A Strategic Assessment of Forest Biomass and Fuel Reduction Treatments in Western States

United States Department of Agriculture
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In partnership with the Western Forestry Leadership Coalition

Fig. 1. Monument Canyon Research Natural Area, Santa Fe National Forest, NM

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A Strategic Assessment of Forest Biomass and Fuel Reduction Treatments in Western States

Summary

In the 15 western states there are at least 28 million acres of forest that could benefit from some type of mechanical treatment to reduce hazardous fuel loading. It is estimated that about 60 percent of this area could be operationally accessible for treatment with a total biomass treatment volume of 345 million bone dry tons (bdt). Two-thirds of this forest area is on public lands. Most of the volume is in trees 6 inches diameter and greater that have conventional utilization opportunities. Transportation cost and distance to markets, however, may preclude actual recovery. Treatment costs are increased by the need to treat large numbers of low-volume stems less than 4 inches in diameter. Gross costs can range from $35 to over $1000 per acre depending on type of operation, terrain, and number of trees to be treated. Some areas will likely be prohibitively expensive to treat, although cost estimates presented here may be high because they are based on the use of conventional timber harvesting systems applied to small diameter treatments. Implementation of any significant fuel reduction effort will generate large volumes of biomass and require the development of additional workforce and operations capacity in western forests.

The Issue

Natural fire cycles have been altered across large areas of the West, changing the vegetative character of many fire-adapted ecosystems, and increasing wildland fire risk and hazard. Responding to GAO Report 99-65, the USDA Forest Service outlined a strategy to address forest health and wildland fire problems in the West (Laverty and Williams, 2000). The Cohesive Strategy and the subsequent 10-year Comprehensive Strategy clearly identify key components of an effective approach to wildland fire:

a) *improve fire prevention and suppression*
b) *reduce hazardous fuels*
c) *restore fire-adapted ecosystems*
d) *promote community assistance*

Land management agencies have been actively addressing the need for both hazardous fuels reduction and restoration of fire-adapted ecosystems. In fiscal year 2001, the Departments of Interior and Agriculture treated 2 million acres across the nation at a cost of about $200 per acre (National Fire Plan 2002). Some areas have been treated with relatively low-cost methods such as prescribed fire while others have required more expensive manual or

Fig. 2. Prescribed fire, Francis Marion National Forest. SC

mechanical operations to reduce high fuel loading. Projects have been prioritized with an emphasis on areas that present risk to communities or significant ecological values.

While managing fire-adapted forests with prescribed fire is often the least expensive option to reduce hazardous fuels when utilization opportunities are limited, there are many areas and times where prescribed fire cannot be used. High fuel loadings, air quality restrictions, short windows of appropriate weather, and risk of escaped fire in the wildland-urban interface are some of the factors that limit application of prescribed fire. Thus, mechanical treatments remain an indispensable tool for land managers. However, to implement National Fire Plan objectives using mechanical treatments a significant barrier must be overcome--the disposal and/or utilization of significant quantities of small trees.

There is currently a lack of comprehensive information about the extent, condition, biomass volume and characteristics, treatment opportunities, and potential yields of western forests. Planners, contractors, and policy makers need to know where biomass volumes will be located and the size-class distributions of the treated material. Potential markets need information about material quantities and characteristics. This report provides a strategic assessment of biomass in western forests as a first step to help address this knowledge gap.

Fig. 3. Thinning slash pile, Coconino National Forest

Assessment Objective

The objective of this assessment is to characterize, at a regional scale, forest biomass that can potentially be removed to implement the fuel reduction and ecosystem restoration objectives of the National Fire Plan for the western U.S. The assessment area covers forests on both public and private ownerships in the region and describes all standing tree volume including stems, limbs, and tops. The assessment includes analysis of treatment areas and potential removals. Additionally, the operational systems necessary to effect the treatments as well as potential erosion impacts and utilization opportunities were examined.

Methodology

This strategic assessment estimated current forest conditions for areas needing hazardous fuel reduction treatments based on the combination of Forest Inventory and Analysis (FIA)[1] data and the coarse-scale fire regime assessment by Schmidt et al. (2002). The

[1] *The Forest Inventory and Analysis (FIA) program of the USDA Forest Service has been in continuous operation since 1930. FIA collects, analyzes, and reports information on the status and trends of*

forest inventory data presents an estimated "snapshot" of stand conditions at the present time. Potential removal volumes were identified based on selective removal prescriptions using the Stand Density Index (SDI) criterion. SDI (Reineke 1933) is a long-established, science-based forest stocking guide that can be adapted to uneven-aged forests (Long and Daniel, 1990) using data available from broad-scale inventories. Using an SDI criterion allowed a uniform prescription approach across a wide range of ecosystems.

The FIA plot data were summarized by forest type and ecoregion, and specific SDI-based prescriptions were developed for each combination. The basic approach was to reduce stand density to 30 percent of maximum SDI for the given stand. Removals generally came from small to mid-size trees. However, larger trees could also be removed if SDI surpluses occurred in those size classes. There was no upper diameter limit imposed on the prescription. Figure 4 illustrates an SDI-derived treatment applied to a ponderosa pine forest type in Colorado.

