Arnold Schwarzenegger
Governor

BIOMASS TO ENERGY:

FOREST MANAGEMENT FOR WILDFIRE REDUCTION, ENERGY PRODUCTION, AND OTHER BENEFITS

APPENDIX 2

PIER FINAL PROJECT REPORT

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APPENDIX 2: B2E Fire Behavior Domain

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Notice of Change in Scenario Naming Conventions

Key assumptions, modeling structures and terminology were altered and refined to accommodate new thinking during the course of this study. The reader will observe in the appendices that the scenarios are referred to as "Scenarios 1, 2 and 3" or "S1, S2 and S3."

In both the main text of the Final Report and in the Life Cycle Assessment appendix (Appendix 4), the former Scenario 1 (S1) was renamed to the "Reference Case." Scenario 3 (S3) has been renamed the "Test Scenario." Scenario 2 (S2), focused on the relative contributions and impact of Industrial Private Forestry (IPF) has been eliminated from most of the analyses that make up the entire study. These changes better reflect the focus of the study, which is fundamentally about the landscape level changes in wildfire, habitat, and other dynamics. The modification of terminology do not substantively affect the findings or recommendations of the study.

Fire behavior domain and key relationships to other domains

Recognizing the urgent need for reducing "catastrophic" fires[1] at a landscape level, the LCA B2E fire behavior domain team developed a modeling strategy for depicting fire behavior changes on the landscape as a result of emerging biomass opportunities on private industrial and public multiple-use lands. This modeling strategy is dependent on the SFA vegetation modeling domain and directly influences all other domains from the habitat relationship, carbon cycling, and ecosystem services domains to the emissions modeling domain (critical to the final renewable energy technology comparisons).

The vegetation domain and the fire behavior domain are highly reliant on one another. The fuel models are derived from the vegetation layers and the fire effects will influence vegetation growth over time (tracked in the vegetation domain). Depending on the flame length and fire type (ground fire, passive crowing fire, or active crowing fire). The fire modeling outputs are categorized into severity classes which determine the numbers of trees killed (tracked in the vegetation domain) and the quantity of biomass consumed by the wildfire (tracked in the emissions modeling domain). Thus, the wildfire behavior modeling is a critical component of the LCA B2E foundation. This modeling strategy also depends on a series of assumptions, which will be described in the following approaches/ methods section.

Key Questions

1) What are the effects of treatment on large-scale fire behavior?

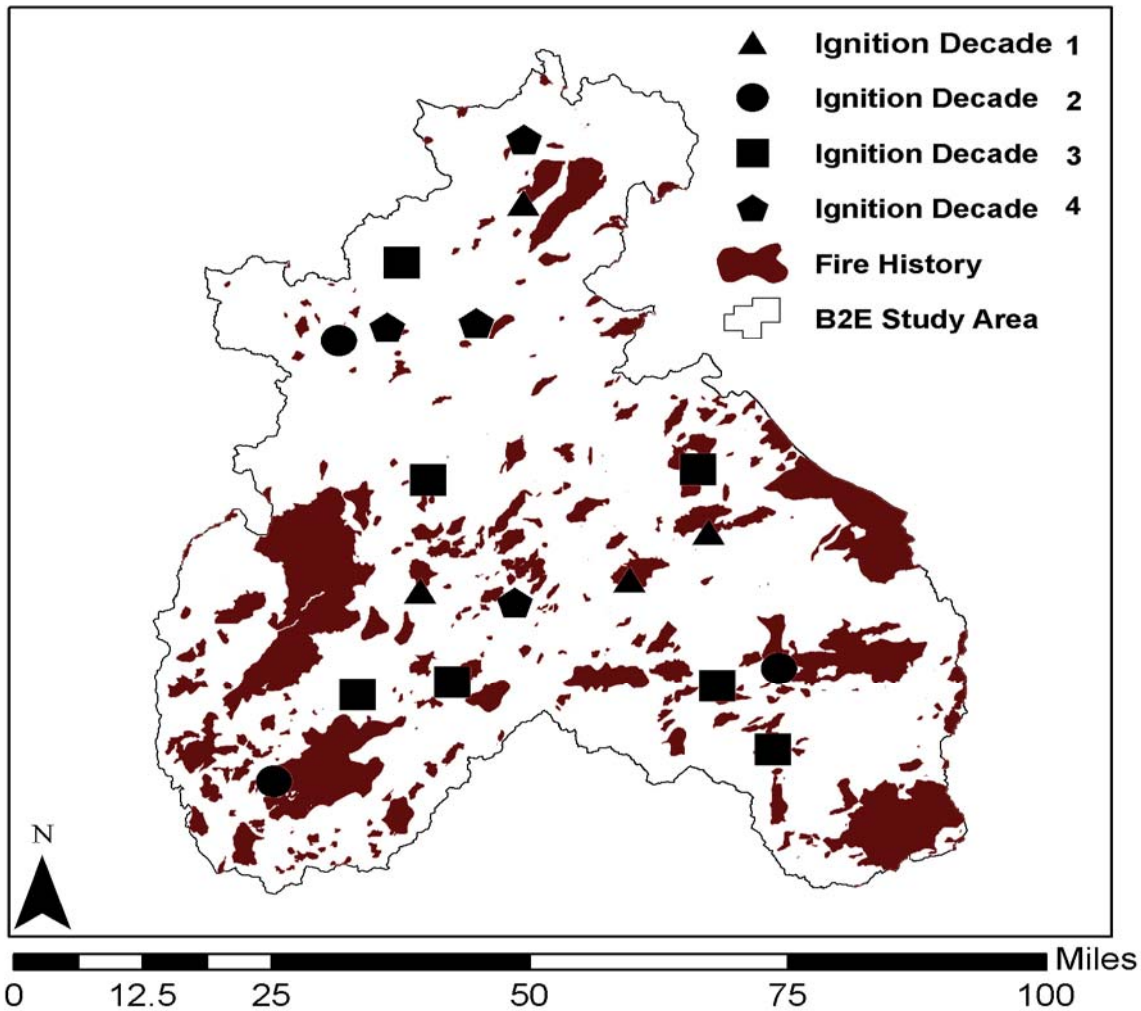
2) What are the contributions of private and public land treatments toward modifying large-scale fire behavior?

