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From renewable energy to fire risk reduction: a synthesis of biomass harvesting and utilization case studies in US forests

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Abstract

The volatile costs of fossil fuels, concerns about the associated greenhouse gas emissions from these fuels, and the threat of catastrophic wildfires in western North America have resulted in increased interest and activity in the removal and use of woody biomass from forests. However, significant economic and logistical challenges lie between the forests and the consumers of woody biomass. In this study, we provide a current snapshot of how biomass is being removed from forests and used across the United States to demonstrate the wide variety of successful strategies, funding sources, harvesting operations, utilization outlets, and silvicultural prescriptions. Through an analysis of 45 case studies, we identified three themes that consistently frame each biomass removal and utilization operation: management objectives, ecology, and economics. The variety and combination of project objectives exemplified by the case studies means biomass removals are complex and difficult to categorize for analysis. However, the combination of objectives allows projects to take advantage of unique opportunities such as multiple funding sources and multiparty collaboration. The case studies also provide insight into the importance of ecological considerations in biomass removal both because of the opportunity for forest restoration and the risk of site degradation. The national view of the economic aspects of biomass removal provided by this wide variety of case studies includes price and cost ranges. This study is an important first step that helps define woody biomass removals which are becoming an essential part of forestry in the 21st century.

Keywords: bioenergy, fuel reduction, haul distance, mechanization, operations, treatment costs

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Introduction

The removal of biomass material from forests to achieve management objectives such as hazardous fuel reduction or stand improvement presents both unique challenges and opportunities that are increasingly important. Woody biomass has long been a useful but underutilized byproduct of forest management activities. Now rising energy costs, concerns about carbon emissions from fossil fuels, and the threat of catastrophic wildfires have greatly increased interest in removing and using woody biomass from forests. For example, the US Department of Energy (DOE) has set a goal to increase domestic biofuels use 25 times and almost double biopower use by 2030 (DOE, 2006). A substantial portion of the biomass needed to fuel this increase in renewable energy may come from forests. In fact, one report estimates US forests could yield 334 million dry metric tons of useable biomass per year, which is 260% of current estimates of woody biomass use (Perlack *et al*., 2005). The market for wood bioenergy has increased dramatically with 65 new wood energy projects across North America in 2008 alone (RISI Inc, 2008). Use of wood as a replacement for fossil fuels has the potential to reduce greenhouse gas emissions and contribute to climate change mitigation (Eriksson *et al*., 2007; Perschel *et al*., 2007).

Much of the biomass that will be used in place of fossil fuels will likely come from conifer forests across western North America, where a century of fire suppression has resulted in increased risks of catastrophic

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wildfires (Covington & Moore, 1994; Fulé *et al*., 2004; Noss *et al*., 2006). Large fires, such as those seen in the last decade, release massive amounts of greenhouse gases to the atmosphere (Wiedinmyer & Neff, 2007). Currently, there is widespread implementation of forest thinning treatments that aim to reduce fire risk by reducing the density of trees. In doing so, woody biomass is generated that could be used for bioenergy and forests become less likely to release mass pulses of carbon through wildfire (Kashian *et al*., 2006).

What is woody biomass?

The term woody biomass includes all trees and woody plants in forests, woodlands, or rangelands. This biomass includes limbs, tops, needles, leaves, and other woody parts (Norton *et al*., 2003). From a commercial perspective, woody biomass usually refers to material that has had a low economic value and cannot be sold as sawtimber or pulpwood. As wood processing technologies and markets change, however, different sizes and qualities of material are considered as biomass. In this paper, the term woody biomass refers to vegetation removed from forests, usually logging slash, small-diameter stems, tops, limbs, or trees that otherwise cannot be sold as higher-value products such as sawtimber.

Although interest in and implementation of woody biomass removal projects has increased recently, little research is available to document and characterize these harvests. On a national scale, little is known about the objectives behind biomass removal, how these projects are implemented, or the characteristics of successful projects. While some studies have considered aspects of biomass removal such as fuel reduction treatments on public land (USFS, 2005; Barbour *et al*., 2008b), to date there are none that provide a national view of biomass removals. This paper uses a case studies approach to provide a current snapshot of biomass removal operations in the United States, including an analysis of ecological and economic components of each case.