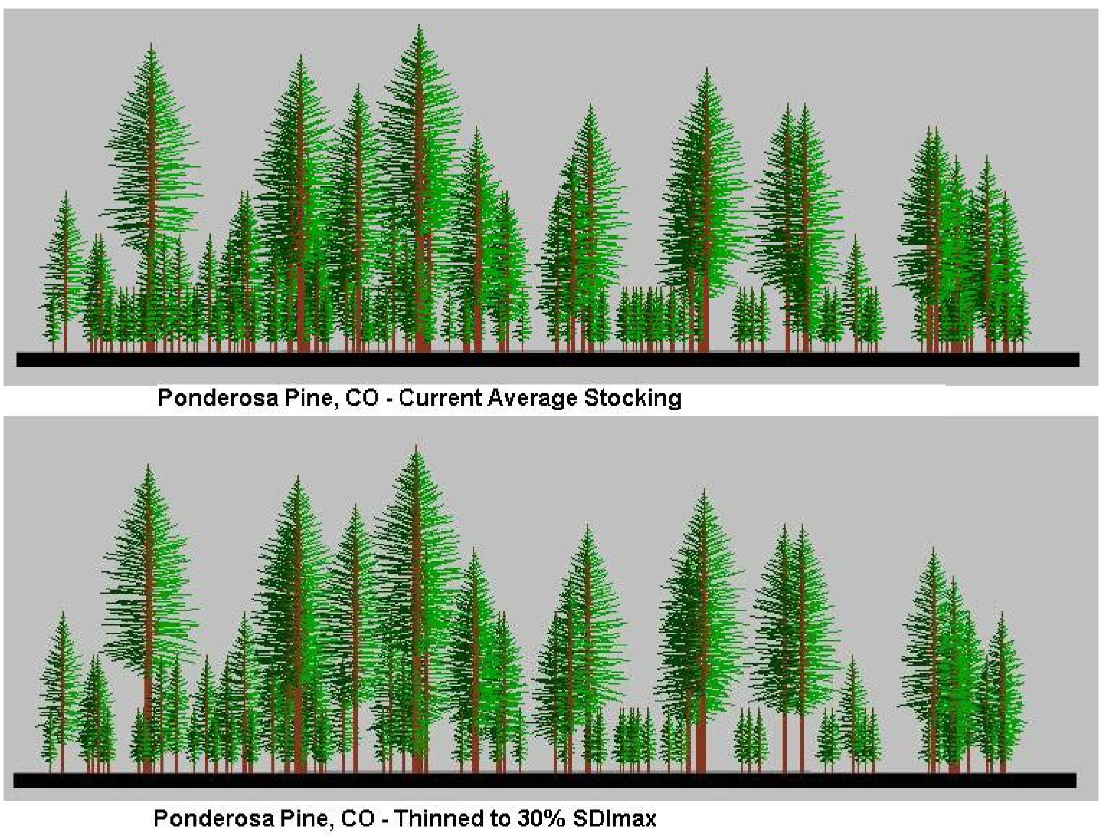

Fig. 4. Example of an SDI-defined removal in a ponderosa pine forest type.

America's forests: how much forest exists, where it exists, who owns it, and how it is changing. The latest technologies are used to acquire a consistent core set of ecological data about forests through remote sensing and field measurements. The data in this report are summarized from 37,000 permanent field plots in the western U.S.

Since the prescriptions were developed for very large areas (regional forest types), they statistically describe average forest conditions over the landscape, not specific forest stands. Actual stocking may exist on the ground as uneven-aged forests, or as clumps, groups, or dispersed stands of even-aged trees. The landscape level uneven-aged approach allows a wide variety of management prescriptions at operational scales to accommodate old-growth, T&E species, wildlife habitat, insect outbreaks, watershed protection, and other ecologic and multi-resource objectives. The SDI prescription was selected to provide an ecologically-based conservative estimate of removal volume, so as to assure that the projected biomass outputs are attainable at broad scales. Specific treatments to address fuel loading in a given stand should be based on assessment of predicted fire behavior.

This assessment does not define a preferred fuel reduction management prescription for a particular forest stand, however other work has examined the impact of selective cutting prescriptions on fire behavior in western forests. While removal of sub-merchantable seedlings and saplings is important to reduce ladder fuels, thinning only small material does little to reduce crown fire spread (Keyes and O'Hara, 2002). Fiedler et al. (2001), for example, found that a comprehensive selection treatment, removing some trees from all diameter classes, had a more significant effect on reducing measures of fire risk than removing only small trees.

The potential removal volumes that would result from the application of these prescriptions were summarized by forest type and state. Using the diameter and volume distributions of the removals, operational costs to implement basic fuel reduction treatments were estimated using a harvesting cost model. Production functions incorporated into the model are based on existing conventional forest harvesting technology. Regional comparisons of sediment yield from thinning, prescribed fire, and wildfire were developed using the Disturbed WEPP program (Elliot et al., 2000).

The removal volumes were also partitioned into two potential utilization groups—stem volume of trees greater than 7 inches diameter at breast height (dbh) taken to a 4-inch minimum top diameter (merchantable volume); and all the remaining volume from small trees, limbs and tops (biomass volume). Merchantable volumes in board feet were estimated by converting the weights to cubic volumes and then by converting the cubic volumes into board feet using conversions given in Haynes (1990). Weights were converted to cubic volumes based on density factors for ponderosa pine and lodgepole pine found in USFS (1999).

Discussion of current western manufacturing technology is based on the draft 2002 RPA.

The Findings

Inventory

The 15 western states encompass almost 1 billion acres of land, of which 236 million acres are forested. Slightly more than half of the forested area (130 million acres) is classified as timberland according to standard definition (i.e., capable of growing at least 20 cubic feet per acre per year and not reserved by law or administrative action from timber harvest (Smith et al. 2001)). Treatment opportunities exist on timberland areas that have stocking in excess of the residual stocking specified by the SDI-based prescription. Using this criterion, treatment opportunities exist on three-quarters of the timberland area (Table 1).

