Arnold Schwarzenegger
*Governor*

# BIOMASS TO ENERGY:

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

# APPENDIX 3

PIER FINAL PROJECT REPORT

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# Appendix 3:
# B2E Forest Operations and Equipment Configuration

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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.

## Brief Description of Forest Operations and Equipment Configuration Domain

The Forest Operations and Equipment Configuration Domain team sought to accurately characterize the type and blend of forest harvest and removal equipment used to perform forest remediation activities on the B2E Beta landscape archetype. Equipment readily available and currently in use in Northern California was selected specific to the forest remediation treatment prescriptions and topography (slope) as defined by the Stewardship and Fireshed Assessment (SFA) team.

## What Key Questions was the Analysis Trying to Answer

What are the blends of equipment currently utilized by practitioners to implement forest remediation activities on the B2E landscape?

What are the financial costs to implement forest remediation activities using equipment configurations specific to treatment prescriptions and anticipated outputs of sawlogs and biomass fuel?

How many individual operations (sides) will be required in each of the four decades to effectively conduct forest remediation treatments consistent with treatment prescriptions, acres treated, and products produced?

## Approach or Methodology Utilized

Our approach utilized explicit statements by experts (harvesting contractors and supervisors) currently conducting forest remediation activities in Northern California regarding what representative harvest operations or sides[1] would consist of, in terms of specific types and quantities of equipment for each harvest treatment prescription and range of slope conditions. Table 1 provides a summary of slope class, treatment prescription and equipment configuration code.

Table 1. Equipment Configuration Code by Slope Class and Treatment Prescription

| SLOPE CLASS | TREATMENT PRESCRIPTION | EQUIPMENT CONFIGURATION CODE |
|---|---|---|
| | **Clearcut** - Even-aged management. Only occurs on industrial forest lands. | |
| <35% | | CC <35 |
| 35 to 50% | | CC 35-50 |
| >50% | No harvest treatment planned. | |
| | **Pre-Commercial Thinning** - No sawlogs removed. Only biomass fuel removed. Typically in plantations. | |
| <35% | | PCT <35 |
| 35 to 50% | | PCT 35-50 |
| >50% | No harvest treatment planned. | |
| | **Commercial Thinning** - Sawlogs and biomass fuel removed. Typically in plantations. | |
| <35% | | CT <35 |
| 35 to 50% | | CT 35-50 |
| >50% | No harvest treatment planned. | |
| | **Salvage** - Assumes that no biomass fuel (3"-9.9" DBH or limbs/tops) is recovered. | |
| <35% | | SAL <35 |
| 35 to 50% | | SAL <35 Public |
| <35% | | SAL 35-50 |
| 35 to 50% | | SAL 35-50 Public |
| >50% | No harvest treatment planned. | |
| | **Select Harvest** - Uneven-aged management harvest removing high-risk trees in mature stands. | |
| <35% | | SH <35 |
| 35 to 50% | | SH 35-50 |
| >50% | | SH 50+ |
| | **Restrictive Thinning** - A "light" thin, but retain 40% canopy. Public lands only. | |

[1]Side is a common term used by harvest contractors to denote a separate and distinct blend of harvest equipment conducting harvest activities as a separate operation.

| | | |
|---|---|---|
| <35% | | RT <35 Public |
| 35 to 50% | | RT 35-50 Public |
| >50% | No harvest treatment planned. | |

In our analysis, this blend of equipment is labeled as the equipment configuration and as shown in Table 1 (above), each configuration was assigned a code based on slope class (topography) and treatment prescription. Our analysis also utilized holistic estimates (as provided by experts) of average production rates for each harvest operation (side). This approach contrasts with those that use empirical or mechanistic models to calculate production rates as a function of site and stand conditions such as average tree size and skidding distance. The latter models, once developed, can easily generate estimates for an almost unlimited number of scenarios. Our current approach is limited in that sense due to the time and cost required to elicit expert opinions for a given scenario. However, the equipment configurations generated by our approach are more realistic in terms of the mix of equipment and provide more precise values for overall costs and production rates because of the level of detail included.

