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A Synthesis of Biomass Utilization for Bioenergy Production in the Western United States

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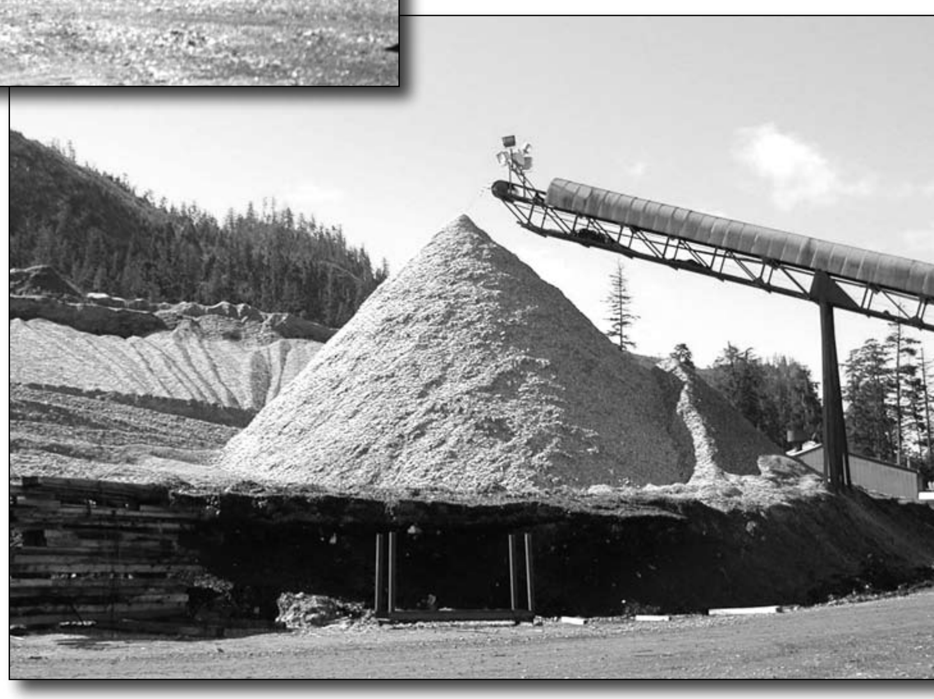

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Abstract

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We examine the use of woody residues, primarily from forest harvesting or wood products manufacturing operations (and to a limited degree from urban wood wastes), as a feedstock for direct-combustion bioenergy systems for electrical or thermal power applications. We examine opportunities for utilizing biomass for energy at several different scales, with an emphasis on larger scale electrical power generation at stand-alone facilities, and on smaller scale facilities (thermal heating only) such as governmental, educational, or other institutional facilities. We then identify west-wide barriers that tend to inhibit bioenergy applications, including accessibility, terrain, harvesting costs, and capital costs. Finally, we evaluate the role of government as a catalyst in stimulating new technologies and new uses of biomass material.

Keywords: Biomass, bioenergy, fuel hazard reduction, renewable energy, harvesting, forest products.

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Introduction

In recent years, increased risk of forest fires owing to 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. Fire hazard reduction 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 have been identified as being at high risk of wildfire (table 1). Although a plentiful supply of biomass is available, challenges remain to find economic uses given the high removal costs and relatively limited markets for biomass material.

Table 1—Communities in the vicinity of federal lands that are at high risk from wildfire, Western United States

State	Number of communities at risk
Arizona	122
California	845
Colorado	712
Idaho	442
Montana	182
New Mexico	60
Nevada	245
Oregon	367
Utah	398
Washington	160
Wyoming	261
Total	3,794

Source: U.S. Department of Agriculture and U.S. Department of the Interior 2001.

Although prescribed burning represents one relatively low-cost option for reducing stem densities in overstocked stands, 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 pose other hazards such as respiratory ailments from smoke. Often, mechanically removed stems must be reduced in size (i.e., chipped or ground) or bundled, transported to a market destination, and used within a relatively short period of time. The costs of harvesting, chipping, and transporting biomass are often several times the final value of the products obtained from the biomass. A key challenge for natural resource managers 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 USDA Forest Service land costs about $70 per oven-dry 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. Even small-diameter saw-timber, ranging from 6 to 10 inches in diameter at breast height (d.b.h.), may require a subsidy for profitable manufacture under current market conditions in the Western States (Wagner et al. 1998).

In this paper, we examine opportunities for utilizing biomass for energy at several different scales, with an emphasis on large-scale electrical power generation at stand-alone facilities, and on smaller scale thermal heating projects at governmental, educational, or other institutional facilities. We then identify barriers that tend to inhibit bioenergy applications, including accessibility, terrain, harvesting costs, and capital costs. Finally, we evaluate the role of government as a catalyst in stimulating new technologies and new uses of biomass material. This information will be most useful for landowners, natural resource managers, wood products facility managers, and government agency personnel in Western States.

In this synthesis, we address several questions that could shape the path of biomass utilization in Western States, including many of the following:

- What is a reasonable level for biomass utilization in Western States when considering factors such as hazardous fuel reduction, community development, and wood products industry sustainability?
- How will future wildfire severity, acreages burned, and potential disruptions in fuel supply influence the amount of biomass material remaining for bioenergy?
- How will the utilization of dead trees (from fire, insects, and other agents) influence bioenergy production? How will the volume and quality of biomass from these sources influence utilization?
- How will fire hazard reduction projects, carried out over the near term, complement the needs of bioenergy facilities to secure steady biomass supplies over the long term?
- What role will stewardship contracting play in fire hazard reduction projects on national forests, and how will this influence community development and wood products industry sustainability?
- How will the use of agricultural residues influence bioenergy production?

- What commitment will be needed in terms of policy measures and project financing from government entities (state, federal, and local) to ensure sustainable bioenergy production?
- What role will biomass play within the mix of merchantable forest products, (e.g., engineered wood products and other biobased products), and how will the market value for different types of forest residues influence utilization?
- What role will wood products manufacturing facilities have in providing residues to bioenergy facilities, and how will changing mill technologies influence this?
- How will emerging bioenergy technologies (such as small-scale electrical production, cellulosic ethanol, and biofuels) influence biomass use?
- How will emerging harvesting and transportation technologies influence biomass use?
- What scale of bioenergy operation (ranging from school-sized systems to large power plants) will be preferred, and what mix of bioenergy (for thermal vs. electrical applications) will be realized?
- How will concerns over global warming influence biomass utilization among other renewable energies such as wind, solar, and hydropower?

The scope of this paper is limited to the use of woody residues, primarily from forest harvesting or wood products manufacturing operations (and to a limited degree from urban wood waste), to be used in direct combustion bioenergy systems for electrical or thermal power applications. This information is expected to be useful for natural resource professionals, wood products manufacturing personnel, and state and federal agency personnel involved in land management decisions.

Unless otherwise specified, all biomass weights in this report are oven-dry tons. In this paper, we do not consider the use of biomass for other purposes such as liquid fuels (including ethanol or biodiesel), energy from gasification, residential heating use (including pellets), biobased products (e.g., compost, wood composites, or other wood engineered products), or solid wood products from small-diameter timber. We also do not consider bioenergy applications from agricultural residues, animal wastes, or municipal sewage wastes.

National and Regional Perspectives on Bioenergy From Woody Biomass

Overview

Nationwide, bioenergy is a proven energy option. With more than 11 gigawatts (GW) of installed capacity, it is the largest source of renewable energy after hydroelectric power (Bain and Overend 2002, Bain et al. 2003) (table 2). Recently, wind power has become a close third, with almost 10 GW of capacity in the United States (AWEA 2006). The contribution of wood to U.S. energy consumption has decreased somewhat from 1980 (3.7 percent of total) to 2000 (3.2 percent of total) (U.S. Department of Energy 2005a). Despite this decrease, over the long term, wood energy could potentially supply up to about 10 percent of the U.S. energy demand under a program that would include fossil fuel conservation efforts (Zerbe 2006). Other sources estimate that combined biopower use by the industrial sector and electric utilities will meet about 4 percent of energy demand in 2010 and 5 percent in 2020 (Perlack et al. 2005).

