation, except under perhaps the most favorable conditions (Skog et al. 2006). Net revenues from thinned stands can be influenced by numerous factors, including slope, thinning regime, subsidies (if any), and wood product options such as solid products versus chips. The study by Skog et al. (2006) found uneven-aged treatments on gentle slopes to be the only scenario (of four evaluated) that provided an overall positive net revenue, averaging $686 per acre.

Total treatment costs can vary widely from $35 to more than $1,000 per acre, depending on terrain, number of trees to be treated, and the size distribution of stems to be removed, among other factors (Rummer et al. 2003). Other estimates indicate thinning costs of $150 to $550 per acre, translating to about $70 per ODT (LeVan-Green and Livingston 2001). Financial returns from thinning simulations on New Mexico forests indicate few cases where harvested volume was merchantable and no cases where the harvested material would pay for thinning costs (Fight et al. 2004).

Tools for evaluating biomass resources

Forest inventory and analysis (FIA)

The USDA Forest Service conducts detailed periodic surveys of forest material through its Forest Inventory and Analysis (FIA) unit, providing source data for both public and private lands. An important component of FIA stand inventories is an assessment of small-diameter stems and down woody materials. FIA data have been used effectively to evaluate stands where increasing stem densities have changed the long-term patterns of forest fires, including frequency and intensity (Vissage and Miles 2003).

In western forests, 29 million acres have been identified, based on FIA data, as "high priority hot-spots" that could yield up to 576 million ODT of biomass if thinned (Vissage and Miles 2003). In this work, a stand density index was developed to compare actual stocking levels with desired levels. Trees were identified by diameter

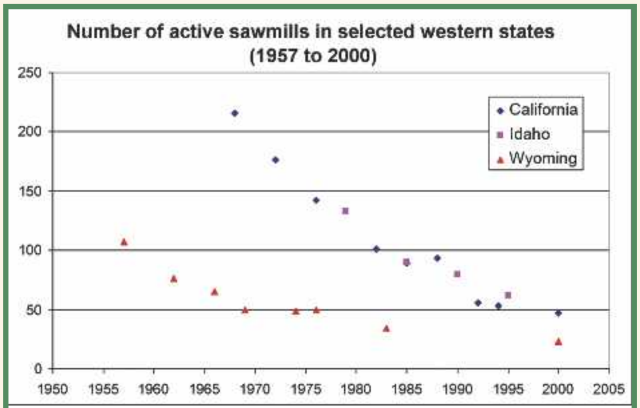

Figure 1. — Number of active sawmills in selected western states (1957 to 2000).

Sources: Morgan et al. 2004a, 2004b, 2005.

class for fuel-reduction removals. In related work, Fiedler et al. (1999) used FIA data to determine that up to 80 percent of Montana's mixed conifer stands were at moderate or high risk for crown fires.

BioSum simulation model

BioSum is a management tool that can be used to estimate how revenues from forest thinnings can offset treatment costs at a landscape scale, for example, when providing woody biomass as a power-plant feedstock (Fried et al. 2003). BioSum simulations are based on FIA inventory data. Effective utilization of biomass can be an important determinant of whether landscape-scale fuel treatments are financially feasible (Fried et al. 2005). The BioSum model addresses this question by incorporating a transportation cost model, a treatment cost accounting module, a log valuation model, and a crown fire hazard evaluator.

Fried et al. (2003) examined 6,200 FIA plots over a 28-million-acre study area in southern Oregon and northern California. They determined that four 50 MW biomass electrical plants could be strategically located within the study area, and that fuel treatments could yield either 75, 79, or 94 million green tons, depending on whether revenue maximization, harvest volume, or torching index criteria were used to set treatment regimes (Fried et al. 2005). These amounts are based on fuel treatment policy scenarios in which all effectively treatable plots are treated. It was also determined that fewer than 50 percent of the forested acres in this study area would be amenable to fuel treatments because of poor access, reserved status of lands, or low basal area of stands (Fried and Christensen 2004).

