HARVESTING COSTS FOR POTENTIAL BIOENERGY FUELS IN A FIRE RISK REDUCTION PROGRAMME*

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ABSTRACT

This paper documents the harvesting costs for a representative wildland-urban interface zone project around Flagstaff, Arizona—the 134-ha Fort Valley Research and Demonstration Project. The economic impacts of three treatment prescriptions on three types of *Pinus ponderosa* P. Lawson et Lawson (ponderosa pine) stands utilising three different harvesting techniques were analysed. In addition, the opportunities of two potential bioenergy markets were examined from the harvesters' revenue perspective. The costs of fully mechanised harvesting of the whole tree (WT) and hauling merchantable-size logs equalled US\$28/m^3, when averaged over the three different prescriptions in the three blackjack (BJ) units. There was little variation in WT cost from unit to unit. Under a direct cost hand-felling and mechanised-forwarding scenario (HD) scenario, the predicted costs, when averaged over the three blackjack-yellow pine (BJ/YP) units, equalled US\$25/m^3. Similarly, the cost to treat the three yellow pine (YP) units with a small cut-to-length forwarder system (CTL) averaged US\$26/m^3. The variation from unit to unit, however, for the HD and CTL operations was significant. The costs were a function of volume per unit area and average volume per tree and varied from a low of US\$19/m^3 to a high of US\$43/m^3. A comparative analysis of the three harvesting operations found the WT operation to be the most cost-effective in BJ and BJ/YP units. A slow forwarding system limited HD and CTL effectiveness. In the YP units (characterised by excessive numbers of closely spaced, very small, blackjack trees surrounding widely

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spaced, mature, yellow pine trees), forwarding times were no longer of consideration. Cutter rates and associated expenses became the dependent economic variable. The pre-commercial work in the BJ and BJ/YP units was modelled as a minimal-cost operation using a contract sawyer crew. These costs were found to average, respectively, US$21/ha (US$0.28/tree) and US$193/ha (US$0.15/tree). Within the YP units, the CTL machine completed the pre-commercial work as it made its way through the units cutting the available merchantable trees. This slower operation resulted in very high pre-commercial costs, averaging US$393/ha (US$0.36/tree). The economic analysis of an existing solid firewood market from the harvesters' perspective indicates that a high-value pole market subsidises the lower value firewood opportunity. The ethanol projections were not favourable and the fibre costs were prohibitive.

Keywords: harvesting costs; fuel reduction; wildland-urban interface; *Pinus ponderosa*.

INTRODUCTION

A partnership of Federal, State, local, and private organisations began a fire risk reduction programme in 1997 for restoring 97 500 ha of overstocked conifer forests around the Flagstaff, Arizona, wildland-urban interface (WUI) zone (Neary *et al.* 1999a). Flagstaff lies within the largest contiguous forest of the 16.2 million ha of ponderosa pine in North America. The original ponderosa pine forests of the Mogollon Rim consisted of open stands of uneven-aged trees with a significant grass-forb understorey. Light surface fires ocurred at an average interval of 2–5 years. These fires consumed forest floor material, burned most of the young regeneration, and promoted growth of a dense, grassy understorey. Catastrophic crown fires were rare due to lack of ladder fuels, and the clumpy widely spaced ponderosa pine canopy (Dieterich 1980; Sackett 1980). Fire suppression from heavy sheep and cattle grazing and then modern forest fire control resulted in the development of dense overstocked stands. Forest floor fuel loads that were 0.4–4.5 Mg/ha prior to 1870 increased by nearly two orders of magnitude to an average of 49 Mg/ha, with some stands accumulating up to 112 Mg/ha (Sackett *et al.* 1966). Ponderosa pine stands reached a critical ecological point in 1991 so that wildfires now consume four times the area that they did in the period from 1910 to 1990 (Neary *et al.* 1999b).

One of the objectives of the fire risk reduction project is to manage the fuels that have created high fire risks by harvesting and utilising large amounts of small diameter (<40 cm) ponderosa pine. Fire risk reduction cannot be accomplished by simply introducing fire back into forests that have had fire excluded for nearly 120 years (Sackett *et al.* 1996). This paper documents efforts to advance the state of knowledge regarding the harvesting and treatment costs associated with a representative WUI zone forest restoration and fuels reduction programme—the 134-ha Fort Valley Research and Demonstration project. In addition, these costs are contrasted to the revenue opportunities that two biofuel markets represent.