For each type of equipment, we selected one or more representative models used in California or currently available equivalents. We then collected data, including purchase prices, fuel consumption rates and other parameters. Our choices do not indicate recommendations or preferences for these models over others; it was not practical nor did we consider it necessary to include the full range of equipment model options in the analysis.

A machine-rate approach similar to that described by Miyata (1980)[2] was used to calculate costs per unit time for each piece of equipment. Although machine-rate values differ somewhat from those developed with explicit cash flow approaches, they require fewer assumptions and have been used widely in the forest operations field. Our approach differed slightly from Miyata's in that we first estimated equipment life in productive hours rather than in a fixed number of years; this is more realistic if the assumed number of operating hours per year is varied. Capital cost (depreciation plus interest) was tracked separately as a fraction of the total cost so it could be reported separately for use in a later step of the LCA project (B2E Benefit/Cost Analysis).

## Calculation Process for Each Equipment Configuration

For a specific equipment configuration, the machine-rate costs for each machine were combined with the expert opinion-derived numbers of machines of each type to calculate the annual cost for each type of machine for the side. Total annual fuel and oil consumption were also calculated by type of machine with fuel usage estimates provided by the equipment vendors. Hourly fuel usage rates were cross checked with relevant studies (Brinker et al, 2002)[3] to confirm that fuel usage rates quoted were reasonable. Oil usage was estimated using relevant studies that provided a ratio of oil utilized per gallon of diesel consumed as cited by Brinker et al, 2002.[4]

[2]Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. General Technical Rep. NC-55. USDA Forest Service, North Central Experiment Station, Houghton, MI.
[3]Brinker, RW, Kinard, J, Rummer, B and Lanford, B: Machine Rates for Selected Harvesting Machines. Alabama Agricultural Experiment Station, Circular 296, September, 2002.
[4]ibid.

The production rate (BDT[5]/day) for a side was calculated from the per-acre removals and the experts' estimates of the acres that would be treated by the side in a day. The total costs and the fuel and oil consumption were then allocated to the two different products – chips and sawlogs – using the following logic. Since a primary intent of these operations is to remove fuel and remediate forest stands, the biomass and sawlogs should share equally, on a per-ton basis, the costs of all activities that handle or process both products. This contrasts with an incremental cost allocation approach which, for example, allocates all felling and bunching of sawlog trees to the logs produced and none to the biomass recovered from those trees. Costs of activities that handle only one product should be borne by that product. Thus, costs were partitioned by weight over the biomass and sawlogs for any of the following activities associated with a side: powersaw felling, limbing and bucking, in the stand or at the landing; felling and bunching; skidding; yarding; and mechanized processing at the landing. Ancillary activities – supervision, equipment transport by lowbed, crew transport, road maintenance, mechanic, fire patrol and fire wagon, and sporax application – were also shared on the same basis. The costs allocated solely to biomass included chipping (and costs of the loader used to feed the chipper if biomass was cold-decked for later processing) and hauling of chips.

The model did not consider the loading and hauling activities associated only with sawlogs; therefore, the total reported costs for sawlogs were stump-to-landing, i.e., logs were brought to a deck on the landing. For the biomass, the costs covered the full span of harvest, skid, process and transport activities from the stump to delivery of chip to the biomass power generation facility.

As noted previously, capital costs were calculated separately in order that total costs could be separated into capital and other (Operating & Maintenance, O&M) costs per ton for each product. These were multiplied by the amounts of biomass and sawlogs projected to be removed each decade, then divided by ten years to generate an average annual capital and O&M costs ($/year) for each of the two products, sawlogs and chips.