[1]"Catastrophic fire" refers to stand replacement or high intensity fires that cause damage to assets and values. We also refer to these as "uncharacteristically severe wildfires."

Approach/Methods

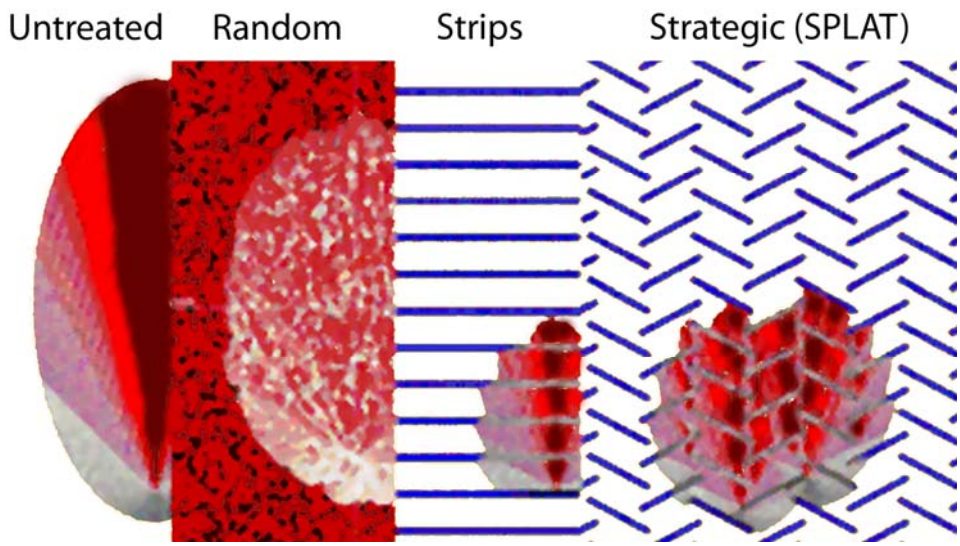
The LCA B2E was able to track the contribution of private and public land treatments toward modifying large-scale fire behavior by comparing the difference in fire behavior between three management scenarios. Fire modeling outputs included the number of acres in three classes of fire severity, the number of burned acres with crown fire behavior, and flame lengths less than and greater than four feet. Historical fire occurrence was used to locate ignitions. Discrete ignition points at locations across the landscape were chosen recognizing that demographics, human activities, and climatic conditions will vary with time (Figure 1). The LCA B2E fire behavior modeling approach used pre-determined ignitions instead of a random generator. Randomization of ignition locations did not yield the "catastrophic" events needed to measure differences between the three main treatment scenarios.