THE FORT VALLEY RESEARCH AND DEMONSTRATION PROJECT

Background

The Fort Valley Research and Demonstration Project (Fig. 1) is a particularly valuable project from a harvesting perspective as it provides the opportunity to examine three treatment alternatives applied to each of three types of ponderosa pine stands. Yellow pine stands contain ponderosa pine trees characterised by yellow bark; they are larger in size and

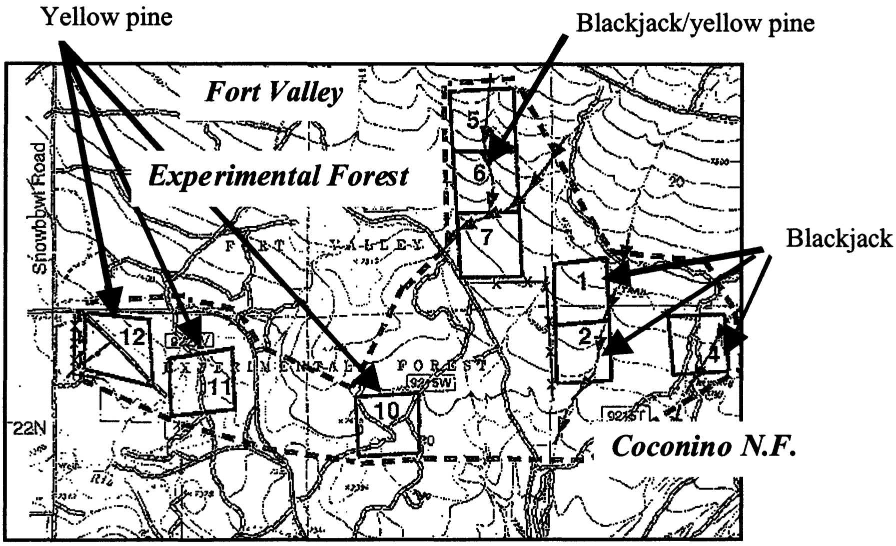

FIG. 1–Map of the Fort Valley Research and Demonstration Project restoration units showing locations of the blackjack ponderosa pine (Units 1–4), blackjack/yellow pine, (Units 5–8), and yellow pine (Units 9–12) stands; control treatments (Units 3, 8, and 9) are not mapped.

older than 150 years. Blackjack stands contain younger and smaller trees with black bark. The stand configurations in this project included: (1) yellow pine units with more than 12 trees/ha (Units 9-12), (2) units of mixed yellow pine and blackjack with less than 5 yellow pine trees/ha (Units 5-8), and (3) blackjack units (Units1-4).

The blackjack units had standing tree counts ranging from 650 to 815 trees/ha. These units are managed by the Coconino National Forest and were thinned in the past. Consequently, the inventory reflected a small percentage (ranging from 8.3% to 23% of the total stem count) of trees in the 10.2 cm class and less. The majority of existing stems were found in the 12.7 to 38.1 cm dbh class, with percentages ranging from 70% to 92%. The number of trees >40.6 cm dbh was small, accounting for only 3.7% of the overall tree population sampled over the three units.

The blackjack/yellow pine units had high live-stem counts ranging from 1391 to 2659 trees/ha due to the large numbers of trees <12.7 cm dbh; this reflected a lack of pre-commercial thinning in the Experimental Forest part of the Fort Valley area managed by the Rocky Mountain Research Station. Trees <12.7 cm dbh represented 59% to 75% of the total number of standing trees. These blackjack/yellow pine units had a smaller percentage (16.6% to 31.2%) of 12.7 to 38.1 cm dbh trees, even though the absolute numbers were very similar to those found in the blackjack units. The blackjack/yellow pine units contained greater numbers of large (>40.6 cm dbh) trees, averaging 69.2 trees/ha.

Units 10, 11, and 12 represent sites that are characteristically called yellow pine units, with 12 or more yellow pine trees/ha. In these units there were, on average, 25 trees/ha in the >55.9 cm dbh class. It is of interest to note that both Units 10 and 11 contained trees >76.2 cm dbh at a rate of 7 to 15 trees/ha. No other study units yielded trees of this magnitude. These yellow pine units have a bi-modal tree population, demonstrating larger numbers of small trees (0 to 20.3 cm dbh) and very large trees (>55.9 cm dbh) with smaller numbers of mid-size (22.9 to 38.1 cm dbh) and large (40.6 to 55.9 cm dbh) trees. Units 10 and 11 were similar in overall stand character. Unit 12, however, was different from 10 and 11 due to the excessive numbers (>1977 trees/ha) of very small trees. In this regard, Unit 12 was similar to Unit 5 (mixed yellow pine and blackjack).