Fuel treatment evaluator

The Fuel Treatment Evaluator (FTE) is a tool that identifies, evaluates, and prioritizes fuel treatment opportunities (Perlack et al. 2005). Used in conjunction with the Forest Vegetation Simulator (Crookston and Havis 2002), the FTE evaluates stand stocking by identifying a threshold level representing minimally stocked stands. Any stands with greater stocking densities then become candidates for thinning. The FTE requires data on individual trees on a stand-by-stand basis.

Bioenergy production in western states

Electrical power generation

The first large-scale development of stand-alone biomass electrical plants occurred in California in the 1980s. Most of these facilities are relatively large by bioenergy standards, with generation capacities up to about 50 MW, and use a variety of biomass feedstocks including wood products residues, agricultural residues, and urban wood wastes. The largest wood-fired facility in the United States, located in Hurt, Virginia, is capable of generating 67 MW, but is a peaking facility (generating power only during periods of peak demand). The McNeil generating station in Burlington, Vermont, is a large facility (52 MW) that generates electricity on an intermittent basis, and over the past 10 years has used between 200,000 and 400,000 green tons of wood per year (Irving 2006).

Most stand-alone wood-fired systems are designed to produce at least 15 MW to take advantage of economies of scale associated with construction costs, power generating efficiency, and also biomass harvesting and transportation. Wood-fired electrical systems could become more efficient with the incorporation of wood fuel dryers and/or design of more efficient steam cycles. These improvements could help lower the capital costs of wood-fired plants from $2,000 per kilowatt of installed capacity (today's average) to about $1,275 per kilowatt of installed capacity (Bain and Overend 2002).

Among western states, California has most vigorously pursued the use of biomass for electrical power generation. Rapid growth in project development during the 1980s was aided by Interim Standard Offer 4 (ISO4), a California initiative that provided guaranteed rates for bioenergy facilities during their initial years of operation. At full capacity, existing bioenergy plants could supply about 2 percent of California's peak electrical needs. Currently, 26 plants are operating with a total generating capacity of 550 MW (**Table 5**). In 1994, steps were taken by the California Public Utilities Commission to restructure the state's electric industry, with biomass subsidies being reduced. As a result, some bioenergy facilities closed after just a few years of operation.

Additionally, the number of operating bioenergy facilities in California declined by 28 (from 1980 to 1999), representing a 264-MW reduction of generating capacity. An important outcome of these plant closures is the loss of infrastructure (including harvesting, processing, and transportation) needed to sustain a viable wood energy industry. These examples and others underscore the importance of a long-term policy approach for bioenergy project development, so that facilities are able to weather short-term variations in fuel prices and other economic uncertainties. Bioenergy plant closures in California could have been even more extensive except that many facilities were able to use a variety of feedstocks such as forest harvesting residues, sawmill residues, agricultural residues, and municipal solid waste.

Wood residue utilization within the forest products industry

Nationwide, the primary wood products industry produced about 91 million ODT of residues in 2002, of which 89 million were recovered, burned, or otherwise utilized, leaving less than 2 million ODT for new bioenergy project development (Perlack et al. 2005). In western states, the wood products industry has traditionally produced substantial amounts of mill residues such as hog fuel, bark, chips, slabs and edgings, and sawdust. Historically, high-value chips have been sold to pulp mills, although in some areas (including northern California) chip markets have weakened as fewer pulp mills remain in operation. At the Wheelabrator Shasta Energy facility in Anderson, California, use of wood products mill residues peaked in the late 1980s and had decreased by about 50 percent as of 2004 (Jolley 2006). Remaining wood products residues are often burned for energy, either on site or at another power producer. Many of the larger wood products facilities have combined heat and power plants, with heat often being directed to lumber dry kilns, and electricity being used for on-site processing or sold to outside markets.