Table 2—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[a]	5,078
Solar-thermal	354
Solar-photovoltaics	60

[a] Wind generation has increased to 9,149 MW installed capacity in 2005 (AWEA 2006).
Source: National Renewable Energy Laboratory (REPiS online).

Several new bioenergy advances hold promise for more widespread application in coming years, including gasification and small-scale electrical generation, microturbines, and Stirling engines.

Electrical energy generation from wood is based largely on mature technologies, which includes 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 vs. other technologies such as wind energy, typically resulting in biomass electricity costs of 8 to 12 cents per kilowatt-hour (kWh). Several new bioenergy advances hold promise for more widespread application in coming years, including gasification and small-scale electrical generation, microturbines, and Stirling engines. Although wood energy for electrical generation in the United States has seen its greatest development in California, numerous large-scale facilities exist in New England and the Great Lakes States.

These examples and others illustrate the widespread technical feasibility of stand-alone electrical wood energy systems as well as efficient biomass harvesting and collection infrastructure on this scale. Power costs for wood biomass systems are approaching conditions competitive with fossil fuel systems (table 3). However, generally declining energy costs in the 1990s as well as loss of state incentives (e.g., in California) have made wood less competitive, resulting in some plant closures. Adoption of new wood-burning technologies, use of wood in co-firing applications, and use of low-grade or diverse biomass sources could help create favorable trends for biomass fuels. The next generation of bioenergy facilities is expected to be more efficient through use of combined-cycle gasification systems, more rigorous steam cycles, or fuel dryers (Bain and Overend 2002).

Table 3—Renewable electricity generation costs in the United States

	Electrical generation cost			
Renewable energy source	**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.

Renewable Energy Portfolios of Western States

Renewable energy standards, or portfolios, are state policies requiring a certain percentage of electrical needs to be met with renewable energy resource by a specified date. Currently, 20 states plus the District of Columbia have developed renewable energy standards, and these states collectively account for more than 42 percent of U.S. electric sales (U.S. Department of Energy 2005b). 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 (table 4). California has taken an aggressive approach toward increasing its use of renewable energy above target levels. Senate Bill 1078 requires California to generate 20 percent of its electricity from renewable sources by 2017. Since then, this goal has been accelerated to an even higher target of 33-percent renewable energy by 2020 (Hamrin et al. 2005).

Table 4—Renewable electric standards, by state, indicating target dates for reaching goals

State	Electrical energy from renewables	Target date
	Percentage of total	*Year*
Western region:		
Arizona	1.1	2007
California	20	2017
Colorado	10	2015
Hawaii	20	2020
Nevada	15	2013
New Mexico	10	2011
Texas	2.7	2009
North-central region:		
Iowa	2	1999
Minnesota	19	2015
Wisconsin	2.2	2011
Northeast region:		
Connecticut	10	2010
Maine	30	2000
Maryland	7.5	2019
Massachusetts	4	2009
New Jersey	6.5	2008
New York	24	2013
Pennsylvania	8	2020
Rhode Island	16	2019
Washington, DC	11	2022

Source: U.S. Department of Energy 2005b.

Forest residues are potentially an important part of the renewable energy portfolio. The Tahoe Green Power program in California has a goal of marketing green power produced specifically from forest thinning residues on public lands in and around the Lake Tahoe basin (McNeil Technologies, Inc. 2003). Under this plan, electrical power would be marketed as “Tahoe Green Power” and sold at a premium to consumers. An outreach effort would include increasing awareness of forest health issues and the benefits of biomass power to consumers. Among the market barriers indicated in this report is that the cost of producing biopower is 1 to 4 cents per kWh higher than current wholesale electrical rates in California (McNeil Technologies, Inc. 2003).

The Western Governor’s Association has adopted a resolution to examine the feasibility of developing 30 GW of “clean and diverse energy” by 2015.

Western Governor’s Association—The Clean and Diversified Energy Initiative

The Western Governor’s Association (WGA), serving the governors of 19 Western States, has adopted a resolution to examine the feasibility of developing 30 GW of “clean and diverse energy” by 2015, of which 15 GW (50 percent of the target) is expected to be obtained from biomass (WGA 2006b). Energy sources considered include not only biomass, but also advanced coal, natural gas, solar, and wind. Other goals of this initiative include increasing energy efficiency 20 percent by 2020 and providing adequate energy transmission.

It has been estimated that 10 GW of electrical energy from biomass could be provided at 8 cents 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). Power generation technologies could include direct-fired steam turbines, biomass co-fired with coal, and gasifiers (internal combustion engines or combined-cycle). An important consideration in many western regions will be electrical transmission costs from power plants to remote energy consumers.

The WGA Biomass Task Force, comprising over two dozen members from diverse backgrounds, has developed 10 recommendations (WGA 2006b), including:

- Production tax credits for biomass should be equal to those for wind and geothermal.
- State and federal governments should purchase biomass power to meet their energy needs.
- A single, broad-based definition for biomass should be established.
- Remote energy facilities should be supported by grid connections, including proper voltage and load requirements.

Recent Federal Initiatives to Stimulate Biomass Utilization

Biomass Research and Development Act of 2000—
This act created a research initiative to produce fuels, power, chemicals, and materials from a wide range of biomass sources. This law described an "outstanding potential for benefit to the national interest" through:

- Improved strategic security
- Healthier rural economies
- Near zero net greenhouse gas emissions
- Technology export
- Sustainable resource supply

This act emphasizes biobased industrial products and has provisions for fundamental research as well as applied research seeking cost-effective new technologies. Competitively awarded grants are intended to stimulate collaborative research among integrated and interdisciplinary partnerships.

As specified in the act, the U.S. Department of Energy, U.S. Department of Agriculture, and five other federal agencies are coordinating research and development programs to promote biomass conversion technologies. The act also established an advisory committee (Biomass Research and Development Technical Advisory Committee) to provide strategic planning advice to the Secretaries of Energy and Agriculture. The advisory committee has predicted that national growth in bioenergy (including industrial use and electrical generation) will lag behind that of biobased transportation fuels and biobased products over the next 15 to 25 years (table 5).

Table 5—Feedstock resource vision goals for energy use in the United States, as established by the Biomass Research & Development Technical Advisory Committee

	National energy use			
Energy source	**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.

The National Fire Plan—
The National Fire Plan (NFP) was initiated 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" (NFP 2006a). The Secretaries of Agriculture and Interior cooperated in developing the plan.

An immediate task is to reduce fuel loads in the immediate vicinity of communities, zones often characterized by high densities of small stems having little or no value for solid wood products.

A goal of the NFP is to assist communities at risk 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, zones 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
- Accountability

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

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 2005b). An efficient appeals process is called for, including National Environmental Policy Act (NEPA) categorical exclusions to hasten the review process for selected projects where significant community risks could result if hazardous fuel removals become delayed by litigation.

Over a 4-year period ending in August 2006, fuel treatments had been conducted on more than 5.5 million acres of Department of the Interior and Forest Service lands in 11 Western States (table 6). Stewardship contracting projects are playing an increasingly important role in hazardous fuel removals, and 189 such projects had been authorized on Forest Service and USDI Bureau of Land Management lands as of fiscal year 2003 (table 7). On Arizona's Apache-Sitgreaves National Forest, an ambitious 10-year stewardship contract is underway, and after 1.5 years, more than 200,000 green tons of biomass have been removed, with 20,000 acres under contract (Zieroth 2006).

Over a 4-year period ending in August 2006, fuel treatments had been conducted on more than 5.5 million acres of Department of the Interior and Forest Service lands in 11 Western States.

Table 6—Fuel treatments[a] occurring on Department of the Interior and Department of Agriculture, Forest Service lands in Western States

	Fiscal year of treatment				
State	**2003**	**2004**	**2005**	**2006[b]**	**Total**
			Acres		
Arizona	191,266	223,264	228,176	172,519	815,225
California	184,899	243,977	243,548	122,111	794,535
Colorado	64,110	118,607	99,112	72,581	354,410
Idaho	135,192	185,813	153,055	106,238	580,298
Montana	52,602	115,186	119,971	66,937	354,696
New Mexico	123,621	197,773	176,795	122,423	620,612
Nevada	51,752	31,797	37,554	16,262	137,365
Oregon	208,562	345,829	368,554	227,734	1,150,679
Utah	73,381	92,761	97,387	70,879	334,408
Washington	33,194	68,128	58,764	50,274	210,360
Wyoming	36,531	55,188	56,126	24,547	172,392
Total	1,155,110	1,678,323	1,639,042	1,052,505	5,524,980

[a] Includes fire treatments and mechanical treatments within wildland-urban interfaces and "other" forested areas for the following agencies: Bureau of Indian Affairs, Bureau of Land Management, Fish and Wildlife Service, National Park Service, USDA Forest Service.
[b] As of August 2006.
Source: National Fire Plan 2006a.