## Process for Obtaining Information on Equipment Configurations

Data regarding sawlog and chip volume removals, as provided by the SFA team for each of the harvest and remediation treatments (clearcut, thinning, selection, etc.) and the three slope categories (<35%, 35-50%, >50%) was tabulated for each scenario (2 and 3) and each of the four, ten-year periods. Each combination was characterized by sawlog volume removed (thousand board foot per acre or MBF/acre)[6] in each of three diameter-at-breast-height (DBH)[7] categories (10-14.9", 15-24.9" and 25"+), and by weight (BDT/acre) of sawlogs in the same three diameter categories and of biomass fuel from the combination of small trees (4-9.9" DBH) and residues (limbs and tops) from the larger trees that produced sawlogs.

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[5] BDT – Bone dry tons. One BDT is a standard unit of measure used by the forest products manufacturing sector and represents 2,000 pounds of material with zero percent moisture content.

[6] MBF represents 1,000 board feet log measure. One board foot is nominally a solid wood board measured 12 inches square by 1 inch thick.

[7] DBH is a common forestry term for diameter of a stem measured in inches. Measurement of diameter is taken at 4 ½ feet above ground level (aka breast height).

For many of the harvest treatment and slope combinations, there was little or no variation between the areas to be treated under the two scenarios; therefore, the number of essentially unique cases (equipment configurations) was reduced to 15 for each ten-year period. It was not practical to solicit expert opinion on 60 equipment configurations. We examined the variabilities in removals over the four time periods (four decades) and felt that the averages across the entire four decades could be used to define the 15 equipment configurations and average production rates in acres per day. Costs per ton would be derived for each equipment configuration and then applied to the tons removed during each time period. This was considered more realistic than applying the same production rate (acres per day) across the whole analysis period.

Initial estimates of the equipment combinations and production rates were generated for each of the 15 harvest treatment-slope combinations. These were based on personal experience and simulations of appropriate equipment configurations made with the Fuel Reduction Cost Simulator software.[8, 9] We met with harvesting experts and presented, one at a time, each of the harvest treatment-slope combinations and the associated removals (MBF/acre and BDT/acre by size category and type, and our estimates of approximate numbers of trees per acre removed in each DBH size category). Through a process of discussion, the experts provided their estimates of which equipment and how many of each would constitute an appropriate side for the removals in question and how many acres would be treated per day. Based on our previous estimates, we interjected questions when anomalies appeared, such as imbalances between chipper capacity and the biomass produced by the rest of the side. After coming to agreement on one treatment combination, we proceeded to the next.

After meeting with the harvesting experts, we entered configurations and production rates into the forest operations equipment model and calculated costs per BDT of chips and per MBF of sawlogs. With few exceptions, the costs for the 15 equipment configurations were consistent with our field experience and expectations, i.e., costs were higher on the steeper slopes and higher for thinning than for clearcut treatments. We made adjustments for the few inconsistent cases and then consulted the harvesting systems expert most experienced with spreadsheets to confirm our adjusted assumptions and results.

## Actual Results

#### Costs for Biomass

Estimated costs for the biomass chips removed ranged from $50-120 per BDT.