Over the last several decades western sawmills have become larger and more efficient, while regional timber harvests have fallen. As a result, a smaller number of mills account for a larger portion of the "mill residue pie" (**Fig. 1**). Increases in mill overrun (defined as lumber recovery that exceeds the volume estimated by a log rule (Bowyer et al. 2003)) can be attributed to smaller log diameters as well as technological advances in sawing and planing. For example, lumber recovery in Idaho, as measured by the Scribner log rule, increased by 39 percent between 1979 and 2001 (Morgan et al. 2004b). In 2004 the average lumber recovery factor, another measure of sawmill efficiency, was greater in the western region (at 8.52 board feet per cubic foot) than in any of the other seven regions evaluated in the United States (Spelter and Alderman 2005). Even though

Table 5. — Number and status of California's biomass-to-energy facilities (current 2001).

Status	Number of plants Megawatts	Generating capacity
Operating	26	550
Idled	17	217
Dismantled	14	97
Converted to gas-fueled	5	111
Total	62	975

Source: California Integrated Waste Management Board 2006.

less wood waste is being produced per board foot of lumber produced, larger mills are still generating concentrations of wood waste. The Kettle Falls, Washington, and Williams Lake, British Columbia, facilities are both examples of successful bioenergy plants supplied by a cluster of mills that are eager to get rid of their wood wastes.

In many western states, including California (Morgan et al. 2004a), Wyoming (Morgan et al. 2005), and Idaho (Morgan et al. 2004b), sawmill residues are already almost fully utilized, and therefore could contribute little to a developing bioenergy industry. In California and Idaho, between 97 and 100 percent of coarse residues, fine residues, and bark generated by sawmills is already utilized. In Wyoming, almost all coarse and fine residues are also utilized, but only about one-third of bark residues in that state are utilized. In all three of these states, the most significant residue types were coarse or chippable residues, including slabs, edging, trim, log ends, and flawed pieces of veneer.

In other western states, wood residue production is less than current demand. In Montana, timber processing industries generated more than 1.5 million ODT during 2004. However, 2.2 million ODT were consumed by residue-utilizing firms. The excess residue needs (0.7 million ODT) were met either by out-of-state sources or by Montana facilities processing timber directly into fuel (Keegan and Morgan 2005). In other states where the wood products industry is less well developed (e.g., New Mexico), there are currently no mills processing small logs (Fight et al. 2004). Thus, there is little or no capacity to process sawlogs of the type that would be produced from fuel-reduction treatments.

In Colorado's Front Range, wood products residue production was estimated to be fewer than 20,000 tons per year (Ward et al. 2004), an amount insufficient for most stand-alone bioenergy facilities, but potentially enough to supply several small-scale thermal energy systems. Throughout western states, residues from wood products manufacturers are unlikely to play a significant role in further growth of bioenergy production, unless changes in sawmill efficiency and/or timber harvest levels occur.

Small-scale thermal wood energy systems

Thermal systems for institutional applications are typically sized in the range of 1 to 10 million British Thermal Units (BTUs) per hour, and are large enough to have automated fuel handling and feeding systems (Maker 2004). In thermal wood energy systems no electricity is produced; instead, heat from wood combustion is transferred via hot water or low pressure steam to the building(s) requiring heat (**Fig. 2**). Although school heating systems use relatively small amounts of biomass (typically on the order of a few thousand green tons or less per year), they have strong potential applications in western states because they are often motivated by hazardous fuel removals adjacent to at-risk communities.

Bioenergy for small-scale institutional use in western states has been exemplified by the "Fuels for Schools" program (Fuels for Schools 2006), which has seen its greatest development in western Montana but is also encompassing other western states. To date, 6 systems have been completed and are fully operational, 11 are under construction, and close to 47 sites have had feasibility assessments (Fuels for Schools 2006). The success of this program could help catalyze new applications in other regions of the country, as well as provide new techniques for harvesting and collecting relatively small amounts of biomass material.