Figure 1 – B2E Beta Landscape Fire History and Ignition Placement by Decade



Fundamental to the assumptions of the B2E treatments is the concept of SPLATs as described by the research and fire behavior modeling of Mark Finney of the Missoula Fire Lab in the Rocky Mountain Research Station (Finney 2001). Finney's research on optimized treatments reveals that how you spatially arrange fuel treatments across the landscape is much more important than how much of the area is treated. Using the fire behavior modeling software FARSITE and FlamMap, Finney and his colleagues at the Missoula Fire Lab have shown that treatments on only 20 to 30 percent of the landscape can be effective in reducing the threat of crown fires and other severe fire behavior if the spatial arrangement of the treatments interrupts the fire's rate of spread (Figure 2).

Figure 2 – The effects of various fuel treatment patterns on fire size (adapted from Finney 2001): Left to right - homogenous fuel conditions (untreated), random treatments, complete overlap of parallel strip treatments, and strategic, slanted overlapped treatments.



Fire behavior was summarized into three classes of severity to distinguish and report changes in wildfire effects across the B2E landscape (Figure 3). Burned areas were classified based on spatially explicit FlamMap (Finney, Britten et al. 2006) model results of fireline intensity and the crowning behavior of the fires. The effects of wildland fire behavior on vegetation were tracked in the vegetation portion of the larger B2E-LCA project (domain), and overseen by the USFS Region Five's Stewardship and Fireshed Assessment (SFA) Team. The severity of wildfire was assigned to three classes (non-lethal, mixed lethal, or lethal effects) depending on its flame length and fire type (ground fire, passive crowing fire, or active crowing fire). Fire severity determines the numbers of trees killed and the amount of biomass consumed by fire. Simulations were performed on a 10-year temporal sequence for 40 years with a series of fires taking place immediately at the beginning of each decade in each management scenario.

Figure 3 - Classes of fire severity used in B2E fire modeling (Stewardship and Fireshed Assessment Team) (N) – Non-Lethal, (X) – Mixed-Lethal, (L) – Lethal

Fire Severity Classes		Fire Type (Crown Fire Activity)		
		Ground	Passive Crowning	Active Crowning
Flame Length (feet)	0.00-3.99	N	X	L
	4.00-7.99	X	X	L
	8.00-11.99	X	L	L
	12.00+	L	L	L

The modeling strategy was to measure and treat changes in wildfire effects as expected value outcomes, reflecting average outcomes over long time periods of 10 years or more. The team averaged probabilities of wildfire occurrence across space and time. 10-year intervals over a forty year timeframe for the fire modeling effort has been selected because this timeframe because it fits well with the economics that drive timber harvest (single entry at 20 year intervals for un-even aged management) as well as the life cycle of the technology being evaluated (biomass conversion plants are likely to become obsolete).

Results

With a no treatment weighted average biomass levels of 79 bone-dry tons (BDTs) per acre, the private treatments removed an average of 31 BDTs/acre while SPLATs removed an average of 24 BDTs/acre (Table 1). Downstream models are evaluating the effects of these three fuel treatment scenarios on economic feasibility, energy production supported, ecosystem impacts and the location and capacity of modeled biomass facilities. For the purposes of this B2E project, by comparing the difference in fire behavior between three management scenarios over the forty year management trajectory we can evaluate the contribution of private and public land treatments toward modifying large-scale fire behavior.

While the ownerships, forest type, density and slope dictated the type of treatment prescriptions, we found that the spatial arrangement of treatments has a greater impact on their ability to change fire intensity and extent than the prescription applied. While we recognize that the optimal pattern for preventing catastrophic wildfires (or reducing their impacts) is not always a realistic option, we have modeled scenarios two and three with the necessary adjustments to protect sensitive wildlife habitat, reduce

Table 1- B2E Pre-treatment Inventory and Amounts of Biomass Removed by Scenario and Year (in BDTs/acre)

Scenario	Year	Inventory	Treatment
1: No treatment	2006	64	
	2016	73	
	2026	80	
	2036	86	
	2046	91	
	Average	**79**	
2: Industrial Private Forests (IPF) only	2006	64	30
	2016	69	35
	2026	73	28
	2036	76	31
	2046	79	
	Average	**72**	**31**
3: (IPF) & Public Multiple Use (PMU)	2006	64	28
	2016	67	34
	2026	70	23
	2036	73	26
	2046	75	
	Average	**70**	**28**
3b: (PMU) SPLATS	2006	64	26
	2016	66	34
	2026	67	17
	2036	70	20
	2046	72	
	Average	**68**	**24**

negative watershed effects, shape recreational opportunities, and to capture timber volume under industrial private forest ownerships (that are both realistic in turns of net revenues and yet protects their proprietary information). Many of these assumptions are depicted in the treatment allocation rule sets and logic described in the vegetation domain summary.