Table 7—Stewardship contracting projects in Western States[a]

State	USDA Forest Service	Bureau of Land Management	Total
Arizona	6	2	8
California	24	5	29
Colorado	11	3	14
Idaho	16	4	20
Montana	35	2	37
Nevada	0	2	2
New Mexico	4	3	7
Oregon	26	4	30
Utah	8	5	13
Washington	17	0	17
Wyoming	9	3	12
Total	156	33	189

[a] Includes USDA Forest Service stewardship contracting pilot projects authorized under appropriations acts of FY 1999–2002, and Bureau of Land Management and Forest Service 10-year authority projects authorized under the Consolidated Appropriations Resolution of FY 2003.

Source: http://www.healthyforests.gov/projects_map.html.

Specific provisions of the HFRA (Office of the President 2005a) include:

- Reducing dense undergrowth, through thinning and prescribed burns, that could potentially fuel catastrophic fires.
- Improving public involvement in the review process by providing opportunities for earlier participation, thus permitting projects to be accomplished in a more timely fashion.
- Selecting projects on a collaborative basis involving local, tribal, state, federal, and nongovernmental entities.
- Focusing projects on federal lands that meet strict criteria for risk of wildfire damage to communities, water supply systems, and the environment.
- Encouraging biomass energy production through grants and assistance to local communities.
- Developing an accelerated program on certain federal lands to combat insect infestations.

The Billion Ton Initiative—

The Forest Service and the U.S. Department of Energy have evaluated the potential for the United States to sustainably displace 30 percent or more of domestic petroleum consumption with biofuels, a goal that would require 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 MODT (million oven-dry tons) per year, broken down into the following categories:

• Fuelwood harvested from forests	52 MODT per year
• Residues from wood products facilities	145 MODT per year
• Urban wood residues	47 MODT per year
• Logging and site clearing residues	64 MODT per year
• Fuel treatment operations to reduce fire hazards	60 MODT per year

Although biomass combustion produces a range of combustion products and gases (as do coal and other fossil fuels), several advantages are worth noting. Biomass burned for energy (whether from forest residues, mill residues, agricultural residues, or urban wastes) is renewable and can potentially be regrown in the near future, whereas fossil fuel sources are nonrenewable on any scale of time that matters to humans. In a sustainable system, carbon dioxide and other greenhouse gases emitted from biofuels during combustion are recaptured by growing biomass, resulting in no net increase in atmospheric greenhouse gases.

Energy Policy Act of 2005—
This act provides a long-range national energy strategy, including incentives for traditional energy technologies and for new technologies and energy efficiency measures. Some of the diverse areas covered within the act include tax credits for hybrid vehicle owners, clean coal energy, and increased residential energy efficiency. The following are some of the authorizations related to renewable energy production:

- Loan guarantees for "innovative technologies" that avoid greenhouse gases, which could include renewable energy.
- Increases in the amount of biofuel (primarily ethanol) that must be mixed with gasoline (to 7.5 billion gallons by 2012).
- Subsidies for wind energy and other alternative forms of energy.
- Ocean energy sources now recognized as renewable energy technologies, including wave power and tidal power.

Specific provisions of the act related to biomass energy include a $50 million annual authorization for biomass grants. Separately, the renewable electricity production credit was extended for 2 years (through the end of 2007), and includes a credit of 1.9 cents per kWh generated. For the first time, this credit includes "open loop biomass" systems (those in which biomass is not grown as an energy crop), potentially affecting millions of acres in western forests where hazardous fuel removals are driving biomass supply.

Notably, the Energy Policy Act of 2005 did not include a requirement that utilities purchase a certain percentage of energy from renewable sources (as many states are doing through renewable portfolio standards). However, there is a provision that the federal government purchase an increasing proportion of its power from renewables (reaching 7.5 percent in 2013). Nor were any climate-change-related measures included, such as greenhouse gas emissions caps, emissions inventories, or credit trading programs (Neff 2005).

Available Woody Biomass Resources in Western States

Estimated Biomass Resources

In the 15 Western States, more than 28 million acres of forest could benefit from hazardous fuel removals, yielding an expected 345 MODT of material.

There are extensive biomass resources throughout the Western United States, and estimates differ 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 MODT of material that should be removed from accessible areas to reduce fire risk (Rummer et al. 2003). The actual availability of biomass, for energy or other purposes, will depend on the stand management objectives (e.g., whether removals are part of harvesting operations in which merchantable timber is removed). This may be influenced to a large degree by land ownership, as about one-third of the 28 million acres mentioned earlier are on private lands. 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 MODT of nonmerchantable timber (including limbs, tops, and saplings).

Separately, biomass availability has been estimated at about 270 MODT for removals from 10.6 million acres (WGA 2005). This report assumed treatments only on forests producing at least 300 ft^3 (about 4 ODT) per acre per year, and considered merchantable removals (including pulpwood, lumber, posts, and poles) separately from biomass removals. Skog et al. (2006) identified 59.2 million acres of timberland in 12 Western States having high risk 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 d.b.h. and greater).

Still other estimates consider annual availability for price ranges likely to reflect market values. Biomass resource availability is estimated for Western States at prices ranging from \$25 to \$55 per ton (Bain et al. 2003) (table 8). However, no assumptions about spatial distribution or transportation distances are made. Included in this evaluation were forest residues, wood products mill residues, urban wood wastes, and agricultural residues. A study by Ince et al. (2006) on the potential economic effects associated with extensive removals of biomass to reduce forest fuels suggested that although timber markets could economically use substantial

Table 8—Estimated biomass resource availability, by state and by price

State	Delivered price < \$25 per ton	< \$35 per ton	< \$45 per ton	< \$55 per ton
	Thousand dry tons per year			
Arizona	220	575	863	1,100
California	1,588	6,158	8,224	11,299
Colorado	181	652	3,357	3,582
Idaho	204	2,572	4,117	7,166
Montana	69	1,422	2,159	6,761
Nevada	184	315	333	337
New Mexico	168	424	961	1,082
North Dakota	327	558	2,507	21,043
Oregon	193	3,341	4,126	9,810
South Dakota	132	286	9,602	16,005
Utah	159	388	648	723
Washington	297	3,979	5,939	9,920
Wyoming	224	552	787	1,466

Source: Bain et al. 2003.

amounts of wood from fuel-reduction treatments, raw material prices and producer profits would be reduced significantly unless significant new markets, such as bioenergy plants, were developed.

Table 9 illustrates the complex nature of accurately estimating available biomass, even on a state-by-state basis. Three treatment scenarios are considered: harvesting residues, precommercial thinning residues, and fire reduction treatments, each having different treated acres and different assumed tons per acre of biomass removed. Further, four land ownerships are considered: national forest, other public, forest industry, and other private lands. Based on these methods, including harvests once every 35 years, the total biomass availability for Montana alone is estimated to be more than 136 MODT.

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.

Table 9—Potential biomass material available for feedstock in Montana, based on harvests occurring once every 35 years

Ownership	From harvest residuals[a]	From precommercial thinning[b]	From fire reduction treatment[c]	Total
	Million oven-dry tons			
National forest	8.964	7.438	27.654	44.056
Other public	4.071	3.378	12.559	20.008
Forest industry	3.827	3.176	11.807	18.810
Other private	10.916	9.058	33.676	53.650
Total	27.778	23.050	85.696	136.524

[a] Assumes 4.7 oven-dry tons (ODT) per acre of biomass.
[b] Assumes 3.9 ODT per acre of biomass.
[c] Assumes 14.5 ODT per acre of biomass.
Source: Emergent Solutions and Christopher Allen & Associates 2003.