Figure 2. — This biomass-fueled boiler facility provides heat for multiple school buildings in Montana.
Photo credit: USDA Forest Service

New advances in wood energy

A small modular biomass (SMB) power system has been developed for use in rural electrical markets (Scahill et al. 2002) (**Fig. 3**). This fixed-bed, down-draft gasifier design is being used with units ranging from 5 kW to 15 kW, with 50-kW to 100-kW units currently under development (Zerbe 2006). One evaluation indicates an estimated payback period of 3.1 years for an SMB operating 16 hours per day, 300 days per year, when the market value of electricity is assumed to be $0.12 per kWh (USDA Forest Service 2004).

Community Power Corporation (2006) in Littleton, Colorado, lists at least 4 SMB installations in western states, all of which are rated at 15 kW. Current development efforts are focusing on continuous operation of 50-kW systems, with a planned installation at Mount Wachusett Community College in Gardner, Massachusetts. This system has expected energy savings of $276,000 per year, and a simple payback period of about 9 years (Livingston 2006).

Some other features of SMBs include:
- — flexible fuel sources, including wood and agricultural wastes,
- — portability (trailer mounted units),
- — stand-alone or connected to utility grid,
- — possible future use with Stirling engines or fuel cells,
- — combined generation of electricity and thermal energy.

Delivered fuel costs and scale of operation are important considerations for SMBs, as well as for other wood energy systems. One study evaluating conditions in southern Oregon determined that, in theory, a 1,000 kW SMB (about 10 times larger than prototypes now in development) could operate profitably if a Federal energy tax credit of $0.018 per kWh (indexed for inflation) were in place, and if merchantable logs removed with biomass during forest health thinnings could be sold at $175 per 1,000 board feet to offset harvesting and handling costs (Bilek et al. 2005). Although SMBs are still under development, they have the potential to meet small-scale electrical needs in diverse applications throughout western states, especially remote locations lacking electrical grid access.

Barriers to biomass utilization in the Western United States

Although several classes of barriers to biopower development have been identified (Bain et. al. 2003), all point to one central issue: rarely will the value of biomass products pay for the costs of harvesting, collecting, and transporting to markets in the western states. For example, while energy and chip markets have historically paid $25 to $35 per ton, the average cost to thin small-diameter and underutilized material is typically on the order of $70 per ODT (LeVan-Green and Livingston 2001). This is significant for western forests, because some type of mechanical thinning will likely be required on up to 90 percent of overstocked stands due to risk of wildfire and hazards associated with the use of prescribed fire.

Federal agency officials cite two primary barriers to increased use of woody biomass: cost-effective use of materials (especially harvesting and transportation costs), and lack of reliable supply (USGAO 2005). For example, in California it has been estimated that costs of electrical generation from woody biomass were about 7.5 cents per kWh (including harvesting, transporting, processing, operations, and maintenance), yet wholesale power prices were only 5.3 cents per kWh (USGAO 2005). A lack of long-term contracts, ranging up to 10 years, was cited as another obstacle for successful biomass use.

The Billion Ton Initiative (Perlack et al. 2005) identified several biomass utilization issues and barriers, including:

— poor accessibility, including steep slopes and environmentally sensitive areas;
— marketing larger-diameter trees for higher value products, separately from biomass products;
— transportation costs (typically $0.20 to $0.60 per dry ton-mile);
— environmental impacts resulting from fuel treatment operations;
— high harvesting costs, which could potentially be reduced as specialized, more efficient harvesting equipment becomes developed; and
— a lack of federal support for forestry programs vs. other program areas (such as agriculture).

Biomass harvesting and fire hazard reduction

Biomass harvesting, collection, transportation, and fire hazard reduction can involve numerous processing steps, each with associated costs and challenges. The economic feasibility of smallwood harvesting in western states can be very site-specific, given the wide variation in harvesting systems, road systems, hauling distances, and market prices for thinned material (Han et al. 2004).