Methods

The case studies approach used in this paper is particularly useful for studying biomass removals because they are not well classified or tracked. No database or survey covers the range of biomass removals. For example, the National Fire Plan Operations and Reporting System records and permits study of fuel reduction treatments on federal lands, but no such system covers harvests for bioenergy production. Additionally, collecting case studies allowed the researchers to include harvests that might have been missed by restrictive definitions of biomass removal. For instance, our methodology ensured that harvests which included woody biomass removal but were primarily focused on timber production were included in the study. The broad view permitted by the case studies is ideal for an emerging phenomenon, such as woody biomass removals, because it identifies trends and patterns that deserve future study.

To collect the data and build the collection of case studies, we identified federal agency personnel at the national level with responsibility for biomass or fuel reduction. Based on their recommendations, we contacted private consulting foresters; representatives from federal, state, and tribal agencies; and other forest managers. We also emailed members of a professional organization for foresters and natural resource managers (the Forest Guild, http://www.forestguild.org) to find biomass removal case studies on private lands. We gathered examples from a wide array of ecosystems, removal methods, and land ownerships. For case studies to be included in the study, a project manager or forester had to be willing to provide details about the biomass removal operation. This constraint reduced the number of potential case studies. All case studies for which sufficient data were available were included in the study. For regions or land ownerships that were poorly represented in the early phases of data collection, we sought out projects to expand the diversity of projects in the final analysis. We ceased collection of additional case studies when all major forested regions and land ownerships were represented.

We assembled a nation-wide advisory council of land managers, academics, public agency line officers, representatives from nonprofit organizations, and administrators to advise the project (see supporting information for a list of advisory council members). The advisory council helped identify additional case studies that would ensure representation of a broad and diverse spectrum of land ownerships, forest types, removal methods, and outcomes. The advisory council also identified the key variables to measure in each case study (Table 1), and identified the aspects of planning and implementation that led to a project's success. Variables were designed to capture the key facets of a wide range of biomass removal project types including management objectives, area treated, products generated, product price, cost/income, equipment used, distance to utilization, pre- and poststand conditions. All the variables were not applicable to every case study. For instance, fire risk reduction objectives would not be a concern in northern hardwood forests unlikely to experience fire. Biomass removal project managers or foresters completed a questionnaire made up of the

Table 1 Project variables measured

• *Project ID*	
1	Project name
2	Land ownership
3	Location
4	Forest type
• *Context*	
5	Is this project a part of a landscape plan?
6	In a wildland urban interface (WUI)?
7	Acreage treated
8	Type of contract
9	Funding source
10	Collaborators and partners
11	Project start date
12	Project completion date
• *Treatment goals*	
13	Restoration, watershed, or habitat improvement
14	Reduce fuel load
15	Firebreak
16	Salvage
17	Forest stand improvement
• *Treatment specifics*	
18	Primary treatment objective
19	How does biomass removal fit with other objectives?
20	Treatment description
21	Description of contractors
22	Travel distance for contractors
23	Type of equipment used
24	Treatment of residual slash if any
25	Treatment cost per acre
26	Trucking costs
• *Utilization*	
27	Products from project
28	Price for products
29	Date of sale
30	Did biomass markets exist before the project?
31	Type of utilization
32	How well did the woody biomass match the utilization options?
33	Distance to utilization
• *Treatment guidelines*	
34	Diameter limit
35	Basal area reduction
36	Crown coverage
37	Fuel loading
38	Retention guidelines
39	Treatment of snags and downed logs
40	Soil impacts
41	Other ecological impacts monitored
• *Pretreatment data*	
42	Fuel load
43	Stem density (stems/ac)
44	Basal area (ft^2/ac)
45	Canopy closure (%)
46	Height to live crown base
47	Snags and downed woody material
48	Size class distribution
49	Tree species composition
50	Presence of invasive species
51	Soil and other ecological data
• *Posttreatment data*	
52	Fuel load
53	Stem density (stems/ac)
54	Basal area (ft^2/ac)
55	Canopy closure (%)
56	Height to live crown base
57	Snags and downed woody material
58	Size class distribution
59	Tree species composition
60	Presence of invasive species
61	Soil and other ecological data

Continued

project variables (Table 1) and provided any available auxiliary material such as written management plans. We followed up with each project manager to clarify any uncertainties in the questionnaire. Even with this follow up some data were not available and could not be included in the results.