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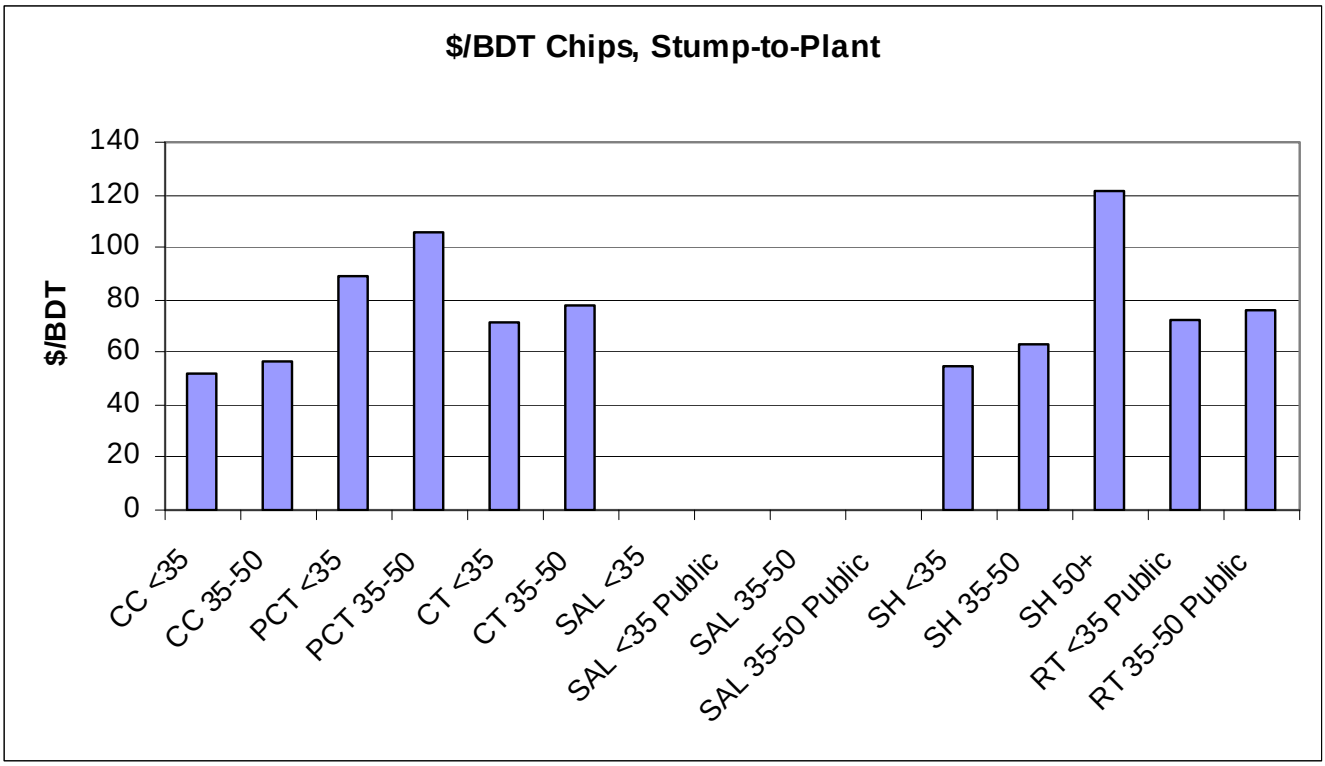
[8]Fight, R.D. and B.R. Hartsough. 2005. FRCS: Fuel Reduction Cost Simulator to estimate the cost of thinning for fuel reduction. USDA Forest Service Pacific Northwest Research Station, Portland, OR. http://www.fs.fed.us/pnw/data/soft.htm.

[9]Fight, R.D., B.R. Hartsough and P. Noordijk. 2006. Users guide for FRCS: fuel reduction cost simulator software. Gen. Tech. Rep. PNW-GTR-668. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.




As would be expected, the estimated costs were least for the clearcutting treatment on the gentler terrain (CC <35). Under this combination, total removals average 76 BDT per acre (30 of chips and 47 of sawlogs), with half of the removed weight being in trees larger than 15" DBH. The two highest-cost treatments were for selective harvest on the steepest terrain (SH 50+), due to the need for cable yarding, and precommercial thinning on steeper terrain (PCT 35-50). For the latter, an average of 8 BDT/acre of chips are to be removed, but all from trees of less than 10" DBH. Precommercial thinning on gentler terrain is also expected to be rather expensive due to the small average tree size.

The restrictive thin and commercial thin treatments are expected to have intermediate costs for chip removal. On both the gentle and steeper terrain, total removals average between about 20-30 BDT/acre.