For example, Skog et al. (2006) found that slope can play a key role in influencing net financial returns from fuel reduction treatments. Fiedler et al. (1999) evaluated restoration thinnings for ponderosa pine forests and found that on slopes of less than 35 percent, net revenues of $950 per acre were possible when a roundwood-pulpwood market was present. However, steeper slopes requiring cable-yarding systems could only be undertaken if subsidies of either $300 or $600 per acre were provided, depending on whether a market for pulpwood was present.

A fuels reduction harvest on flat terrain in eastern Oregon resulted in profits of $611 per acre owing to sawlog revenues (valued at $515 per thousand board feet (MBF)) that more than compensated for pulpwood losses (Brown and Kellogg 1996). Skidding and yarding operations have been identified as an important cost component, with costs in Montana ranging from $25 per million board feet (MMBF) (rubber-tired grapple skidder) to $182 per MMBF (helicopter systems) (Keegan et al. 1995).

New, more efficient harvesting equipment could greatly influence the way biomass is removed from the woods. For example, energy wood harvesters compact and bundle wood into bales weighing about 0.5 tons each, ready to be burned in bioenergy systems without further processing or chipping (**Fig. 4**). These harvesters, which have been used successfully in European forests, can prepare 20 to 30 bales per hour and have environmental advantages such as low soil compaction. Test trials are evaluating the effectiveness of forest residue bundlers on conditions typical of western landscapes (Rummer 2003). When considering the capital cost of this equipment (about $450,000), profitability remains to be seen, especially for smaller operators. Smaller (and much less expensive) balers are currently undergoing evaluation for use in western forests and may provide a more economical solution (Dooley et al. 2006).

Biomass transportation

In the intermountain west, biomass resources are often dispersed and located at considerable distances

Figure 3. — This portable modular power system gasifies wood pellets or other biomass and generates 15kW electricity.
Photo credit: USDA Forest Service

Figure 4. — Specially designed harvesting equipment bundles biomass into bales for bioenergy systems.
Photo credit: Forest Residues Bundling Project, USDA Forest Service, Southern Research Station, Auburn, Alabama.

from wood energy conversion facilities. Thus, transportation costs are often an important factor when considering biomass project development. Hauling distances were evaluated for mechanized whole-tree harvesting in Idaho by Han et al. (2004), who found that distances of less than 53 miles were needed to maintain positive financial returns. Although transportation costs for forest-derived biomass are typically in the range of $0.20 to $0.60 per dry ton-mile (Perlack et al. 2005; Bilek et al. 2005), in some cases they may be considerably lower.

Typically, in-woods chippers or tub grinders are used to reduce harvesting residues to a form suitable for bioenergy fuel. Alternatively, harvesting residues can be loaded into waste salvage bins, each holding up to about 15 tons of wood. Bins can be detached from trucks, left on site, located with either GPS or an RFID (radio frequency identification) transmitter, and retrieved when full. The bins can be discharged (dumped) at wood energy sites, eliminating the need for inclined truck unloaders specially designed to unload chip vans and often found only at larger facilities.

Discussion

Western states have substantial biomass resources, including material from forest thinnings (both commercial and restoration), wood products mill residues, and agricultural and urban wood wastes. Successful biomass utilization on a large scale can have many local benefits such as reduced fire risk, improved forest health, increased employment, reduced reliance on imported fossil fuels, and improved environmental conditions. In many regions of the west, the primary bioenergy feedstock will be small-diameter stems removed from stands to reduce wildfire hazards. However, there are relatively few cases where small diameter material will "pay its own way" out of the woods, and these cases can be very site-specific (Larson and Mirth 1998, Wagner et al. 1998, Skog et al. 2006, Rummer et al. 2003, LeVan-Green and Livingston 2001, Fight et al. 2004). In many instances, the best-case scenario is to minimize harvesting cost deficits by producing higher value products from larger stems (such as lumber and engineered wood products) and/or attempting to offset production costs through subsidies or credits. Other factors making it difficult for biomass harvests to be economical in western states include long transportation distances, steep or inaccessible terrain, inefficient harvesting of many small-diameter stems, a dispersed labor force, and poorly defined markets for biomass.