Quantifying effectiveness of fire mitigation treatments is a challenge as there is no accepted system of measurement. Evaluations of fire hazard mitigation programs tend to focus primarily on the number of acres treated and treatment costs associated with mitigation without adequately assessing the benefits of these treatments. These programs also tend to focus on monitoring the total number of acres burned from one year to the next to determine efficacy of certain fire mitigation strategies (for instance, comparing DFPZs and/or SPLATs with traditional fuel break systems). Wildfire behavior modeling, especially with FlamMap, lends itself well to landscape comparisons (e.g., pre- and post-treatment effectiveness) and for identifying hazardous fuel and topographic combinations, thus aiding in treatment prioritization and landscape-level assessments such as the B2E Beta model. The B2E Beta wildfire behavior modeling of these three treatment scenarios showed a 6% reduction in the number of acres burned from private treatments and a 16% reduction from SPLATs on public lands (Table 2). Scenario three had the overall greatest effect on the number of acres burned (i.e. fire perimeters) with a 22% reduction from the no treatment scenario. For scenario two, decade two had the greatest impact on reducing the fire perimeter with a 19% reduction in total acres (Table 2). We expected to see a similar trend for reducing fire perimeters across all four decades but recognize that differences existed due to modeling assumptions and fire placement. These heightened effects for decade two were attributed to the location of the ignitions, higher proportion of private industrial ownership, and the topography within the fire perimeters.

Table 2- Summary of B2E Beta Model Burned Acres by Scenario and Year

Year	1: No treatment	2: Industrial Private Forests (IPF)	3b: (PMU)	3: (IPF) & (PMU)
2006	92,684	92,168	81,004	80,487
2016	60,153	48,616	51,383	39,846
2026	69,953	65,241	49,097	44,385
2036	76,543	75,758	68,582	67,796
Total Acreage	**299,334**	**281,782**	**250,066**	**232,514**
% Change from No TMT	**0%**	**-6%**	**-16%**	**-22%**

As expected scenario one generated the most acres burned with an average of 74,833 acres. While not all fires will achieve the same size, the average burned acreage per decade averaged 67,802 acres for all three scenarios. Ignoring the small fires, the B2E Beta landscape's fire history on record (last 80 years) averaged around 65,000 burned acres per decade. The wildfire behavior modeling efforts for this B2E LCA Beta model has tried to mimic the fire history on record burning 65,000 acres in a variety of fire size and intensities with acres in each severity class approaching 30% based on work by Jay Miller and Jo Ann Fittes (2006).

Evaluations of fire hazard mitigation programs tend to focus primarily on changes in the number of acres burned (since those are easiest to monitor). A modeling venture such as the B2E LCA Beta model allows us to evaluate the contribution of private and public land treatments toward modifying large-scale fire behavior using intensity as the change metric. Across all scenarios, 30.8% of the acres burned were characterized as non-lethal, that is, surface fires with flame lengths between one and four feet (Table 3). The percentages of fire severity classes from the B2E wildfire modeling effort corresponds well with USFS severity monitoring for the Sierra Nevada (Miller and Fites 2006).

Table 3- Summary of B2E Beta Model Severity Class Acres by Scenario

	Scenario			Summary	
Fire Severity Class	**1**	**2**	**3**	**Total**	**%**
N - nonlethal	81,471	82,160	86,586	250,216	31%
X - mixed lethal	136,887	125,156	98,560	360,603	44%
L - lethal	80,976	74,465	47,368	202,809	25%
Grand Total	**299,334**	**281,782**	**232,514**	**813,629**	**100%**

These fire severity classes are important to the B2E LCA Beta modeling project because many of the downstream models are evaluating the effects of these three fuel treatment scenarios based upon these three classes. For instance, fire consumption rates for canopy fuels and resultant wildfire emissions for green house gases are all modeled and calibrated to these fire severity classes.