Results

We collected 45 case studies from 21 states (Fig. 1 and supporting information). Forty-seven percent of the project occurred on federal land, 29% occurred on private land, and the remainder occurred on tribal, state, municipal, land trust, or university land. Most projects occurred at least partially in the wildland–urban interface (67%). The median project size was 31 ha. Further details are presented below and in Figs 2 and 3. Three main themes emerged from comparing the biomass removal case studies: *multiple objectives*, *ecology*, and *economics*.

Multiple objectives

Biomass removal projects tend to combine multiple objectives such as ecological restoration, wildfire hazard reduction, forest-stand improvement, rural community stability, employment, and habitat improvement. Indeed, 75% of the case studies surveyed in this study included two or more desired outcomes such as reducing fuel loads in fire-prone forests and wildlife habitat restoration. Although much attention has been focused on biomass removals where the main purpose is fuel reduction, it is important to recognize that many projects are driven by silvicultural or restoration aims. While 71% of the case studies had a fuel reduction objective, 77% of the case studies included a restoration, watershed or habitat improvement objective and 56% of the case studies were implemented for forest stand improvement. Forest managers often want to remove

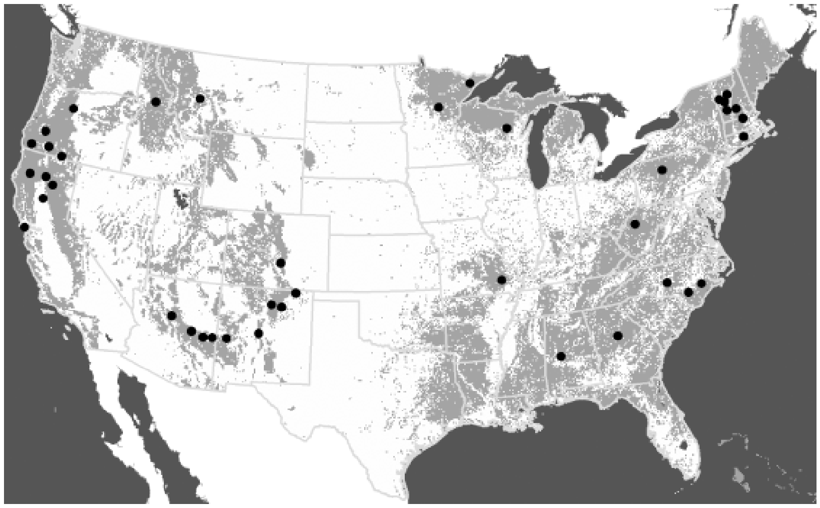

Fig. 1 Map of case studies locations. Gray shaded area represents forest cover from the US National Atlas (http://www.nationalatlas.gov). Case studies in Alaska, USA not pictured.

small-diameter or otherwise low-value trees to increase the growth of the remaining trees or to permit new seedlings to grow. These silvicultural objectives are easier to achieve when markets and infrastructure reduce the cost of biomass removals. Restoration objectives are often required with biomass removal where fire is the dominant disturbance regime, but in some cases the objective may be to accelerate the growth of larger trees to emulate late successional (i.e., old growth) forest conditions as soon as possible.

Projects with multiple objectives common to biomass removal treatments often involve a high degree of collaboration between diverse entities. Partners and collaborators were mentioned as important resource in 77% of the case studies. While involvement of the general public in biomass removal projects is more important for public than private lands, two case studies from private lands demonstrate the importance of public engagement across land tenures. Public participation can help overcome hurdles through support for public funding, responses to specific stakeholder concerns, and strengthening of partnerships and collaborations that are increasingly necessary for effective forest management. In contrast, public opposition can result in costly litigation and delays. Community participation can range from direct involvement of community members in forest management and utilization to general support for biomass removal and utilization. Contractors, those that harvest and move biomass material, can make or break a biomass removal project. In areas with well-trained and efficient workers, projects can become partnerships between land managers and contractors. In other areas, the case studies show that projects can help to train and support loggers. For example, in the Boulder Stewardship Demonstration Project, biomass removal was linked with workforce development that helped train local loggers in ecological restoration and harvests of small diameter trees. In contrast, the P&M Plastics case study from New Mexico only treated a small fraction of the intended area, in part because of the workforce's lack of familiarity and training with harvester and skidder machinery.