Where communities are at risk of wildfire, incentives are already in place for harvesting and removing woody biomass quickly. More than 5.5 million acres of Department of Interior and Department of Agriculture lands have already been treated through the National Fire Plan in western states (National Fire Plan 2006). This total includes both prescribed fire and mechanical treatments within wildland-urban interface zones and other areas occurring from 2003 to 2006. For successful bioenergy development, biomass removals will need to occur over longer time frames (often 20 years or longer) so that capital costs can be recovered.

An important aspect of hazardous fuel removals has been more than 189 successful stewardship contracts that have been implemented by the Forest Service and Bureau of Land Management (Office of the President 2005). Stewardship contracts are becoming longer in duration (often up to 10 years) and cover larger areas. The White Mountain Stewardship contract on the Apache-Sitgreaves National Forest in Arizona (Zieroth 2006) has often been cited as a successful example of hazardous fuel reduction on a large scale. After just 1.5 years of this 10-year stewardship contract, more than 200,000 green tons of biomass have been removed, with 20,000 acres under contract (Zieroth 2006).

Biomass heating of schools and other community buildings can utilize hazardous fuel removals, although such bioenergy systems are often relatively small in size. More than 17 facilities are under construction or in operation through the Fuels for Schools program in western states (Fuels for Schools 2006). However, innovative approaches are needed for providing infrastructure to harvest and transport relatively small amounts of biomass. Single harvesting operations could supply biomass to several wood energy systems within an economic transportation distance, probably less than about 50 miles (Bain et al. 2003). The types of bioenergy systems used in schools can be easily adapted to similar applications in hospitals, governmental buildings, and municipal buildings having similar fuel requirements.

In the longer term, hazardous fuel removals in western states may be supplemented with forest products manufacturing residues, harvesting residues from sustainable forest management activities, and possibly urban wastes. However, forest products residues are already fully utilized in many areas. In California, Idaho, and Wyoming, more than 95 percent of coarse and fine residues are already being used for some purpose, including hog fuel for energy (Morgan et al. 2004a, 2004b, 2005). Thus, new bioenergy project development would need to find sources other than residues from wood-products mills for the bulk of its fuel needs. However, certain regions of the West (including portions of Washington, Idaho, and Montana) are capable of producing an additional 60 to 80

Figure 5. — Transportation cost is one factor making biomass harvesting uneconomical in the West.
Photo credit: USDA Forest Service

million cubic feet of timber per year (Keegan et al. 2005). Increased timber utilization on this scale could potentially create significant volumes of mill residues that might be available for bioenergy.

Harvesting higher value timber along with biomass removals is perhaps the best way to create more favorable economics for wood utilization. Innovative uses of small-diameter trees will also help offset harvesting costs, and could include rustic furniture, posts and poles, water restoration products, and wood shavings (LeVan-Green and Livingston 2001). Emerging technologies such as wood-plastic composites (Yadama and Shook 2005) or the TimTek scrimber process (Sheriff 1998, Jarck and Sanderson 2000) could also help produce a positive economic balance in a fire hazard reduction project. More efficient logging practices will likely generate less biomass residue per volume of harvested wood product (Haynes 2003), and more efficient sawmills will generate less wood waste per unit of product.

Perhaps the biggest success factor for bioenergy projects in the West will be finding appropriate niches among other renewable energies. The past quarter-century has seen significant bioenergy developments in western states, starting with large-scale electrical generation and, more recently, small-scale thermal energy systems. However, several significant barriers have been identified, relating to feedstock production, appropriate technology, project financing, and infrastructure requirements (Bain et. al. 2003). Will these barriers become more significant or less significant for western states? The answer is unclear, although within the near future electrical generating costs for nonbiomass renewable energy (including solar, wind, and geothermal) are all projected to remain lower than those for biomass energy systems (NREL 2002).

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