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 (WGA 2005), a scenario of 6.2 MODT per year of biomass would be likely from just the 10.6 million acres mentioned earlier. This volume of wood fuel could supply at least 12 large (approximately 50 MW) electrical generation facilities.

Several factors have been identified that could make biomass energy production attractive for a specific site within Western States (Loeffler et al. 2006), including:

- An abundance of nearby national forest land.
- A growing population (particularly within wildland-urban interface areas).
- A significant amount of low-elevation forest in need of treatment.
- Public support resulting from having experienced a recent, severe fire season.
- Proximity to existing wood products manufacturing facilities.

Potential electrical generating capacity when using forestry residues for bioenergy has been estimated for Western States (table 10) (WGA 2005). Forestry-related biomass resources also occupy a significant share when considering other biomass resources, such as municipal waste, agricultural residues, landfill waste, and waste-water treatment (table 11).

Table 10—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: WGA 2006b.

Table 11—Potential annual electrical energy generation in megawatt-hours (MWh) from biomass allocated in Western United States

Biomass source	Annual electrical generation	Biomass sources
	MWh × 10^6	*Percent*
Forestry	16.6	20
Agricultural	28.4	34
Municipal wastes	28.4	35
Landfill waste (in place)	7.2	9
Waste water treatment	1.5	2
Total	82.2	100

Source: WGA 2006b.

Current market values for biomass fuel generally will not pay for all associated costs of harvest, collection, size reduction, and transportation.

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 harvest, 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, subsidy level (if any), and wood product options such as solid products versus chips. The study by Skog (Skog et al. 2006) found uneven-age 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 range 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).

Although extensive biomass resources are physically present throughout the Western States, economic utilization of biomass can be challenging even under the most favorable conditions of harvesting and transportation (Ince et al. 2006). Although there is clearly enough woody biomass in Western States to stimulate substantial bioenergy project development, a key question is how much material can be economically recovered. Managers of certain types of forest stands, especially those within wildland-urban interfaces, have strong incentives to remove relatively large amounts of biomass quickly, whereas bioenergy plants often require stable, long-term fuel supplies (typically 20 years or longer). The timeframe during which biomass removals occur will be an important variable affecting the success of both hazardous fuel reductions and bioenergy production.

Tools for Evaluating Biomass Resources

Forest Inventory and Analysis—

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. The 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 MODT 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 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—

The FIA source data can be used to develop management tools, such as “Biosum” (Fried et al. 2003). Biosum can be used to estimate, at a landscape scale, how revenues from forest thinnings offset treatment costs, for example, when providing woody biomass as a power-plant feedstock. 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 (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 75, 79, or 94 million green tons, depending on whether revenue maximization, harvest volume, or torching index criteria were used, respectively (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 less than 50 percent of the forested acres in this study area would be amenable to fuel treatments owing to poor access, reserved status of lands, or low basal area of stands (Fried and Christensen 2004).

Fuel Treatment Evaluator (Forest Vegetation Simulator)—
Other tools developed by the Forest Service can be used to evaluate specific harvesting sites. Among these tools is the Fuel Treatment Evaluator (FTE), which 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 fully 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. The FTE has been used to identify close to 8 GT (gigatons, or billions of tons) of treatable timberland biomass nationally (Perlack et al. 2005).

My Fuel Treatment Planner—
My Fuel Treatment Planner is an economic tool developed by the Forest Service to help forest planners develop harvesting prescriptions and analyze costs related to fuel-reduction treatments (Biesecker and Fight 2006). The model requires detailed information on the sites to be treated and is operated as an add-on to conventional spreadsheet software. Its overall objective is to help users evaluate the cost of alternative treatments and compare those costs with the prices of products that might be recovered in order to determine whether a fuel-reduction operation could cover all or part of its costs.

Bioenergy Production in Western States

Electrical Power Generation

One of the earliest modern-era bioenergy plants, built in Springfield, Oregon, during the 1940s, was motivated by a need to dispose of sawmill residues in a controlled manner while reducing air pollution in the Willamette Valley. Most biomass energy facilities and cogeneration facilities developed over the next several decades were associated with wood products facilities and used manufacturing residues as a fuel source. Many of these energy facilities did not offer electricity for sale (Bain et al. 1996). Of the approximately 1,000 wood-fired plants currently operating in the United States, close to two-thirds are owned and operated by wood products industries, including paper mills.

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, 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 at Hurt, Virginia, is capable of generating 67 MW, but is a peaking facility (generating power only

Technology and design improvements in wood fuel dryer or steam cycles could allow wood-fired electrical systems to become more efficient in coming years.

during periods of peak demand). The McNeil generating station in Burlington, Vermont, is a large (52 MW) facility 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 (table 12). Technology and design improvements in wood fuel dryer or steam cycles could allow wood-fired electrical systems to become more efficient in coming years. These improvements could help lower the capital costs of wood-fired plants from $2,000 per kW of installed capacity (today's average) to about $1,275 per kW of installed capacity (Bain and Overend 2002).

Table 12—Biomass capital cost estimates for electrical generating facilities

Plant output	Estimated capital cost per megawatt	Total capital cost
Megawatts	*Thousand dollars*	*Million dollars*
15	2,200	33.0
20	1,900	38.0
30	1,750	52.5
40	1,600	64.0
50	1,550	77.5
60	1,500	90.0
70	1,475	103.3

Source: Bain et al. 1996.

The California Wood Energy Story

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 and special payments for bioenergy facilities during their initial years of operation.

In 1994, steps were taken by the California Public Utilities Commission to restructure the state's electric industry. As a result, some bioenergy facilities were closed after just a few years of operation, including three plants under common ownership in the San Joaquin Valley. In this case, the local utility bought out the contracts of the power plants (paying more than they would have received by continuing to generate energy), while still saving the utility money (WGA 2005). In a similar manner, Southern California Edison offered $127 million to terminate the power purchase contract with Colmac Energy (Mecca, California), claiming that rate payers would save up to $58 million versus continuing with the original contract (WGA 2005).

Other regions of California were also affected. Between 1980 and 1999, the number of operating bioenergy facilities declined by 28, representing a 264-MW reduction of generating capacity. Of these, 14 plants were idled and 14 were dismantled. Recently, three more plants were idled, an additional loss of 51 MW of generating capacity. Currently, only 26 plants are operating with an aggregate generating capacity of 550 MW (table 13). 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.

Table 13—Number and status of California's biomass-to-energy facilities (2001)

Status	Number of plants	Generating capacity
		Megawatts
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.

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. Facilities having multiple feedstocks within an economic transportation radius are more likely to continue operation during periods of temporary supply shortages. For example, Wheelabrator Shasta (Anderson, California) is one of the largest stand-alone facilities in California at 50 MW net generation capacity, burning waste materials from each of the four feedstocks previously mentioned (WGA 2005). Colmac Energy (Mecca, California) and Tracy Biomass Plant (Tracy, California) both have burned urban wood wastes and agricultural residues.

Case Studies—Electric Power From Biomass

Wheelabrator Shasta Energy Company, Anderson, California—
This facility is one of the larger wood energy electrical plants in California. It is designed at 50 MW net generating capacity and processes about 350,000 to 400,000 ODT per year of mill wastes and forest residues (WGA 2005). This wood volume

equates to about 100 green tons per hour, or one chip van every 15 minutes around the clock, in order to keep the facility running. Total staffing for this facility is 45 full-time positions.

By the early 1990s, competition for wood fuel in northern California had become great, with residues from wood products plants meeting only about 50 percent of the estimated needs of 400 MW of biomass generating capacity (WGA 2005). Seeking alternative biomass sources, the Wheelabrator Shasta facility added eight other fuels to its permitted list, including agricultural residues, fuel from clearing and development projects, and yard and urban wastes. Unmerchantable (cull) logs up to 6 feet in diameter can be chipped on site for fuel (Wheelabrator Technologies, Inc. 2004). Fuel is blended in a three-stage process to ensure a uniform mix of biomass as it enters the combustor. A novel fuel source being used by this facility is plantation-grown eucalyptus species, harvested on a 7-year rotation, from a fiber farm within 50 miles of the power plant.