Treatable areas were further classified by Fire Regime Condition Class (FRCC)--a measure of how much a forest has departed from natural wildland fire conditions (Schmidt et al. 2002). The fire regime in Class 2 areas is moderately altered from the historical range. Moderate levels of restoration treatments such as fire or mechanical treatments would be required to begin managing a more natural fire cycle. In Class 3 areas, fire regimes have been significantly altered and there is a high risk of losing key ecosystem components in a wildfire. Due to high fuel loadings, mechanical treatments are expected to be needed before the reintroduction of fire. This assessment estimates a total of 67 million treatable acres in FRCCs 2 and 3. About half of those acres (28.5 million) are in the high-risk FRCC 3.

Table 1. Assessment Area Statistics by State

	Land Area (million acres)			Treatment Opportunities (million acres)		
State	Total	Forestland	Timberland	Timberland	Class 2 + 3	Class 3
AZ	72.7	19.4	3.5	3.1	2.9	1.9
CA	99.8	40.2	17.8	13.4	11.8	5.5
CO	66.4	21.4	11.6	9.5	6.0	2.5
ID	53.0	21.6	16.8	12.1	8.0	3.3
KS	52.4	1.5	1.5	1.3	0.4	0.2
MT	93.2	23.3	19.2	14.3	9.5	3.7
NE	49.2	0.9	0.9	0.7	0.1	*
NV	70.3	10.2	0.4	0.2	0.1	*
NM	77.7	16.7	4.4	3.9	3.3	2.1
ND	44.2	0.7	0.4	0.4	*	*
OR	61.4	29.7	23.8	16.9	12.2	5.6
SD	48.6	1.6	1.5	1.1	0.9	0.6
UT	52.6	15.7	4.7	3.6	1.2	0.1
WA	42.6	21.8	17.3	12.4	8.5	2.5
WY	62.1	11.0	5.7	4.0	1.9	0.4
Total	**946.1**	**235.7**	**129.6**	**96.9**	**66.9**	**28.5**

* less than 100,000 acres

Class 2 areas need prescribed fire or mechanical treatment to restore ecosystem function

Class 3 areas need mechanical treatment prior to using fire as a restorative tool

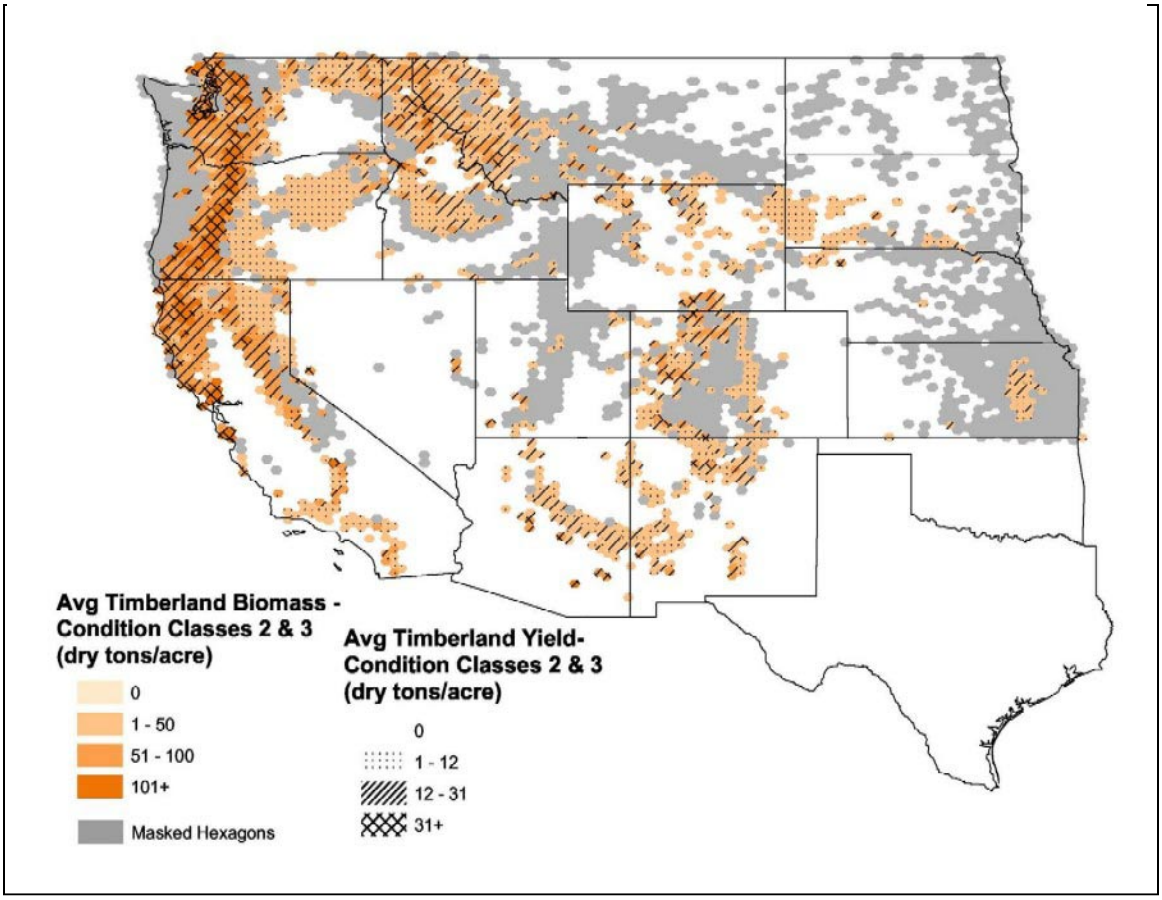

Fig. 5. Distribution and volumes on Class 2 and 3 forests in the western U.S.

The total standing timberland volume is nearly 6.9 billion bone dry tons (bdt), including the volume of stems, limbs and tops. Treating all "overstocked" western forests would remove just over 2 billion bdt (Table 2). Focusing only on areas that would require mechanical fuel reduction before fire can be used as a management tool (Class 3) could yield 576 million bdt. About two-thirds of the potential treatment volume is located on National Forest lands (62 percent). About 30 percent of the treatment volume would come from private lands and the remaining 8 percent is on state, local and other federal ownerships.