Ecology

The majority of case studies (77%) in our analysis contained important elements of ecological restoration, watershed management, or habitat improvement. In some cases, the restoration element was limited to reducing the potential for uncharacteristic wildfires and the resulting negative ecological impacts. In addition to reducing wildfire hazard and severity, biomass utilization can have both smoke management and carbon sequestration benefits. By removing woody biomass from fire-adapted forests, not only can total smoke loads be reduced but managers have more control over the timing of the smoke that is produced. By utilizing woody biomass in wood products, carbon is stored temporarily that otherwise would be released to the atmosphere more rapidly through decomposition or combustion. Alternatively, woody biomass can provide a substitute for fossil fuels to generate heat or power and thereby reduce emissions from geologic stores. Some portion of the biomass removed from 84% of

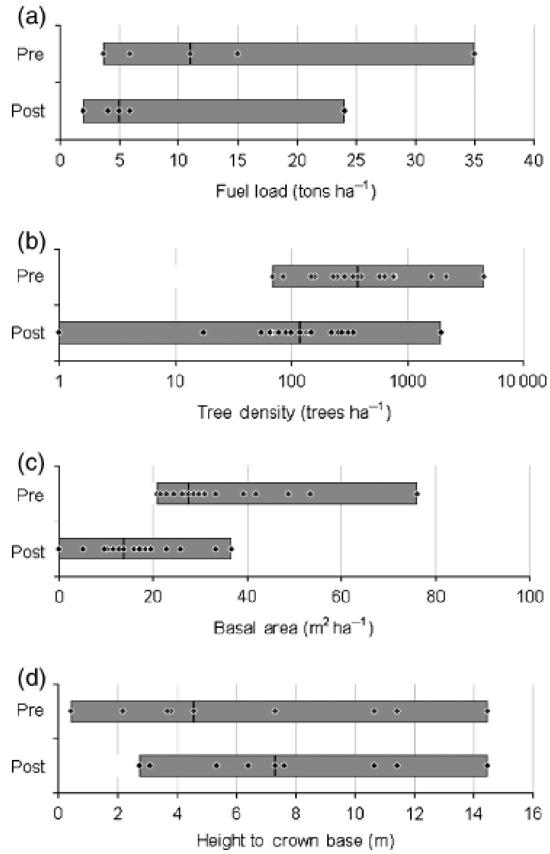

Fig. 2 Stand variables pre- and post-treatment. Gray bars show values ranges, black lines show median values, and black dots show actual data values. (a) Surface fuel load ($N = 5$). (b) Tree density ($N = 19$). (c) Basal area ($N = 21$). (d) Height to crown base ($N = 9$).

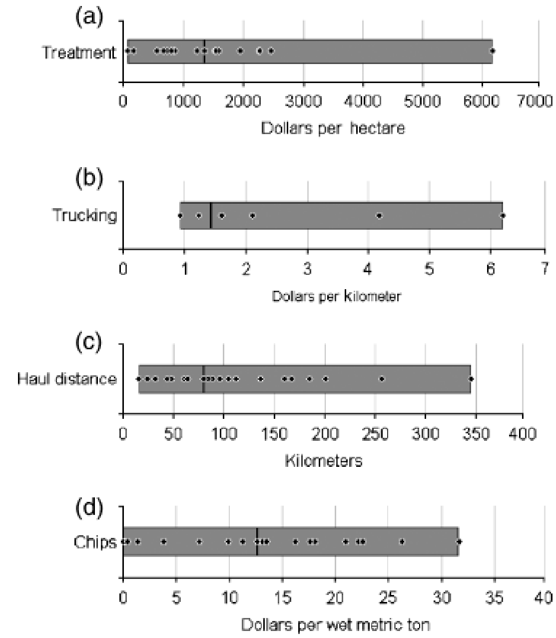

Fig. 3 Biomass removal costs, haul distances, and revenue. Gray bars show values ranges, black lines show median values, and black dots show actual data values. (a) Treatment costs ($N = 18$). (b) Trucking costs ($N = 8$). (c) Hauling distance ($N = 32$). (d) Price for chips ($N = 21$).

the case studies was used for energy production or firewood.