Tracy Biomass Plant, Tracy, California—
The Tracy Biomass Plant (Tracy, California) is an 18.5-MW (net) wood-fired electrical plant burning 100,000 to 120,000 ODT per year of biomass from urban wood wastes and orchard wood wastes. Orchard wastes are typically about three times as expensive as urban wood wastes, although both fuel types are used in approximately equal amounts. The Tracy, California, plant came online in 1990, and received the ISO4 subsidy until 2000. This facility has a high-visibility location, approximately 35 miles east of Oakland, California, next to a major highway. Numerous outreach efforts have informed and involved the public in renewable issues and environmental benefits associated with this plant, including Ag Fairs, Chamber of Commerce meetings, and various activities with school students and teachers.

San Joaquin Valley Energy Partners, El Nido, Chowchilla, and Madera, California—
This group of three power plants is under common ownership and all are located within a 25-mile radius in central California, near Fresno. These facilities range from 10 to 25 MW in size, all use bubbling fluidized bed boilers, and have successfully burned more than 35 types of agricultural and wood wastes (and are permitted to burn more than 50 types). Whereas most of the California biomass plants have focused on higher grade wastes (such as clean orchard or urban residues), the San Joaquin group has sought a niche market in lower grade, lower cost wastes, including those rejected by other biomass plants. These wastes included four primary categories:

- Woody agricultural wastes (derived from whole orchard removals and orchard pruning)
- Miscellaneous agricultural wastes (derived from processing agricultural produce)
- Urban wood (including construction wood waste and urban tree removals)
- Forest wood wastes (including harvesting residues)

Colmac Energy, Mecca, California—
This 49-MW facility is the largest user of urban wood wastes in California, receiving 1,000 to 1,200 ODT per day, primarily from the Los Angeles area. The remaining 10 to 20 percent of fuel requirements are met by agricultural residues from nearby orchards. Petroleum coke is at times burned to lower overall fuel costs.

Kettle Falls Power Plant, Kettle Falls, Washington—
This plant is rated at 46 MW design capacity, and was inaugurated in 1983. At the time, it was the largest utility-operated, stand-alone biomass power plant in the Nation (WGA 2005). Fuel consumption is about 500,000 green tons per year of residues from about 15 log-processing plants in Washington, Idaho, and British Columbia within about a 100-mile radius. Average one-way haul distance is about 46 miles. The plant has been able to run entirely on mill residues (hog fuel) from the area mills, and on occasion has found it necessary to curtail deliveries from some mills (including those in Canada) because of surplus fuel inventories.

City of Tacoma, Washington—
The city of Tacoma operates a multifueled facility that has fluidized bed combustors and can burn wood, coal, and refuse-derived fuel (RDF) (WGA 2005). Although on average this plant has burned 60 percent wood, 20 percent RDF, and 20 percent coal, it was placed on reserve shutdown in 1998 pending developments in electricity markets in supplies of municipal solid waste. When it did burn wood waste (approximately 1993 to 1997), about 64 percent was from wood products mills and logging operations, 23 percent from land clearings, and 13 percent from urban and industrial residues.

Williams Lake Power Plant, Williams Lake, British Columbia, Canada—
The Williams Lake Generating Station in British Columbia is the largest single-unit, continuously operating biomass energy plant in North America, with a design capacity of 60 MW (WGA 2005). This facility consumes more than 550,000 green tons of mill residues per year, and was motivated by inefficient burning (and associated smoke problems) by five local sawmills each burning waste residues separately. All five sawmills are located within about 3 miles of the wood energy plant, and supply

fuel at no cost (transportation costs are paid by the power plant). Short-haul delivery trucks are used, although conveyors belts linking the sawmills to the power plant were considered. The power plant also paid about $2 million at each sawmill for fuel-preparation equipment. Fuel composition is about 40 to 50 percent bark and the remainder sawdust, chips, and slabs.

Snohomish County PUD/Kimberly-Clark Corporation, Everett, Washington—
This facility is a 43-MW cogeneration facility operating at a paper mill in Everett, Washington, and entered full production in 1996 (WGA 2005). Primary wood fuel sources include mill wastes (bark and hogged residues from mills around Puget Sound, the Olympic Peninsula, and British Columbia), and urban wood wastes (including pallets and land-clearing debris). The mix of fuel has been about 40 percent mill residues and 60 percent urban wastes, with a trend toward increasing urban wastes.

Camas, Washington—
This facility, located on the Columbia River 15 miles east of Portland, Oregon, is part of a paper mill complex in which one of the five boilers uses hog fuel (the others use black liquor and natural gas). Each boiler is capable of burning multiple fuels, enhancing the system's overall flexibility. The hog fuel boiler generates an equivalent of about 23 MW from wood wastes, and was constructed at a cost of about $2,300 per kW of generating capacity.

Biomass utilization at the Eagar facility is a key component of the White Mountain Stewardship Contract, in which 8,000 to 15,000 acres of national forest lands are planned for treatment over the next 10 years.

Western Renewable Energy, Eagar, Arizona—
The Eagar biomass plant is a 3-MW facility that started power production in February 2004 and uses about 100 tons per day of thinnings from nearby Apache-Sitgreaves National Forests. Biomass utilization at the Eagar facility is a key component of the White Mountain Stewardship Contract, in which 8,000 to 15,000 acres of national forest lands are planned for treatment over the next 10 years (National Fire Plan 2004). The wood fuel cost at the Eagar plant is less than $10 per ODT, allowing electricity to be produced for just 7.7 cents per kWh. This fuel cost is considerably below the typical range of $10 to $40 per ODT (Johnston 2004). This project is significant in that it was initiated by using Economic Action Program (EAP) funds and in response to regional fuels-reduction objectives. The Forest Service provides grants through EAPs to "help rural communities and businesses dependent on natural resources become sustainable and self-sufficient" (US GAO 2005).

Snowflake White Mountain Power, Snowflake, Arizona—
A biomass plant currently under construction near Snowflake, Arizona, is expected to generate about 20 MW of energy, of which at least 80 percent will be from forest thinnings. Biomass sources are to include wildfire-damaged timber (from a recent 450,000-acre fire), and waste from an adjacent paper mill.

Wood Residue Utilization Within the Forest Products Industry

Nationwide, the primary wood products industry produced about 91 MODT of residues in 2002, of which 89 MODT were recovered, burned, or otherwise used, leaving less than 2 MODT for new bioenergy project development (Perlack et al. 2005). In Western States, the wood products industry has traditionally produced substantial amounts of mill residues, including 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 onsite process 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, fewer mills are accounting for a larger portion of the "mill residue pie" (fig. 1). Increases in mill

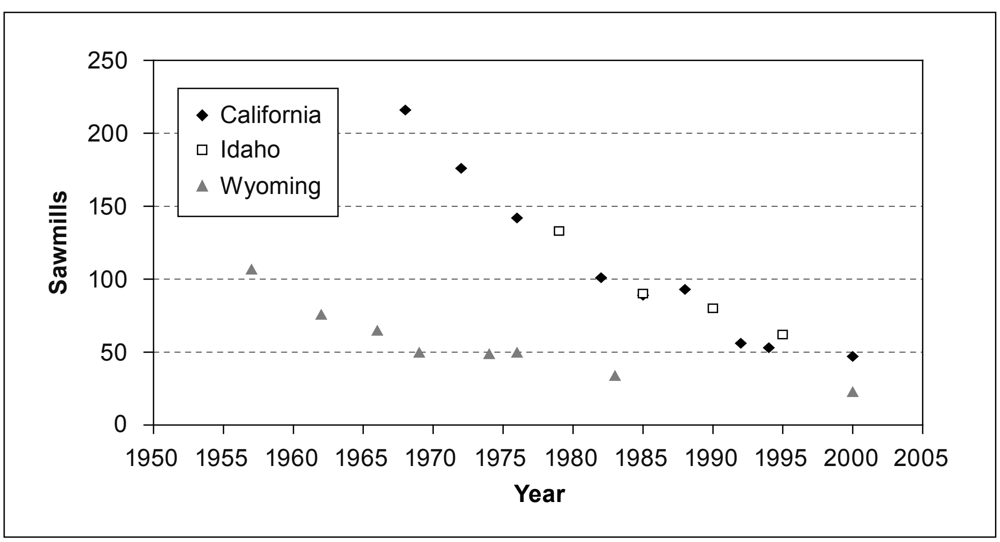

Figure 1—Number of active sawmills in selected Western States (1957 to 2000).
Sources: Morgan et al. 2004a, 2004b, 2005.