While the assessment already excludes reserved forests and low-productivity forests, it is unrealistic to assume that all of the remaining area could be accessed for operational treatments. Steep slopes, sensitive sites, regeneration difficulty, or lack of adequate resource information may exclude an area from operational treatment. According to a global analysis (FAO 2001) about 60 percent of the North American temperate forest is considered accessible (not reserved or high elevation and within 15 mi of major transportation infrastructure). A summary of National Forest land management plans from 1995 also found that about 60 percent of the western National Forest *timberland base* is considered "suitable" for timber production operations (this is only 37 percent of the forestland base). The determination of "suitable" indicates that current forest operations technology would not produce irreversible damage to soil or water resources. The accessible area of private lands may be higher. Even assuming that only 60 percent of the treatable timberland on all ownerships in FRCC 3 is accessible for fuel reduction operations would still require treatment of 346 million bdt.

Table 2. Standing and removal volume by State

State	Total Forest Volume (million bone dry tons)				Volume to Remove (million bone dry tons)		
	All Timberland	Treatable Timberland	Class 2 + 3	Class 3	Treatable Timberland	Class 2 + 3	Class 3
AZ	138.3	134.0	126.4	85.1	61.3	57.8	39.5
CA	1,328.3	1,252.4	1,094.5	483.2	368.1	317.9	125.1
CO	436.1	413.7	250.6	117.8	165.3	99.9	48.3
ID	772.3	704.3	498.7	217.9	242.9	177.6	80.4
KS	52.4	51.0	13.4	5.6	21.9	6.1	2.5
MT	733.7	688.8	485.9	197.9	271.3	188.2	77.4
NE	31.2	28.6	5.9	1.2	11.5	2.1	0.5
NV	11.9	9.5	6.0	2.0	2.8	1.7	0.5
NM	154.8	150.2	129.1	85.3	57.5	49.6	32.2
ND	14.0	13.3	0.8	0.1	5.5	0.3	*
OR	1,629.3	1,534.7	1,037.5	358.4	436.6	291.1	91.0
SD	39.9	35.1	29.7	20.7	11.1	9.0	6.6
UT	155.8	144.6	43.0	4.0	54.5	15.6	1.6
WA	1,159.2	1,101.5	722.8	194.1	371.5	241.5	63.0
WY	197.9	185.6	84.8	17.8	72.1	34.7	7.5
Total	**6,855.0**	**6,447.4**	**4,529.1**	**1,791.1**	**2,154.0**	**1,493.4**	**576.1**

* less than 50,000 bdt
Class 2 areas need prescribed fire or mechanical treatment to restore ecosystem function
Class 3 areas need mechanical treatment prior to using fire as a restorative tool

The vast majority of the trees identified for removal by the SDI prescriptions would be less than 10 inches dbh (Figure 6). There are nearly 2 billion trees in the 2-inch diameter class alone. While 86 percent of the trees that would be cut are less than 10 inches, most of the volume that would be treated comes from the 14 percent of the trees that are larger than 10 inches in diameter. This is the central dilemma of fuel reduction treatments—large numbers of small diameter trees with relatively little volume that can be feasibly utilized must be treated.

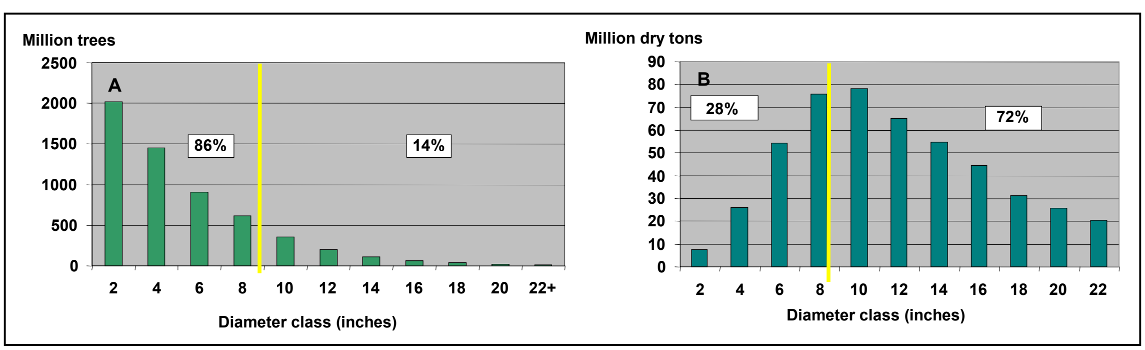

Fig. 6. Diameter distribution of trees (A) and volume removed (B) in the SDI prescriptions (Vissage and Miles, 2003). Both distributions continue to tail off beyond 22-inch diameter.

Utilization Options

The range of potential recovery volumes is huge. At the upper end, if all volume were recovered from thinning treatments on the 97 million acres of treatable timberland, about 617 million bdt of non-merchantable biomass that is typically left on site (limbs, tops, and saplings) and 1,537 million bdt of merchantable timber would be generated. At the lower end, if material were only recovered from the estimated 60 percent of the high-risk (Condition Class 3) areas, about 101 million bdt of non-merchantable biomass and 245 million bdt of merchantable timber would be recovered. If the treatments were spread over 30 years, the annual production would range from 8 million to 51 million bdt of merchantable forest products. This volume doesn't even consider the additional forest growth that would occur over that period.

A breakdown of the size distribution of this material (Figure 6) shows that more than half of the volume would come from trees greater than 13 inches dbh and about three-fourths would come from trees greater than 9 inches dbh. These sizes of trees are well within the current merchantability limits of processing facilities operating in the West.