Table 4- B2E Beta Model Severity Class Acres by Scenario by Year

		Fire Severity Classes		
Scenario	**Decade**	**N**	**X**	**L**
1	**1**	36,579	33,176	22,929
	2	19,447	20,947	19,759
	3	19,296	31,691	18,965
	4	6,148	51,072	19,324
2	**1**	37,953	30,592	23,623
	2	21,491	13,208	13,917
	3	14,312	32,791	18,138
	4	8,404	48,566	18,787
3	**1**	37,889	24,740	17,858
	2	19,914	15,452	4,480
	3	15,417	18,496	10,472
	4	13,366	39,873	14,557

As expected with the higher total number of acres burned, the percentages of acres with lethal and mixed-lethal fire severity classes were also highest in decade two (Table 4). All three fire severity classes were favorably affected by applying both the private and public treatments over the four decades. Only decade three showed a decrease in the number of acres in the non-lethal severity class (3,880 acres) but that is due to the dramatic drop in total acres burned from implementing both public and private treatments in this particular decade with a positive change of 25,568 acres or 36.5% from the non-treated scenario one (Table 2).

Despite a 6% positive effect on the number of acres burned, applying private treatments alone does not always result in a favorable effect on changing the fire severity. Decade one's lethal severity class increased by 694 acres and decade three's mixed lethal increased by 1100 acres (albeit 827 acres of these can be attributed to a decrease in severity from lethal to mixed-lethal classes). Crown fire behavior in even-aged managed stand, especially during early stages of plantation development, can explain for these

two increases in fire severity classes (out of twelve represented in Table 4). Overall, the majority of the acres modeled in this effort demonstrated favorable impacts of implementing industrial private forest treatments with a decrease of 7% in the lethal severity class across the entire B2E Beta landscape.

Key findings:

Modifying landscape-scale fire behavior when only a portion of the landscape can be realistically treated requires attention to layout. Mark Finney's research indicates that fire spread rates can be reduced, even outside of treated area, if a fire is forced to flank treated areas where fuels have been reduced. However, two criteria must be met for the strategy to be effective: 1) the pattern of treatments must be laid out in a manner that interrupts fire spread, and 2) prescriptions within the treatments must be designed to modify fire behavior.

Whether compared for the entire B2E Beta landscape or within perimeters of the 67,800 acres burned per decade, treatments applied to both public and private lands changed fire behavior and growth. The B2E wildfire modeling venture has demonstrated that treating public multiple use lands with SPLATs, albeit not nearly as strategically applied as originally intended by its designers, contributes more (percentage wise) than private sector treatments for modifying landscape-scale fire behavior. The goal of this modeling was not to differentiate between public and private sector treatments, but rather, to improve our understanding of implementing forest treatments across ownerships to prevent catastrophic wildfires (or at least reduce their impacts). The next steps for improving the B2E wildfire modeling component will be to move to another landscape archetype and design vegetation growth simulations for brush types.

Limitations & Caveats

Spatial implementation of treatments on public multiple use lands needs to be strategic as in the true intention of Finney's SPLATs design. 50% of the Beta landscape is on public lands so the strategic nature of SPLATs needs to be modeled for better results from these emerging biomass opportunities. Albeit a decent reduction in acres burned (16%) compared to treatments on private lands (6%), other domains will unveil the limitations of our mass-applied public multiple-use treatments.

Limited in the current B2E fire behavior modeling effort is the in-growth of ladder fuels (especially brush) that may initiate active crown fire behavior. It is common to have under-prediction of active crown fire in FlamMap as compared to observed conditions (Scott and Reinhardt 1999, Fulé et al. 2001a, Fulé et al. 2001b, Scott and Reinhardt 2001, Cruz et al. 2003). Recent research by Scott (2006) indicates that the FARSITE and FlamMap models typically under-predict crown fire initiation compared to other models. Since FVS does not have coefficients for non-forested types, specifically shrublands and grasslands, the B2E growth projections does not allow for an in-growth of ladder fuels from understory vegetation. The B2E forest growth projections do not accurately depict changes in height-to-live-crown with time. In the next steps for the B2E model, further refinement of the growth projections can improve our ability to model crown fire initiation.