In many Western States, sawmill residues are already almost fully utilized, and therefore could contribute little to a developing bioenergy industry.

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 technology advances in sawing and planing. For example, lumber recovery (Scribner basis) in Idaho increased by 39 percent between 1979 and 2001 (Morgan et al. 2004b). In 2004, average lumber recovery factor, another measure of sawmill efficiency, was greater in the U.S. West region (at 8.52 board feet per cubic foot) than in any of the other 7 regions evaluated (Spelter and Alderman 2005). Even though 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 (table 14) and in Idaho (table 15), coarse residues, fine residues, and bark generated by sawmills are all utilized between 97 and 100 percent. In Wyoming, almost all coarse and fine residues are also utilized. However, 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 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 MODT during 2004. However, 2.2 MODT were consumed by residue-utilizing firms. The excess residue needs (0.7 MODT) were either met 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 less 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 thermal energy systems. Also in Colorado, a cement plant near LaPorte is considering converting from fossil fuels to wood energy, which would require up to 350 ODT per day, of which mill residues could play a role (Ward et al. 2001).

Table 14—Volume of wood residue generated by California's sawmills in 2000

Residue type	Wood residue					Type percentage
	Used		Unused		Total	
	BDU	*Percent*	*BDU*	*Percent*	*BDU*	*Percent*
Coarse	1,265,090	98.0	26,000	2.0	1,291,090	45
Fine	852,956	99.0	8,367	1.0	861,323	30
Bark	699,029	97.2	19,873	2.8	718,902	25
Total	2,817,075	98.1	54,240	1.9	2,871,315	100

Bone-dry unit (BDU) = 2,400 pounds of oven-dry wood.
Source: Morgan et al. 2004a.

Table 15—Volume of wood residue generated by Idaho's sawmills and plywood/veneer plants in 2001

Residue type	Wood residue					Type percentage
	Used		Unused		Total	
	BDU	*Percent*	*BDU*	*Percent*	*BDU*	*Percent*
Coarse	806,460	99.6	3,325	0.4	809,785	46
Fine	544,556	100	3	< 0.1	544,559	31
Bark	401,031	100	43	< 0.1	401,074	23
Total	1,752,047	99.8	3,371	0.2	1,755,418	100

Bone-dry unit (BDU) = 2,400 pounds of oven-dry wood.
Source: Morgan et al. 2004b.

Government, Schools, and Other Institutional Applications

Thermal energy—

Thermal bioenergy systems are typically used to heat water that is then circulated to heat buildings. The heat output of these systems is typically measured in units of million British thermal units (MBTU) per hour. Thermal systems for institutional applications are typically sized in the 1 to 10 MBTU per hour range, and are large enough to have automated fuel handling and feeding systems (Maker 2004). However, in certain cases, capital cost savings can be realized when at least part of the fuel handling is not fully automated, having potential applications to smaller systems. 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 buildings requiring heat.

Bioenergy for small-scale institutional use in Western States has been exemplified by the "Fuels for Schools" program.

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 also encompasses other Western

States. To date, 6 systems have been completed and are fully operating, 11 are under construction, and close to 47 sites have had prefeasibility assessments (table 16). This program has been modeled after a successful school bioenergy program in Vermont. The primary difference between these programs is the use of sawmill residues in Vermont (Maker 2004) versus thinned material adjacent to communities in Western States. Twenty Vermont schools used an average of 359 green tons per school during the 1997 to 1998 school year, ranging from 75 to 700 green tons per school (Vermont Department of Public Service 2006).

Table 16—Fuels for Schools status, number of facilities, and locations (as of June 2006)

Wood energy project status	Number of facilities	Location
Completed and fully operating	6	Darby, Montana Phillipsburg, Montana Thompson Falls, Montana Victor, Montana Council, Idaho Ely, Nevada
Under construction	11	Browning, Montana Deer Lodge, Montana Dillon, Montana Eureka, Montana Kalispell, Montana Lewistown, Montana Townsend, Montana Troy, Montana Carson City, Nevada Burleigh County, North Dakota Kellog, Idaho
Prefeasibility assessments completed	About 47	Montana (29 locations) Idaho (9 locations) Nevada (1 location) Utah (2 locations) Wyoming (2 locations) North Dakota (4 locations)

Source: Fuels for Schools 2006.

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. For example, thinning ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in western Montana could generate about 10 green tons of wood residue per acre if treated on 20- to 30-year cycles. A system such as Darby, Montana, has for its schools, burning 700 green tons of biomass each year, would require about 2,000 acres of forest to sustain it, if treated on this basis (Associated Press 2005).

Recent successes with the Fuels for Schools program could set the stage for the widespread adoption of thermal heating systems in schools throughout Western States and perhaps nationally. With most schools using less than a few thousand tons of biomass per year, the overall impact at reducing regional hazardous fuel loads is not likely to be significant. However, the benefits in reducing fire risk in localized zones surrounding at-risk communities could be substantial.

New Advances in Wood Energy

Small-scale gasification for electrical generation—

Biomass gasification is a three-step process that includes gasification in a reactor to create producer gas, followed by cleaning the producer gas, and then combustion within an engine (Abatzoglou et al. 2000). Although biomass gasification is not a new technology, recent advances have enabled small-scale gasification to become advantageous in community power applications.

A small modular biomass (SMB) power system has been developed for use in rural electrical markets (Scahill et al. 2002). This system was originally designed to produce 12.5 kW of sustained electricity (enough power for just a few households), and uses a fixed-bed, down-draft gasifier design. It is currently being used successfully with units ranging from 5 kW to 15 kW, and 50 kW to 100 kW units are under development (Zerbe 2006). Gases are ignited in an internal combustion engine coupled to an electric generator. Waste heat can be used to dry wood chips to about 25 percent moisture content to improve gasification efficiency. One evaluation indicates an estimated payback period of 3.1 years for an SMB operating 16 hours per day, 300 days per year (assuming a 12-cent per kWh market value for electricity) (USDA Forest Service 2004).

Community Power Corporation (Littleton, Colorado) lists SMB installations in Hoopa, California; Ruidoso, New Mexico; Walden, Colorado; and Zuni, New Mexico (Community Power Corporation 2006). These units are all 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 (Gardner, Massachusetts). This system has expected energy savings of $276,000 per year, and a simple payback period of about 9 years (Livingston 2006).

Delivered fuel costs and scale of operation are important considerations for small modular biomass as well as other wood energy systems.

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
- Filters to reduce tar concentrations in raw gas to less than 100 parts per million

Delivered fuel costs and scale of operation are important considerations for SMBs as well as other wood energy systems. One study evaluating conditions in southern Oregon determined that, in theory, a 1,000-kW Biomax system (about 10 times the size of prototypes now in development) could operate profitably if a tax credit of 1.8 cents 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). This study also mentioned the advantages of locating wood energy facilities at or near forest landings that are also near power lines, reducing both transportation costs and electrical grid connection costs.

The National Renewable Energy Laboratory (NREL) is working with several industry partners to develop new biopower technologies. Several scales of small modular biomass development include:

- 5 to 25 kW (Community Power Corporation; small modular biomass gasifiers)
- 30 to 60 kW (Flex Energy; low heating gases)
- 2 to 5 MW (Carbona Corporation; updraft gasifiers)

This Department of Energy Small Modular Biopower Initiative is also considering the use of Stirling engines as the prime mover (External Power LLC). A Stirling engine is a closed system that generates work from the expansion and contraction of a sealed gas as a result of externally applied heat and cooling cycles. Stirling engines also have applications for solar power. Recently, a contract was signed to provide San Diego between 300 and 900 MW using Stirling solar dish technology (Stirling Energy Systems 2005). This technology is the most efficient device for the conversion of solar energy to grid-delivered electricity, nearly twice as efficient as any alternative solar technology (Stirling Energy Systems 2005).