In 1999, western forest industry processed about 28 million bdt of roundwood for lumber and 2.2 million bdt for pulpwood (Howard, 2001). The draft 2002 RPA (USFS, 2002) estimates 32 million bdt of annual growing stock removals in the West are currently going to all products including medium-density fiberboard (MDF) plants, particle board plants, pulpwood and hog fuel. This means that at the upper end of the potential range, broadscale implementation of mechanical fuel reduction could produce nearly twice as much material (51 million bdt) as is currently being processed in the West. Even recovering material only from accessible, high-risk stands would constitute about 25 percent (8 million bdt) of the current conventional processing volume.

Volume from thinning treatments could either replace current sources of raw material within the existing manufacturing infrastructure or it could require investment in new facilities. The market price impacts could range from practically nil to very large. For example, a program that would mechanically reduce fuels on all Condition Class 2 and 3 forestlands and that simply added to current harvests would imply total region harvests of 83 million bdt and large aggregate price reductions. Any fuel reduction program considered at that scale would probably involve large program outlays for participating government agencies and (or) a system of incentives for private landowners. Price reductions arising from such a program would negatively impact non-participating forestland owners through lower timber prices, as well. A program that only addressed fuels on the Condition Class 3 lands but that replaced 8 million bdt of existing harvests would likely have very little if any aggregate price impact, although some local effects would be experienced.

New mills and processing capacity expansions at existing mills would moderate any negative market price effects arising from any large-scale program. If substantial new processing capacity were expected as a result of the large fuel reduction program, then negative price and welfare impacts could be minimized over time by expanding treatment volumes in step with capacity expansions. If no new capacity were expected, then price effects would certainly be negative because local processing capability would be fixed by the maximum local production capacity. New mills could include non-conventional sawmills (small mills that are less expensive to construct than conventional mills but have a lower lumber recovery), biomass-fired power plants, or traditional facilities such as pulp mills, sawmills or particleboard plants. Table 3 lists general ranges of processing capacities for current technology. There are numerous specialty markets for small-diameter material such as post-and-rail, rustic furniture, firewood, animal bedding, and composts. While these facilities are important for local economic development using material from fuel reduction treatments, their scale of operation is significantly smaller than the product applications in Table 3. Levan-Green and Livingston (2001) review a wide range of potential uses for small-diameter trees.

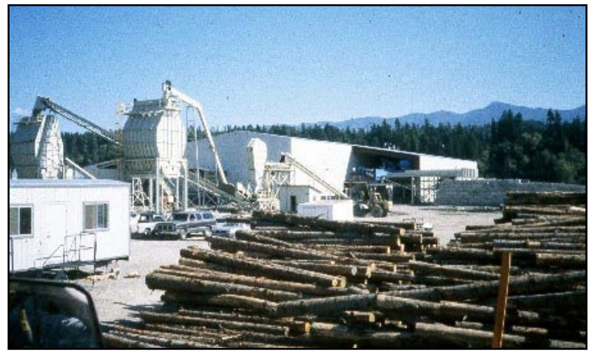

Fig. 7. Small log sawmill—Bonner's Ferry, ID

Table 3. Ranges of individual mill capacity for product lines using materials removed during fuel reduction treatments.

	Roundwood Consumption (bdt/year)		Lumber Output (MBF/year)	
Facility Type	Low	High	Low	High
Pulp Mill	150,000	750,000		
Conventional sawmill	35,750	180,000	20,000	100,000
Non-conventional sawmill	22,750	45,000	10,000	20,000
OSB plant	300,000	500,000		
MDF or particleboard	200,000	300,000		
Cogen (steam and power)	175,000	350,000		

Biomass (tops, limbs, and saplings) from thinning operations as well as hog fuel produced during the manufacture of lumber, chips, and Oriented Strand Board (OSB) could be used for cogeneration of electricity for sale into the power grid and process steam useful in manufacturing operations or other applications. The clean chips generated as residues from lumber processing could be used for pulp production or MDF and particleboard production. Stems of trees less than 7 inches in diameter could be used for pulp chips or OSB.

Fig. 8. Avista biomass power plant—Kettle Falls, WA

The potential size of the manufacturing infrastructure needed to process material from fuel reduction treatments is large. For example, to process the merchantable volume from only the Class 3 fuel reduction treatments will require the capacity of about 75 average-sized conventional sawmills for 30 years. Whether these would be existing facilities, restarted mills, or new construction would depend on many factors. The economics of establishing such a large number of processing facilities is highly uncertain. Attracting investment to new processing infrastructure involves analysis of long-term supply and market forecasts. Today's forest products markets are global and western production will have to compete with material from other wood producing regions. There are considerable challenges associated with establishing new processing plants in the West that go well beyond implementation of the fuel reduction treatments.

A complete analysis of the market effects as well as program costs will be conducted under a separate Joint Fire Science Program study, "A national study of the economic impacts of biomass removals to mitigate wildfire damages on federal, state, and private lands." This study seeks to evaluate market price and other economic effects of alternative scales of fuel reduction programs, with emphasis on Wildland-Urban-Interface zones. The study will also evaluate the differential effects of fuel reduction harvests that produce merchantable materials that substitute for or add to existing regional harvests. Preliminary results of that analysis are expected in late 2004, with final results available in mid-2005.

Forest Operations for Fuel Reduction

Prescribed fire is usually the least expensive option for reducing fuel loading when it can be used. This treatment mimics natural processes for maintaining stocking. Cleaves et al. (2000) examined National Forest prescribed fire programs and found that across the western National Forests, prescribed management-ignited fires averaged $92/acre. However, the need for prescribed fire was nearly double the area actually treated. Key restrictions on opportunities for burning included air quality and smoke management regulations, limited acceptable weather conditions, and lack of resources. High fuel loading was also an issue in some of the western National Forest Regions.