Costs for chip removal in the selective harvesting treatments on gentler slopes were estimated to be about $55-65 per BDT, closer to those for clearcutting than for the thinning treatments. Both the average tree size and chip removals (12-13 BDT/acre) are large enough to keep the side relatively productive and the chipper busy.

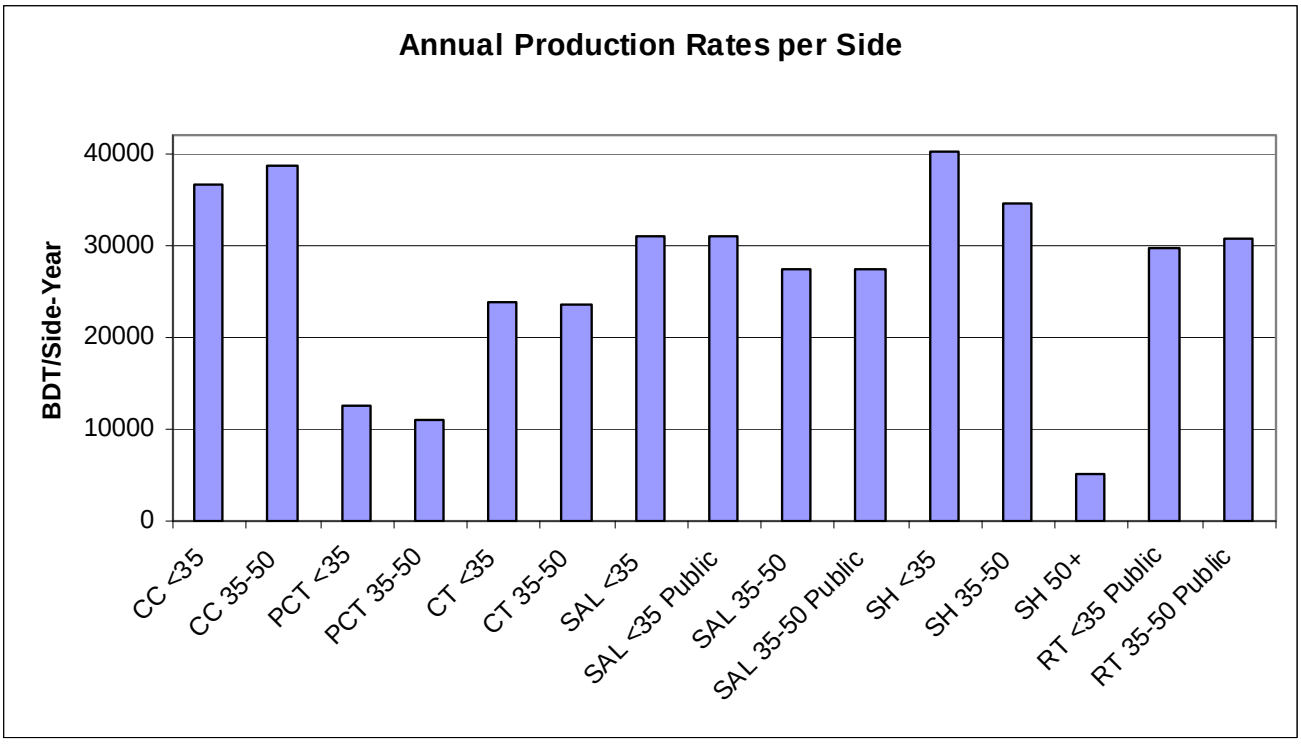
Note that no chip removal is expected from salvage operations, as small stems and limbs are assumed to be consumed by wildfire and thus not available for removal.