Advances in distributed energy (district heating)—
District heating, distributed energy, or decentralized heating all refer to systems in which a single power plant provides heat, usually by circulating hot water through a series of underground pipes, to more than one building. Such systems are widespread in cities across the former Soviet Union. One of the most advanced developments of distributed energy systems is in Austria, where 266 units were in operation in 1995 (Obernberger 1998). In one region of Austria (Upper Austria), more than 160 biomass distributed heating facilities have been installed since 1994, generating more than 705 MW_{th}[1] (Egger et al. 2001).

One of the largest and most sophisticated systems is Fernwärme Wien, a network of 10 interconnected plants, including the Spittelau Thermal Waste Treatment Plant in Vienna, Austria (fig. 2). Fernwärme Wien processes more than 1200 metric tons of city waste per day, distributing heat and hot water to more than 200,000 dwellings and 4,400 industrial customers in Vienna (Hewlett-Packard Development Company 2004).

[1] MW_{th} = thermal megawatts or heat energy.

Robert Monserud

Figure 2—The Spittelau Thermal Waste Treatment Plant in Vienna, Austria (Fernwärme Wien).

In the United States, successful distributed heating projects include those in Montpelier, Vermont (the Vermont Capitol complex), and Waterbury, Vermont (the Vermont State Office complex). A large-scale example of distributed heating is found in St. Paul, Minnesota, where a 25-MW combined heat and power plant, fueled with wood waste, provides heat to more than 75 percent of the downtown area. This project is the largest wood-fired distributed heating system in the United States, consuming about 280,000 tons of urban wood waste per year. In Canada, Charlottetown, Prince Edward Island, a distributed heating system heats 84 buildings by using municipal waste and sawmill residues as fuel. Mount Wachusett Community College (Massachusetts) is another example of successful distributed heating (among other renewable energy uses) (Rizzo 2006).

The University of Idaho operates a steam generating plant that converted from natural gas to wood residue fuel over 15 years ago (Kirkland et al. 1991). The fuel source is chipped or hogged fuel, 35 to 50 percent moisture content (green basis). High-quality, lower moisture fuel is blended with wet hog fuel to increase heating values when steam loads are high. More than 60 campus buildings are heated by the biomass-fired boiler, saving more than $1.5 million per year compared to natural gas (University of Idaho 2005).

Barriers to Biomass Utilization in the Western United States

Several classes of barriers to national biomass-to-electricity development have been identified (Bain et. al. 2003), many of which could also be barriers to biopower development in Western States. These include:

- Technology barriers
- Combustion co-firing barriers
- Gasification barriers
- Small systems barriers
- Feedstock production, harvest, transport, preparation barriers
- Institutional barriers
- Regulatory barriers
- Financial barriers
- Infrastructural barriers
- Perceptual barriers

Barriers to utilizing biomass in the Western States all point to one central issue: rarely will the value of biomass products pay for the costs of harvesting, collecting, and transporting to markets.

Barriers to utilizing biomass in the Western States all point to one central issue: rarely will the value of biomass products pay for the costs of harvesting, collecting, and transporting to markets. For example, whereas 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 (versus treatment by prescribed fire only).

Federal agency officials (US GAO 2005) cited two primary barriers to increased use of woody biomass: cost-effective use of materials (especially harvesting and transportation costs), and lack of reliable supply. 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 (US GAO 2005). A lack of long-term contracts (up to 10 years) was cited as another obstacle for successful biomass use.

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

- Accessibility, including steep slopes and environmentally sensitive areas
- Marketing larger diameter trees for higher value products, separately from biomass
- 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 lowered as specialized, more efficient harvesting equipment becomes developed
- 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 small wood 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 influencing net financial returns on 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 required subsidies of either $300 or $600 per acre (depending on whether a market for pulpwood was present).

A fuel 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), which more than compensated for pulpwood losses (Brown and Kellogg 1996). Skidding/yarding operations have been identified as an important cost component, with costs in Montana ranging from $25 per thousand board feet (rubber-tired grapple skidder) to $182 per thousand board feet (helicopter systems) (Keegan et al. 1995).

In biomass harvesting, it is important to distinguish between forest thinnings scheduled as normal forest management activities versus thinnings (or clearings) to reduce hazardous fuel loads so that fire risk is reduced. For example, for Montana forests it has been estimated that small-diameter underutilized material could yield 4.7 ODT per acre for harvest residuals, 3.9 ODT per acre for precommercial thinnings, and 14.5 ODT per acre for fire reduction treatments (Emergent Solutions and Christopher Allen & Associates 2003). It was assumed that harvesting would occur once every 30 to 35 years, and would be from roaded areas having slopes of less than 40 percent. Separately, comprehensive forest restoration treatments (Ravalli County, Montana) could yield 12 to 14 green tons per acre (Loeffler et al. 2006).

In the Front Range of Colorado, three forest restoration thinnings were completed at an average net loss of about $491 per acre (Ward et al. 2004). Reasons cited included poor log quality and a transportation distance of more than 250 miles from harvest site to sawmill. In another Colorado location, 160 acres were treated on three thinning sites, with an average financial loss of $37 per green ton of logs harvested (Ward et al. 2004). This study estimated that forest restoration projects along Colorado's front range could conservatively yield 9 to 15 green tons per acre, with about 90 percent of removals being less than 12 inches d.b.h.

In general, fire-hazard-reduction treatments can be of three types: a mechanical thinning, thinning followed by prescribed fire, or prescribed fire (without thinning) (Fight et al. 2004). The volume of biomass removed during fuel treatments can differ considerably, depending on the harvest objectives and whether or not harvests are part of normal forest management activities (as compared to hazardous fuel removals). Further, silvicultural treatments can include combinations of mechanical removals and prescribed fire, creating more complex scenarios. For example, one simulation study chose the following two scenarios (Fight et al. 2004):

1. Thin from below to 9-inch d.b.h. (with a minimum basal area), then burn in 10 years, followed by burning at 20-year intervals. Reevaluate stand conditions and thinning options at 30-year intervals.
2. Thin from below to 16-inch d.b.h. (with a minimum basal area), then burn in 10 years, followed by burning at 20-year intervals. Reevaluate stand conditions and thinning options at 30-year intervals.

New, more efficient harvesting equipment could greatly influence the way biomass is removed from the woods (fig. 3). For example, energy wood harvesters compact and bundle wood into bales weighing about 0.5 ton 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). This work considered the influence of terrain (including slope and travel distances), species, pretreatment conditions (including scattered logging slash and landing piles), and specific stand conditions (such as volume per acre, material size, and residual stem spacing). When considering the capital cost of this equipment (about $450,000), profitably 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).

New, more efficient harvesting equipment could greatly influence the way biomass is removed from the woods.


Dennis Dykstra

Figure 3—Commercial energy wood harvester, transporting biomass.


Dennis Dykstra

Figure 4—Commercial energy wood harvester, with bundler unit.

Rather than being bundled, most biomass removals today are reduced prior to transport, either by grinding or by chipping. Wood chips are the fuel of choice for many conventional wood energy systems, and are more easily transported and conveyed than many other types of wood fuel. Chipping could occur either in the woods at the harvest site, at a centralized landing or concentration yard, or at the site of the energy generating facility. A disadvantage of wood chips is that the density of a truckload of wood chips is low, making transportation costs relatively expensive. Chip trucks may be difficult to maneuver on narrow forest roads and small landings, and in some cases unable to navigate at all.

Transportation costs are often an important factor when considering biomass project development.

Biomass Transportation

In the intermountain West, biomass resources are often dispersed and located at considerable distances from wood energy conversion facilities. Thus, transportation costs are often an important factor when considering biomass project development. Bioenergy plant profitability can depend on several logistic variables, including vehicle capacity, vehicle transportation costs, purchased biomass costs, and distribution density, and is directly related to the scale of operation, at least within the range of 5 to 50 MW (Caputo et al. 2005).

Terrain and road conditions can influence transportation costs, which can differ greatly depending on whether fuel deliveries are mill residues or forest harvesting residues. 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 (Bilek et al. 2005, Perlack 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, 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.

A potentially important consideration is the energy expended in harvesting, reducing, and transporting biomass material versus the energy available for combustion. For small-scale chip production, the energy requirements for chip production alone versus the energy content of the fuel had a ratio of 1:38 (Schneider 1987). Energy expended in harvesting and transportation would negatively influence this ratio.