When prescribed fire is not a viable option, there is a wide range of technology available from chainsaws to sophisticated harvesters (Table 4), although few of these have been designed specifically for fuel reduction applications. Managers face the challenge of selecting a system to create the desired fuel conditions while minimizing adverse ecological impacts and meeting economic constraints. Some systems may provide for extraction of usable material while others may simply alter fuel conditions or form on site (Fig. 9). The "best" technology for treating fuels may not always be the least expensive and will vary from stand to stand. Generally, the great challenge of fuel reduction treatments is the need to process or treat a large number of small-diameter stems. The individual handling time (and consequently cost) adds up quickly even though the total volume handled may be relatively low. If small diameter trees are not removed during fuel reduction treatments, they will soon grow to become ladder fuels that spread wildfires to larger trees. Even though it may not be economical to remove small diameter trees and forest residues, most of them should be treated to prolong the beneficial effects of fuel reduction.

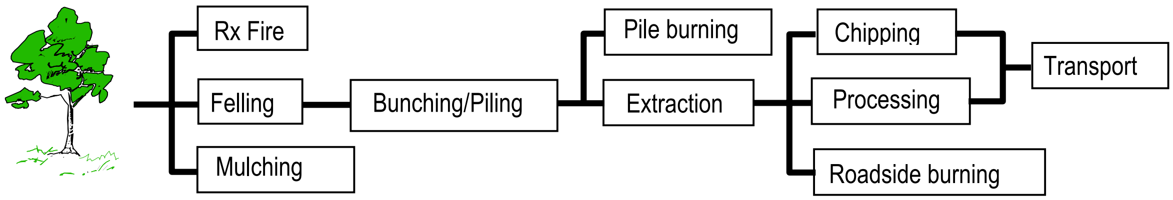

Fig. 9. Operational functions in fuel reduction treatments

Table 4. Generic comparison of fuel reduction treatment alternatives

Treatment	*Cost range*	*Key benefit*	*Key problem*	*Products?*
Prescribed fire	$35-300/ac	Low cost	Restricted use	No
Mastication in-woods	$100-1000/ac	No smoke	Fiber left in-woods	No
Cut/pile/burn	$100-750/ac	Low access	Burning limitations	No
Cut/skid	$30-40/bdt	Offsets costs	Soil impacts	Yes
Cut/skid/chip	$34-48/bdt	Usable fiber	High cost, low value	Yes

If the treated material has no potential product value, there are several approaches that leave material in the stand. About 30 percent of the total biomass to be treated on Class 3 timberland consists of saplings, limbs, and tops. Felling and piling, either with manual crews or mechanized equipment, is widely applied. The piles are subsequently burned under controlled conditions. Mobile mulching or shredding machines can also be used to reduce stand density. This equipment changes the size distribution of forest fuels, producing chunks and sticks that decay naturally in the forest.

Fig. 10. Chipping thinned material—Boise National Forest, ID

In some areas it may be necessary to remove the saplings, limbs and tops from the forest to reduce fuel loading or to extract usable fiber. Moving this material across the landscape can be achieved with people, small machines, large-capacity forwarders, cable systems, or helicopter transport. The selection and cost of the extraction system are very dependent on terrain, material size, and the distance moved and must be designed and optimized to specific stand and terrain conditions to be economically efficient. When material in fuel reduction treatments can meet product specifications, extraction and processing may help offset the cost of stand treatment. Operations to recover products may range from small-scale systems for products such as post-and-rail or firewood to fully mechanized systems that combine log length recovery with slash treatment. The costs of product handling *per unit volume* generally increase with decreasing stem diameter, particularly when using equipment designed for handling conventionally merchantable wood. This makes small-diameter treatments less cost-effective and highlights the need for development of more cost-effective systems.

Fig. 11. Processing small-diameter logs—Medicine Bow National Forest, WY

A new harvesting cost model, called ST Harvest (Fight et al. 2003), predicts costs for fuel reduction/forest health thinning in natural stands. It considers factors of tree size, removal volume per acre, harvest system, unit size and extraction distance. Current model equations are based on older production studies of conventional operations due to a lack of studies of new fuel reduction treatment systems. Estimated gross treatment costs for cut-and-skid vary greatly depending on stand conditions and forest type (Table 5). These costs assume that all cut trees less than 3 inches dbh are left in the stand, trees between 3 inches and 7 inches dbh are cut, taken to roadside and chipped, and trees larger than 7 inches are taken to roadside for processing into products. The costs also include some brush treatment and site rehabilitation. For the western forest types shown in Table 5 there is a wide variation in per acre treatment costs because of variations in the number of trees per acre and the treatment volume removed.

There have been developments in equipment specifically designed for treating small material, but more information needs to be acquired on costs, performance, and compatibility with fuel reduction objectives. Mulching machines, purpose-built small diameter harvesters, and other technologies need additional evaluation.

Table 5. Estimated gross operational cost to cut and extract fuel reduction material to roadside.

	Total Cut		Removed		Treatment cost ($/ac)		Gentle
Forest Type	*trees/ac*	*Bdt/ac*	*trees/ac*	*Bdt/ac*	*Gentle*	*Rolling*	*($/bdt)*
SW ponderosa pine	360	12.5	92	12.2	680	830	55.74
Intermountain ponderosa	85	11.4	82	11.4	630	780	55.26
Intermountain lodgepole	255	22.5	161	22.1	1000	1220	45.24
Sierras ponderosa	134	13.5	82	13.4	600	730	44.78
Sierras lodgepole	463	12.3	105	12.1	700	860	57.85
Rockies ponderosa	188	9.8	85	9.6	590	720	61.46
Rockies lodgepole	378	23.2	263	22.9	1120	1330	48.91
Great Basin ponderosa	75	4.6	63	4.6	400	490	86.96
Great Basin lodgepole	302	38.6	240	38.6	1340	1630	34.72

Accessibility and terrain are key factors limiting operational treatments for fuel reduction. Mobilizing and supporting crews and equipment working in the forest requires some amount of road or trail access. Steep terrain and sensitive sites also commonly limit operational management in western forests. The western National Forests average only 60 percent of timberland as "suitable" for timber production—indicating the difficulty of operation in many areas. While access and slope do not necessarily preclude fuel reduction treatments (treating biomass on site may still be feasible with limited road access) it significantly reduces economically-viable opportunities for product recovery.