As with any silvicultural manipulation of forests, biomass removal operations result in fundamental changes to stand structures. Across the case studies, we identified four structural variables that changed as a result of biomass removal operations (Fig. 2).

- *Surface fuels*: five of the case studies reported surface fuel loading data and on average, biomass removal operations reduced fuel loads. Pretreatment values ranged from 8 to 78 Mg ha^{-1}. Posttreatment surface fuel loadings range from 13% to 111% of pretreatment levels.
- *Tree density*: tree density ranged from 173 to 11 367 trees ha^{-1} with a median of 927 trees ha^{-1}. On average, treatments reduced the number of trees ha^{-1} 60%.
- *Basal area*: pretreatment basal areas ranged from 21 to 76 m^2 ha^{-1} with a median of 28 m^2 ha^{-1}. After an average reduction of 48%, the median basal area was 14 m^2 ha^{-1}.
- *Crown base height:* crown base height, an important variable for measuring wildfire's ability to move from the ground into the tree canopy, ranged from 0.5 to 14.5 m pretreatment with a median of 4.6 m. The median posttreatment crown base height of 7.3 m shows that stands were more crown fire-resistant after the biomass removal operations.

Economics

Removing low-value woody biomass from forests presents economic challenges because of typically high 'harvest cost to economic value' ratios of biomass. In many locations, woody biomass costs more to remove from the forest than it is worth in the marketplace. Because it was impossible to accurately identify the costs embedded in some of the operations that generated net income, those cases have been excluded from the cost results. The median cost for projects was US$1359 ha^{-1} (Fig. 3). As with project costs, prices for low grade wood products vary greatly temporally, regionally, and locally. The case studies demonstrate a price range from US\$0.09 to US\$31.75 per wet metric ton for chips with a median of US\$12.70 per wet metric ton.

In most cases, harvesting woody biomass is relatively costly because smaller stems have low value by volume and high handling costs, and most forest harvesting systems were originally designed for larger-diameter timber. The cost of removing biomass is driven by so many site- and operational-specific variables that it is difficult to provide general estimates. For example, forest type, density, age, slope, elevation, and stand size all affect the costs of harvesting biomass. Similarly the silvicultural prescription, type of harvesting machined used, products extracted, and distance to utilization all affect the efficiency and costs of biomass removal operations. Most of the case studies (67%) relied on some level of mechanization for tree cutting. Moreover, the majority of the projects that generated a profit were also mechanized. Of the 35% of case studies that generated a profit, 78% of those projects were mechanized. However, many biomass removals rely on hand felling, including 45% of the cases in this study.

While a short haul distance from forest to utilization facility would lower project costs, our case studies indicated that longer haul distances do not necessarily doom a project to failure. The median haul distance was 81 km one way and the median per km per truckload cost was US\$1.42 (Fig. 3). The range of per km costs included one project that paid US\$6.21 km^{-1}, the maximum rate identified in the case studies. The four available per metric ton haul rates were US\$9, US\$13, US\$16, and US\$300 while the five per trip rates ranged from US\$156 to US\$484 with a mean of US\$270.

Although some biomass removal projects have been able to generate a profit or at least break even, most (65%) case studies included in this analysis were subsidized by the federal government. Some projects generated a profit by combining multiple forest products in the removal, taking advantage of fluctuations in the biomass market, and selling to established outlets. Contractors, utilization markets, haul distances, and the mix of removed products all affected profitability.