Regulations for public lands can differ in some aspects from those for private lands, placing different constraints on forest operations. For example, regulations on some national forests require that stumps of larger trees be treated with a fungicide. To account for such differences, we created separate equipment configurations for public and private lands. Only two prescriptions, salvage and restrictive thinning, are

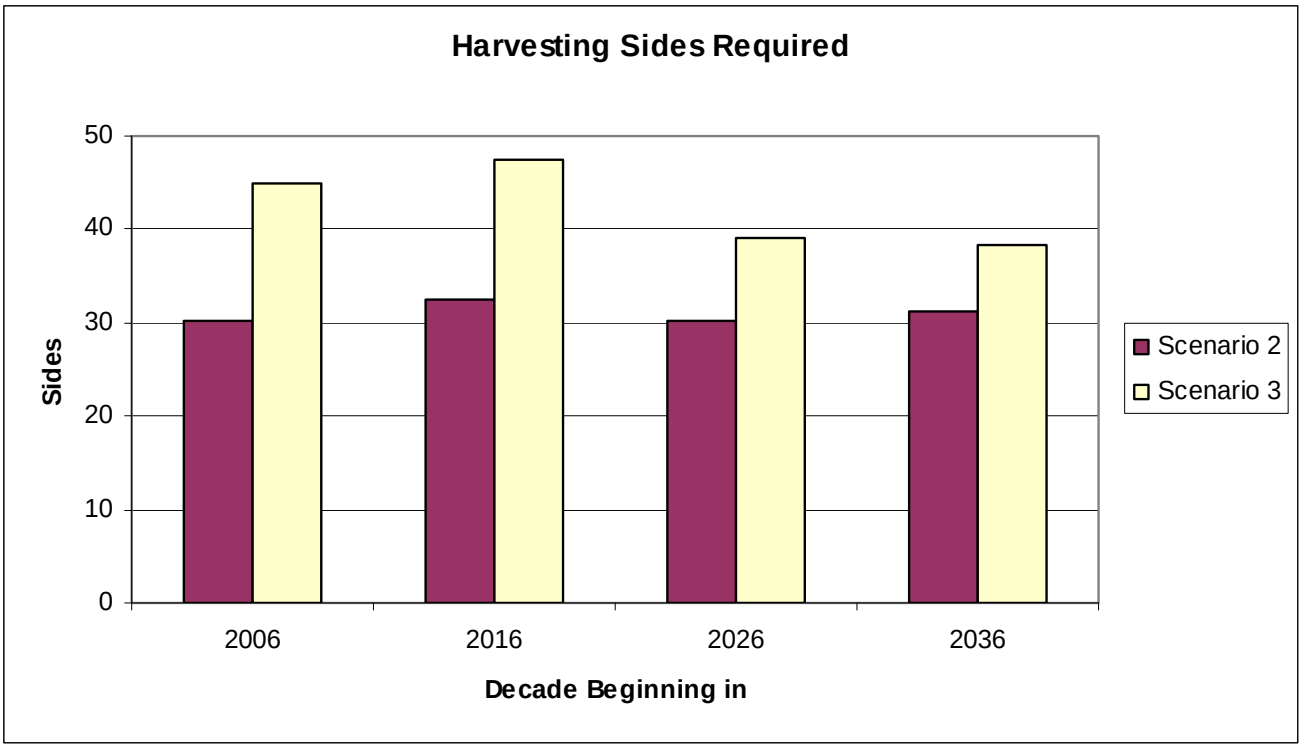
anticipated on public lands (and restrictive thinning is a public-only prescription); thus, only four equipment configurations were established to treat publicly managed forest: one for each of the two slope categories under each of these two prescriptions (salvage and restrictive thinning).

#### Considerations for Harvesting Sides

Most of the sides are expected to produce between approximately 25,000 and 40,000 total BDT (sawlogs and biomass combined) over the assumed 120-day annual operating season. There are two notable exceptions. The precommercial thinning (PCT) equipment configurations are expected to generate only about 10,000-15,000 BDT per year, due primarily to the small sizes of the trees removed. The cable yarding side assumed for selective harvesting on steep terrain requires the use of chainsaw felling rather than mechanical felling and bunching. It also has only one yarding machine per side, resulting in productivity of only about 5,000 BDT/year.