The ability to separate and market larger-diameter logs for higher-value products is critical to the net revenues or costs of fuel treatments. If the opportunity to utilize larger-diameter logs for higher-valued products is lacking, then revenues would not cover costs on all the western forest types studied (Table 6).

Table 6. Estimated revenues minus fuel treatment costs with larger-diameter logs sold for higher-value products or, alternatively, for chips

	Total merchantable (>7" dbh)		Net revenue (cost) with higher-value products ($/ac)		Net (cost) with larger-diameter logs sold for chips ($/ac)	
Forest Type	*MBF/ac*	*Bdt/ac*	*Gentle*	*Rolling*	*Gentle*	*Rolling*
SW ponderosa pine	5.3	11.3	$496	$346	$(1,176)	$(1,326)
Intermountain ponderosa	4.8	10.4	$433	$283	$(1,090)	$(1,240)
Intermountain lodgepole	8.4	18.7	$673	$453	$(1,886)	$(2,106)
Sierras ponderosa	5.4	11.7	$615	$485	$(1,138)	$(1,268)
Sierras lodgepole	4.7	10.7	$247	$87	$(1,184)	$(1,344)
Rockies ponderosa	4.5	8.4	$465	$335	$(975)	$(1,105)
Rockies lodgepole	8.3	15.8	$614	$404	$(2,015)	$(2,225)
Great Basin ponderosa	1.7	3.7	$(16)	$(106)	$(583)	$(673)
Great Basin lodgepole	14.5	32.0	$1,562	$1,272	$(2,881)	$(3,171)

Underlying assumptions:

Ponderosa pine value	=	$300/thousand board feet at the mill
Lodgepole pine value	=	$280/thousand board feet at the mill
Chip value	=	$30/bone dry ton at the mill
Mill distance	=	100 miles
Transport cost	=	$0.35/bone dry ton mile

Transportation costs are also a significant factor in the cost of recovering biomass for utilization. As much as half the cost of the material delivered to a manufacturing facility may be attributed to transportation. Recent studies have cited haul rates from $0.20 to $0.60/bdt-mile, depending on truck configuration, travel speeds, and payload factors. Hauling costs determine the economically-viable distance between the forest treatment site and a processing facility. Assuming chip values of $30/bone dry ton delivered to the mill and chip transport costs of $0.35/bone dry ton-mile, the maximum distance that chips can be transported without additional subsidies is 86 miles. At this distance, the chip value just covers the transport cost and no fuel treatment costs are recovered.

Labor Availability

Another key issue is the availability of sufficient skilled labor and appropriate equipment to perform fuel reduction treatments. This is a question of adequate numbers of workers as well as proximity to areas where work needs to be done. If workers and equipment have to be mobilized across large distances, costs will be higher and competition for contract projects will be reduced. There would also be a need for sufficient qualified agency personnel to plan and administer a fuel reduction program.

Fig. 12. Manual chainsaw work--WY

Forestry workers represent a skilled workforce that will likely be the foundation of any significant fuel reduction program. Given recent reductions in federal timber harvests, a pool of skilled labor may still exist in some areas. However, not all the labor resides in areas where fuel reduction treatments would be concentrated. Because the western US has been managed less intensively than other regions of the country the availability of trained forestry workers is lower per acre of forestland. Based on 1990 Census data, the western US averaged 10.2 forest workers per 100 mi^2 of forestland (compared to 15.4 in the South, for example). Assuming a 30 percent drop in western timber removals since 1990, the currently available workforce in the West may be about 6.4 forest workers per 100 mi^2 forestland. The disparity between the distribution of the forestry workforce and the forestlands requiring fuel reduction can be appreciated by overlaying the Condition Class 2 and 3 areas with logging contractor distribution (Fig. 13).

Sediment Yield

Mechanical operations on the ground have the potential to create site disturbance and adverse effects. One of the most significant concerns associated with forest operations is the potential impact on water quality. Three alternative fuel treatments were compared across western ecoregions using the Disturbed WEPP erosion prediction model (Elliot and Miller 2002). On a per unit area affected basis, wildfire is predicted to produce nearly 70 times as much sediment as a thinning treatment (Table 6). Prescribed fire treatments are estimated to yield about 1.6 times more sediment than thinning.

Table 7. Summary of forest sediment yields for fuel reduction alternatives.