In 84% of the projects, harvested biomass was used for energy generation. On average, the case studies produced 8.1 wet metric tons of woody biomass per hectare. The amount produced ranged from less than one to 38, with a median of 5.6 wet metric tons ha^{-1} (Fig. 4). Assuming a moisture content of 30% (Haq, 2002), the median amount of biomass removed in the case studies was 4 dry metric tons ha^{-1}. The amount of biomass removed was dictated by the forest type, prescription, and treatment goals. For example, one of the case studies from the Warm Springs Reservation, Oregon produced 2.9–4.8 dry metric tons ha^{-1} for fuel reduction treatments, 0.7–1.5 dry metric tons ha^{-1} as a by-product of commercial sawlog harvests, and 2.2–2.9 dry metric tons ha^{-1} from range improvement activities.

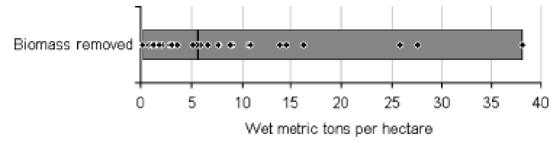

Fig. 4 Amount of biomass removed in wet metric tons per hectare ($N = 31$). Gray bars show values ranges, black lines show median values, and black dots show actual data values.

Discussion

Objectives

The multifaceted nature of most biomass projects is important for project planning and implementation. For example, because biomass removal projects have multiple objectives, many require more than one contractor or may be able to take advantage of multiple funding sources.

The other impact of woody biomass removal projects' multiple objectives is that future analyses must take a wide view of what defines biomass removal. Analyses that focus on single objectives, whether fuel reduction or energy production, will only capture a portion of the complexity of biomass removals.

Ecology

Both the ecological benefits and cost of biomass removal from forest must be considered in full as the number and extent of projects expands. Key potential benefits of biomass removal include fire risk reduction and reduction in carbon emissions.

Changes to stand structure such as those identified in the case studies (Fig. 2) can change fire behavior. Though some controversy about the ability of biomass removal to reduce wildfire severity remains, most research generally supports the idea (Omi & Martinson, 2002; Pollet & Omi, 2002; Martinson *et al*., 2003; Skinner *et al*., 2005; Cram *et al*., 2006; Murphy *et al*., 2007; Lezberg *et al*., 2008).

Use of wood as a replacement for fossil fuels has the potential to reduce greenhouse gas emissions and contribute to climate change mitigation. Where fuel reduction needs dictate removal of woody biomass, using it for power generation reduces overall emissions by 98% in comparison with slash pile burning (Malmsheimer *et al*., 2008). One study shows that taking into account forest regrowth energy can be generated from wood with 0.057 metric tons of CO_{2e} per MWh compared with the average US rate of 0.60 metric tons of CO_{2e} per MWh (IPCC, 2007; Domke *et al*., 2008). In comparison to a coal fired power plant, biomass can generate a MWh of power with 0.41 fewer metric tons of CO_{2e} emissions (Spath & Mann, 2004).

In order for biomass projects to maintain their social acceptability and for energy from woody biomass to be considered environmentally friendly, land managers and researchers must address concerns about the potential negative ecological impact of biomass harvests. Most ecological concerns about biomass harvests focus on dead wood, soil compaction, nutrient loss, plants, or wildlife (Reijnders, 2006). While some research has shown biomass can be removed without significant impacts on dead wood (Arnosti *et al*., 2008), other treatments have shown a possible decrease in the average length of large logs that offer habitat for wildlife (McIver *et al*., 2003). States and nongovernmental organizations are creating guidelines for biomass harvesting that may help to protect forests and alleviate concerns about the impact of removals (MFRC, 2007; MDC, 2008; MFS *et al*., 2008; PA DCNR, 2008; Evans & Perschel, 2009).

Economics

The case studies provide a compelling view of the economic challenges of biomass removal. The median cost of US\$1359 ha^{-1} in the case studies matches well with other studies of fuel reduction costs. For example, estimates for the cost of bringing woody biomass to the roadside in the western US ranged from US\$988 to US\$4028 ha^{-1} depending on forest type and terrain with a median cost of US\$1680 for gentle slopes (USFS, 2005). Costs for biomass cutting in Colorado ranged from as low as US\$247 ha^{-1} where fuels could be left on site to US\$2718 ha^{-1} where markets for biomass were weak (Lynch & Mackes, 2003). New harvesting and transport systems designed for low-value material offer hope that the cost of biomass removal will become most efficient in the future. In addition, the forestry community is gaining needed experience with the removal of woody biomass from forests to meet increased bioenergy needs.