Next Steps

A primary assumption of the B2E fire behavior modeling approach is that SPLATs, as both a theoretical and an applied approach, will indeed fragment the fire-prone environment of the Beta landscape for the desired effect of reducing fire behavior, growth and/or severity. The modeled outcomes demonstrated in our results show a favorable effect from the spatial arrangement of treatments but it is obvious that policy makers will need more empirically data to justify greater application of SPLATs on public lands.

As Mark Finney's research indicates, modifying landscape-scale fire behavior when only a portion of the landscape can be realistically treated requires attention to layout. We agree that that the spatial arrangement of treatments is critical. On the B2E Beta landscape we noticed that strategic placement had a greater impact on fire intensity and extent compared to treatments themselves. Fire severity, as defined by the three classes, decreased by both private and public forest remediation treatments with a greater effect on public multiple use lands. We were not surprised to find that the mass SPLAT implementation on public lands had a greater effect on fire behavior than the treating of private lands for commercial timber values. The next evolutionary step for modeling landscape-scale fire behavior will be for the B2E model to incorporate treatment prioritization and strategic placement of SPLATs.

The next iteration of this model also needs to consider the non-industrial private ownership. Since we found an impact of treating industrial private lands, we will need to evaluate the impact of non-industrial private ownerships. In the B2E landscape, there are several forest dependent communities where these stakeholders will significantly contribute to the flow of biomass feedstock to these emerging biomass energy opportunities. These non-industrial private ownerships also may be located closer to the cities and towns where any reduction in severe fire behavior is highly valued. Often these ownerships are the beneficiaries of federal funding intended to protect assets at risk within the WUI. As we continue to struggle with performing treatments with limited financial resources, the fire prevention community's emphasis of "life and property" should be depicted in the B2E fire behavior and treatment prioritization and modeling.

Project management

It should be feasible to have the LCA vegetation, fire behavior and carbon modeling teams function jointly in their modeling efforts. While not possible to automate many of these modeling efforts, there is a need to develop an integrated approach for these three domains. In order to facilitate this interaction, all team members need to be prepared to function (or at least be conversant) in the other's domain (vegetation modeling using FVS, fire, and carbon modeling). This may require more face time (perhaps a workshop setting) but ultimately it will serve all parties as there is more cohesiveness between these various modeling arms of the B2E team. This will undoubtedly yield better results for downstream carbon model. For instance, the carbon model would benefit from the site specific data generated in the vegetation, wildfire and treatment modeling outputs rather than relying heavily on summary data tables.

Literature Cited:

Cruz, M.G., M.E Alexander, & R.H. Wakimoto. 2003. Assessing canopy fuel structure stratum characteristics in crown fire prone fuel types of western North America. *International Journal of Wildland Fire* 12: 39-50.

Finney, M. A. (2001). "Design of regular landscape fuel treatment patterns for modifying fire behavior and growth." Forest Science 47: 219-228.

Finney, M. A., C. W. McHugh, et al. (2005). "Stand- and landscape-level effects of prescribed burning on two Arizona wildfires." Canadian Journal of Forest Research 35(7): 1714-22.

Finney, M., S. Britten, et al. (2006). Flammap. Missoula, Montana, Fire Sciences Lab and Systems for Environmental Management.

Fulé, P. Z., C. McHugh, T. A. Heinlein, & W. W. Covington. 2001a. Potential fire behavior is reduced following forest restoration treatments. Pp. 22-28 in Ponderosa pine ecosystems restoration and conservation: Steps toward stewardship, ed. R. K. Vance et al. Proceedings RMRS-22. Ogden, Utah: USDA Forest Service.

Fulé, P. Z. A. E. M. Waltz, W. W. Covington, & T. A. Heinlein. 2001b. Measuring forest restoration effectiveness in reducing hazardous fuels. Journal of Forestry 99:24-29.

Miller, J. D. and J. Fites (2006). Sierra Nevada fire severity monitoring: Internal report. Nevada City, CA, USDA Forest Service, Pacific Southwest Region, Adaptive Management Services Enterprise Team: 62.

Scott, J.H. 2006. Comparison of crown fire modeling systems used in three fire management applications. Res. Pap. RMRS-RP-58. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 25 p.

Scott, J. H., & E. Reinhardt. 1999. NEXUS fire behavior and hazard assessment system. Software program available from Systems for Environmental Management, Missoula, MT

Scott, J. H., & E. Reinhardt. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior Res. Pap. RMRS-RP-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.