		Sediment Yield		
	Slope class	Mean	Min	Max
Thinning (tons/mi^2)	Low	24.2	0.0	364.8
	Moderate	41.9	0.0	608.0
Prescribed fire (tons/mi^2)	Low	38.4	0.0	339.2
	Moderate	67.7	0.0	518.4
Wildfire (tons/mi^2)	Low	1639.6	25.6	10873.6
	Moderate	2729.5	51.2	17971.2

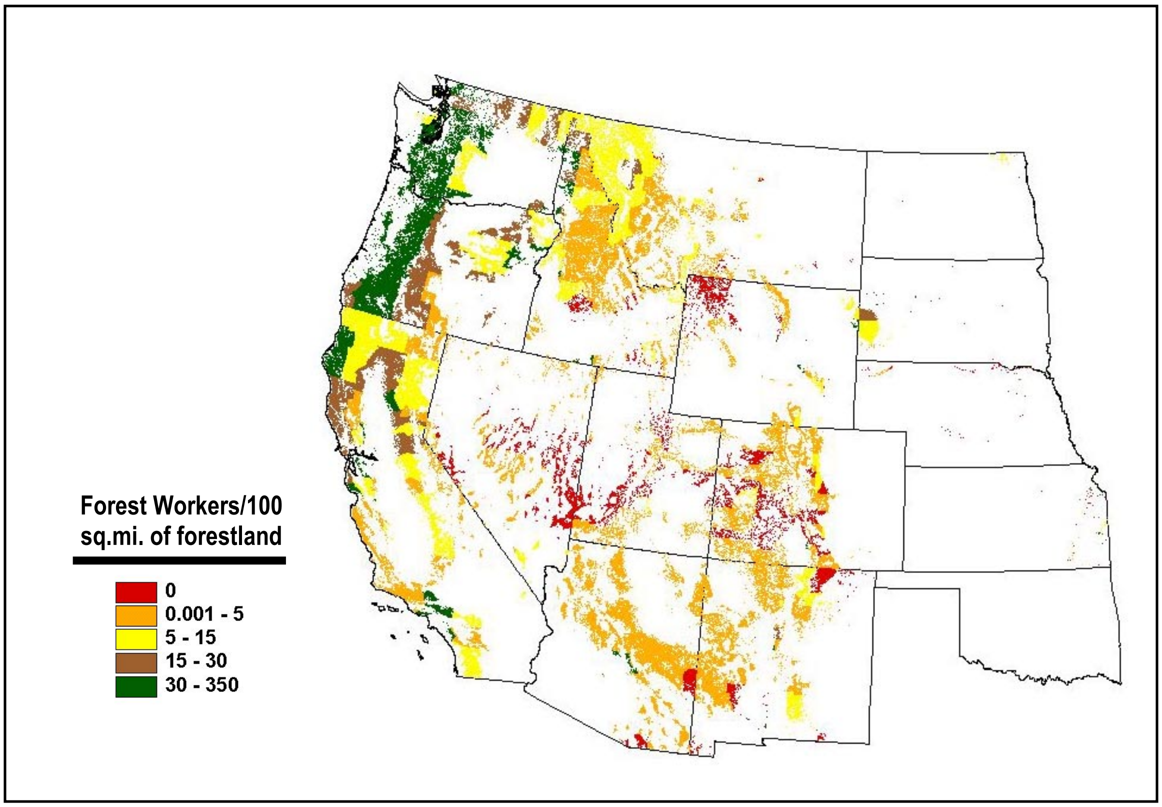

Figure 13. Availability of logging contractors for Condition Class 2 and 3 areas.

Conclusions

The total volume to be treated, even based on just estimated accessible areas, represents a large amount of material (345 million bdt)—nearly 10 times the annual conventional timber harvest of the region. Most of the volume that should be removed can be utilized in conventional forest products processing facilities if markets are within economically-viable transport distances. While most of the *volume* can be used, there is also a need to treat large numbers of small trees that will yield relatively little volume. The operational cost of treating the smallest trees may exceed the market value of any recovered fiber. The most cost-effective systems may be operations that leave processed material in the forest without attempting to utilize marginal volumes.

Implementing a fuels reduction program will affect markets, manufacturers, and contractors. Utilizing the volume that can be recovered for products will either require new processing capacity and markets or it will replace existing sources of raw material in current facilities. Initiating a west-wide fuel reduction program will require contractors to shift operations towards a different type of forest treatment, with an emphasis on methods that can efficiently handle small-diameter material. Researchers, equipment manufacturers, and industrial fiber users will need to develop appropriate operational specifications for this new application. The economic and infrastructure demands of implementing a fuels reduction program will depend to a large degree on the scale of operation. Clearly a fuel reduction program that seeks to address forest conditions across the region would have more significant impacts than a fuel reduction program focused principally on high-risk urban interface areas.

Initial estimates of sediment yield from alternative treatments clearly indicate that active management is less detrimental than wildfire on an area affected basis. Steeper ground and wetter ecoregions showed higher sediment yields than lower slopes or drier sites. On a landscape level, the cumulative effect would depend on the scale of treatment. However, given the overall average sediment yields, the effect of 70 acres of thinning treatment would be about the same as the effect of 1 acre consumed in wildfire.

Finally, the development of this assessment highlights the value of having the ability to measure and describe the forest resource in common terms across a large landscape. To monitor and assess the dynamic changes in western forest fuel conditions it will be necessary to provide inventory updates, expand inventory data collection to better assess small-diameter stocking and growth, and develop easily accessible databases and tools for specific tactical planning and implementation. Research work also needs to be done to develop and test new technologies for treating forest biomass in the stand. Better information about the productivity and cost of specialized systems for fuel reduction treatments should be pursued. Conventional timber harvesting equipment should also be evaluated for use in fuel reduction treatments. The large volumes that may be available offer opportunities for recovery and utilization. There is a need to develop more effective utilization and higher-valued products from small-diameter material.

The National Fire Plan has made a commitment to address the problem of overstocked western forests. This assessment has defined the magnitude of the task and identified some of the operational issues that will affect implementation.

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This assessment characterizes, at a regional scale, forest biomass that can potentially be removed to implement the fuel reduction and ecosystem restoration objectives of the National Fire Plan for the western U.S. The assessment area covers forests on both public and private ownerships in the region and describes all standing tree volume including stems, limbs, and tops. Analysis of treatment areas and potential removals is included. Additionally, the operational systems necessary to effect the treatments as well as potential erosion impacts, utilization opportunities and market implications were examined.

KEY WORDS: assessment, biomass, fuel reduction, inventory