Another element in the pricing of biomass removal is the cost of not removing biomass. For some fuels reduction projects, lower firefighting costs may be an appropriate comparison. One study calculated the avoided future cost of fire suppression to be between US\$588 and US\$1485 ha^{-1} in the Southwest (Snider *et al*., 2006). The value of avoided fire suppression is just one of a number of potential nonmonetary cobenefits from biomass removal. Other cobenefits include reduction of smoke emissions, reduction or offsets of carbon emissions, creation of local jobs and industry expansion, and habitat improvement. Where biomass removal is linked to forest-stand improvement, cobenefits include the future growth of crop trees, regeneration harvests, and avoided costs of planting.

It is important to note that it is difficult to extract general biomass removal costs from the literature because there are critical gaps in the data and differing methods for predicting treatment costs. One of the central data gaps with estimating the cost of biomass removal is the use of machine rates for production and cost. Basic machine rates can exclude tax considerations, overhead costs, and risk (Rummer, 2008). Similarly, broad estimates for repair and maintenance costs can be quite different from actual costs incurred at the project level. Because there is no standard methodology for estimating costs or even for drawing the boundaries of analysis, it is difficult to compare between published studies. For example, studies differ in their treatment of indirect costs, fixed costs such as planning, profit, risk, and overhead (Rummer, 2008).

Distance to utilization facility is often cited as a limiting factor for the economic feasibility of biomass removal projects. While shorter haul distances from forest to utilization site lowers project costs, based on these case studies, longer haul distances do not necessarily doom a project to failure. Other studies have identified 161 km (Arnosti *et al*., 2008), 198 km (Grushecky *et al*., 2007), and 138 km (USFS, 2005) as maximum economic haul distances. The primary determinant of the economic haul distance for a low value commodity such as woody biomass is the cost per ton per km. The case studies included in this study suggest relatively low haul costs. For example one project paid only US\$0.10 dry metric $ton^{-1}\,km^{-1}$, which is half of the minimum presented by Perlack *et al*. (2005). Opportunities to minimize hauling costs such as roll-on containers and low-cost back-hauls may also be available (Livingston, 2008).

Conclusions

Currently, many forest management projects with diverse objectives are extracting small diameter and low-value woody biomass from forests. These biomass removal projects cannot be covered by focusing on a single objective or type of implementation. The case studies presented here demonstrate that not only are many different objectives driving biomass removal projects, but that projects can benefit by integrating multiple objectives. The lack of uniformity of biomass removal projects presents a challenge for researchers because it confounds data collection and summaries. At the same time the increasing interest in removing low-value material makes research to understand the benefits, barriers, and impacts of these harvests all the more important. More information is needed about both the benefits of and successful models for collaborative partnership in biomass removal projects. Similarly, there is insufficient science to guide sustainable biomass removal and more research is needed to identify ecologically appropriate on-site retention of biomass. A strong scientific foundation for sustainable utilization of low-value material will help expand public support and markets.

One of the central questions about woody biomass removals from a bioenergy perspective is the quantity available in forests. Currently, the best estimate of available biomass from US forests is 81 million dry metric tons yr^{-1} (Perlack *et al*., 2005). That estimate includes 37 million dry metric tons from logging residues, 54 millions metric tons of fuel reduction by-products, and 32 million dry metric tons of fuelwood (Perlack *et al*., 2005). The estimate is based on timberlands which includes forest lands that are capable of growing 0.6 cubic meters of commercial wood per year and excludes reserves and parks. Based on the median of 4 dry metric tons of woody biomass removed from the case studies, < 10% of the 207 million hectares of timberland in the United States would have to be harvested each year to meet the 81 million dry metric tons per year estimate.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Biomass Remvoal Case Studies Advisory Council.
Table S2. Database of Biomass Removal Case Studies.

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