The estimated numbers of sides required for the LCA Beta area range from about 30 to 50, depending on decade and scenario. Under Scenario 2, most of the effort and two-thirds or more of the sides at any one time would be selective harvesting; a fifth would be involved with clearcutting. For Scenario 3, the additional activity on federal lands is essentially all expected to be involved with restrictive thinning, employing a third of the sides in the first decade and a fifth in the last decade.




## Key Findings

- The true costs of forest remediation are significant when allocated specifically to the product produced. Forest remediation practitioners have traditionally allocated many of the costs to remove biomass, such as harvest, skid and road maintenance expenses directly to sawlogs produced, so that only incremental costs (chipping and transport) are allocated to production of chips. The latter approach is logical when the harvesting of sawlogs is to be conducted in any case – with or without biomass – but not when the primary objective is to reduce fuel loading and supply biomass to power plants.
- Stump-to-plant costs are expected to range between $50-120 per BDT for biomass. Net costs depend on the value of the delivered biomass, which was not considered in this analysis.
- The expert opinion methodology used in this analysis, while somewhat laborious, is currently the best approach available when realistic equipment configurations are needed for life cycle analysis. Experts, when identifying equipment configurations, were able to take into account the wide range of variables (topography, forest conditions and treatment prescriptions) associated with this analysis.
- Under Scenario 2, approximately 30 sides would be required to treat stands considered in the analysis.
- With the public lands added in Scenario 3, approximately 45 sides would be required during the first two decades, and 40 or so during the last two decades.

## Limitations and Caveats

- Some of the product outputs (sawlogs and biomass) on a per acre basis did not match up with the field experience of the experts interviewed for this analysis. This may be a result of the decision model used by SFA to locate forest remediation treatments. Optimization of treatment location relative to the more densely stocked stands (Fire Regime Condition Class 2+3) will no doubt yield higher volumes of both sawlogs and biomass. This optimization would also tend to have a more profound impact and mitigation of fire behavior.
- When experts specify equipment configurations and production rates, they rely on estimates of trees per acre as well as volume and weight per acre. Data on trees per acre were not made available to the forest operations team but would be useful for future efforts. For the current analysis, we made educated guesses as to average tree size by diameter class and derived approximate values of trees per acre.
- For purposes of specifying equipment configurations, it would be useful to place a DBH breakpoint at 20" rather than at 25", as most trees larger than 20" will be felled with chainsaws as opposed to mechanized equipment. For the current analysis, we estimated the partitioning of trees in the 15-25" DBH class into the sub-20" and larger categories.

## Next Steps

For phase II, the following steps are suggested:

- Optimize location of forest remediation treatments relative to denser, more at-risk forest stands.
- Conduct B2E analysis on additional landscapes.
- Generate journal articles for peer review and publication (as validation of our approach and methodology).

## *1. Key Project Management Questions*

**If we are going to repeat this analysis on another landscape, what would be the bottlenecks and burdens you believe might impede further development of B2E?**

Some potential burdens that may provide challenges include:

- Ready access to current and relatively accurate forest inventory data.
- Time and cost involved with obtaining the equipment configurations.

**What is "hand carried" from one analysis or process to another in the current model that you would want to see automated or streamlined?**

It might be helpful to "automate" the equipment selection task, however due to the large number of variables, i.e., topography (slope), forest conditions, treatment prescriptions

and equipment configurations, it is not practical to attempt this change in equipment selection procedure.

**What efficiencies would you propose based on your experiences with data exchange or data requirements?**

Utilize a web-based data sharing site such as those provided by SharePoint. This type of site can be readily accessed by team members (using passcodes) and provide key project management tools such as:

- Ready access to key documents.
- Up-to-date project schedule and critical timelines.
- Contact information for all team members.