Discussion

Western U.S. States have substantial biomass resources, including material from forest thinnings (both commercial and restoration thinnings), 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. For bioenergy projects to be successful, five primary elements are needed: biomass supply, transportation, handling, conversion, and electrical power generation (Bain and Overend 2002). The biomass supply needs to be steady, reliable, and lasting for the expected life of the project. Community support, often enhanced by local "project champions," is generally regarded as a key factor influencing the success of such projects.

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 (Fight et al. 2004, Larson and Mirth 1998, LeVan-Green and Livingston 2001, Rummer et al. 2003, Skog et al. 2006, Wagner et al. 1998). In many instances, the best-case scenario is to minimize harvesting cost deficits by producing higher value products from larger stems (such as solid wood and engineered wood products) or attempting to offset production costs through subsidies or credits.

For example, in one simulation study, none of the scenarios under consideration showed that harvested material would cover the cost of forest thinnings, given existing markets for small-diameter stems less than 9.5 inches in diameter (Fight et al. 2004). 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. Removing merchantable stems along with biomass during harvests may provide greater economic benefits, while decreasing fire risk in overstocked stands.

For successful bioenergy development, biomass removals will need to occur over longer timeframes so that capital costs can be recovered.

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 the Interior and Department of Agriculture lands have already been treated through the National Fire Plan in Western States (see table 6). This total includes fire treatments 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 timeframes (often 20 years or longer) so that capital costs can be recovered.

Innovative approaches are needed for providing infrastructure to harvest and transport relatively small amounts of biomass.

An important part of these hazardous fuel removals has been more than 189 successful stewardship contracts, that have been implemented by the Forest Service and Bureau of Land Management (see table 7). Stewardship contracts are becoming longer in duration (often up to 10 years) and covering larger acres. 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.

Biomass heating of schools and other community buildings can use hazardous fuel removals, although bioenergy systems are often relatively small. They typically use up to a few thousand tons per year, and in some cases only a few hundred tons per year. More than 17 facilities are under construction or in operation through the Fuels for Schools program in Western States (see table 16). 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, government 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, over 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. This underscores the importance of using biomass from hazard-fuel-reduction projects if new bioenergy facilities are to be established in Western States.

Successful utilization of biomass for energy in Western States will require maintaining economic harvest systems (as harvest locations become more dispersed), and the use of combustion systems that are designed to handle a variety of fuel types. 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 byproducts, and wood shavings (LeVan-Green and Livingston 2001). Emerging technologies such as wood-plastic composites (Yadama and Shook 2005) or the TimTek® scrimber process (Jarck and Sanderson 2000, Sheriff 1998) could also help produce a positive economic balance in a fire-hazard-reduction project. Larger mills in Western States, for example Idaho and Montana, are more efficient at log processing and residue utilization, and therefore are not in a position to supply large amounts of residue for new bioenergy project development. 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.

For new bioenergy technologies, the role of government can be instrumental in stimulating innovation and development. Because biopower is currently about 1 to 4 cents per kWh more expensive than leading market options, government support likely will be needed to induce private investment in this area. For example, $4.4 million in grant funding was announced by the Forest Service for projects to "increase the use of woody biomass that is removed from national forest lands in the effort to reduce hazardous fuels" (USDA Forest Service 2006). In this program, successful applicants were to be announced in 2005, with individual awards ranging from $50,000 to $250,000.

Incentives need to have a long time horizon to be effective, possibly requiring at least 20 years for bioenergy project development. Recall that Brazil subsidized ethanol fuel production from plant biomass (sugar cane) for two decades before ethanol became a viable energy source that no longer requires a subsidy. The Billion Ton Initiative report (Perlack et al. 2005) and the 25 by '25 initiative (setting a goal of 25 percent renewable energy by 2025) are two examples of largely government collaborations that have a long-range focus. This initiative, encompassing agriculture and forestry sectors, has already garnered the support of 26 states through either state alliances or governors' endorsements (http://www.25x25.org).

A key to success for large-scale electrical facilities could be flexible systems designed to accept a variety of fuels. For example, Wheelabrator Shasta Energy in Anderson, California, can accept wood products mill wastes, wood chips, and large cull logs (Wheelabrator Technologies, Inc. 2004). Bioenergy systems such as these can produce up to 50 MW of electrical power, requiring approximately 500,000 tons per year of biomass. Use of agricultural residues in addition to wood allows for additional flexibility in obtaining secure fuel supplies throughout the year while requiring only minimal modifications for fuel storage and handling systems. Bioenergy facilities that become too dependent on a single fuel source (e.g., residues from harvests on national forest lands) risk closing if that fuel source is interrupted.

Perhaps the biggest success factor for bioenergy projects in the West will be finding appropriate niches among other renewable energies.

Perhaps the biggest success factor for bioenergy projects in the West will be finding appropriate niches among other renewable energies. A target for Western States to generate 30,000 MW of electricity from "clean and diversified sources," has been established by 2015 (WGA 2005). In California and other states, the use of wood for energy will be competing with other conventional and renewable sources for a place within electrical energy portfolios. Consumer awareness of "green power" programs (and willingness to pay for them) could also become a driving force for increased use of bioenergy and other renewables.

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 classes of 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 be lower than that for biomass (NREL 2002).

Abbreviations

BTU	British thermal unit
d.b.h.	diameter at breast height
EAP	Economic Action Program
FIA	Forest Inventory and Analysis
FTE	Fuel Treatment Evaluator
GW	gigawatt
GT	gigaton
ISO4	Interim Standard Offer
kT	kiloton (or thousand tons)
kW	thousand watts
kWh	kilowatt-hour
HFRA	Healthy Forest Restoration Act
MT	megaton (or million tons)
MW	megawatt
NEPA	National Environmental Policy Act
NFP	National Fire Plan
NREL	National Renewable Energy Laboratory
ODT	oven-dry ton
ppm	parts per million
SMB	small modular biomass
WGA	Western Governors' Association

Glossary

biobased product—Any manufactured, commercial, or industrial good (non-food) that is made up of biological materials or agricultural resources. Such materials may come from the byproducts of animals, plants, or other biological sources that are not petroleum based.

biomass—Living and recently living biological material that can be used as fuel or for industrial production (most often referring to plant matter grown for use as biofuel, but also including plant or animal matter used for production of fibers, chemicals, or heat).

British thermal unit—The amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

combustion—A complex sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat or both heat and light in the form of either a glow or flames.

forest residues—Typically includes branches, bark, needles, and woody material from the nonmerchantable portion of a tree stem.

gasification—A process that converts carbonaceous materials, such as coal, petroleum, petroleum coke, or biomass, into carbon monoxide and hydrogen.

greenhouse gasses—Components of the atmosphere that contribute to the greenhouse effect, including water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

green weight—The weight of oven-dry biomass plus naturally occurring moisture.

hazardous fuel reduction—Forest management treatments, often within or near wildland-urban interface zones, designed to reduce wildfire risk to people, property, or structures.

oven-dry (or bone-dry) weight—The weight of biomass when containing no moisture.

renewable energy—Energy derived from resources that are regenerative, including wind, water, solar, and biomass.

urban wood waste—A woody waste that includes predominantly household waste (domestic waste) or the addition of commercial wastes collected by a municipality.

watt—One joule (the SI unit of energy) per second.

wildland-urban interface—The area where structures and other human development meet or intermingle with undeveloped wildland.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	.3048	Meters
Miles	1.609	Kilometers
Cubic feet	.0283	Cubic meters
Acres	0.405	Hectares
Tons (U.S. short tons)	.907	Metric tons or megagrams
Tons per acre	2.24	Metric tons or megagrams per hectare
Megatons	907	Metric tons
Gigatons	907,000	Metric tons
Bone-dry unit	1.2	Bone-dry ton
Board feet (log scale)	.0045	Cubic meters, logs (approximate conversion)
British thermal units (Btu)	1,050	Joules
Million British thermal units per hour	.293	Megawatts
Million British thermal units per hour	.00029	Gigawatts
Therms	29.3	Kilowatt-hours (kWh)
Degrees Fahrenheit	.556 (F - 32)	Degrees Celsius

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