Stand Treatments

A different treatment prescription was applied to each of the three units per stand type. As a consequence, each unit was identified according to stand type (e.g., blackjack) and prescription. The prescriptions were designated 1.5–3, 2–4, 3–6 (*see* Neary *et al.* 1999a and the discussions in the following two paragraphs). A fourth unit per stand type was left as the control that did not have treatment. A detailed listing of stand, unit, treatment, unit size, and number of existing trees per acre prior to treatment is given in Table 1.

TABLE 1–Description of the Fort Valley Research and Demonstration units

Unit type	Unit number	Harvest treatment*	Area (ha)	Restoration treatment	Average standing crop (trees/ha) Before	After
Blackjack	1	WT	12.9	1.5–3	815	92
	2	WT	14.2	2–4	793	122
	3	Not cut	—	Control	Unknown	
	4	WT	13.3	3–6	635	217
Blackjack/yellow pine	5	HD	15.1	3–6	2659	187
	6	HD	14.8	1.5–3	1527	149
	7	HD	14.7	2–4	1391	144
	8	Not cut	—	Control	Unknown	
Yellow pine	9	Not cut	—	Control	Unknown	
	10	CTL	15.8	1.5–3	929	127
	11	CTL	16.7	3–6	1100	215
	12	CTL	16.8	2–4	2920	205

* WT = whole-tree, fully mechanised
HD = hand felling, mechanised forwarding
CTL = small cut-to-length, with forwarder system

Although these prescriptions provide for different levels of thinning, they are anchored to the pre-settlement condition as their template. Only brief descriptions of each treatment are provided here as an interpretative aid to the harvesting analyses. These treatment definitions, as provided below, have been taken from the draft document titled "Flagstaff Urban/Wildland Interface Treatment Guidelines" (Ecological Restoration Program 1998). The reader can find additional information about the treatments and their effects in articles by Covington *et al.* (1997, 1998). In each treatment level all living pre-settlement trees, standing snags, and trees greater than 55.9 cm dbh were retained. The proposed cutting resulted in the near 100% removal of all trees 10.2 cm dbh and smaller. In addition, the thinning activity will eventually be followed by fuel treatments to protect pre-settlement trees, the re-introduction of fire on a periodic basis, and possible seeding of native grasses and shrubs.

The 1.5–3 treatment is known as a full restoration prescription. For every direct evidence of a dead pre-settlement tree (stumps, snags, downed trees, stump holes), 1.5 replacement trees are left whenever large (>40.6 cm dbh) and vigorous replacement trees are available within a 9.1 m radius of the evidence. If the only available good-quality replacement trees are <40.6 cm dbh, then three trees are marked for retention. When the available trees within the 9.1-m search radius are not acceptable due to quality or mistletoe infection, the search radius is extended to 18.2 m. More trees per pre-settlement evidence are retained with the intermediate level of thinning known as the 2–4 treatment. In practice, two large or four small dominant and/or vigorous trees are left for evidence of a every pre-settlement tree. The 3–6 treatment is a minimal thinning plan which results in an even greater density of replacement trees where three large or six small trees are left per evidence.

Projected Merchantable Fibre Quantities

Most of the available fibre for pulp, solid wood, or bioenergy came from the 12.7 to 38.1 cm dbh tree groups (e.g., inclusive of trees ranging in size from 12.7 to 40.4 cm dbh), with only Units 2 and 7 yielding significant quantities from the 40.6 to 53.3 cm dbh tree groups. The blackjack/yellow pine and blackjack units were more productive, in terms of small-diameter fibre yields, than the yellow pine units. This difference occurred because much of the merchantable cutting activity for the yellow pine units took place in the small 12.7 to 20.3 cm dbh tree group due to the limited number of larger (22.9 to 38.1 cm) existing trees. In addition, there were no trees larger than 38.1 cm dbh available for cutting in the yellow pine units, whereas there was a more balanced distribution of cutting within the 12.7 to 38.1 cm dbh class for the blackjack-type units. The blackjack-type units with a 2–4 prescription had predicted fibre yields ranging from 3.8 to 4.3 truckloads/ha. The least productive unit, a yellow pine unit with a 3–6 treatment, had a predicted merchantable fibre yield of only 0.4 truckloads/ha. A full reporting of the merchantable quantities on a per unit basis can be found in the report by Larson & Mirth (1999).

HARVESTING AND THINNING MODELS

Three different, actually operational, logging strategies were simulated using spreadsheet models. The models closely replicated the processes and equipment set-ups of the actual three operators that performed the thinning of the Fort Valley Research and Demonstration Project. Models of case studies with slightly different equipment types were used. The three harvesting and thinning models were as follows.

(1) Whole-tree mechanised harvesting (WT):
   (a) This scenario uses a mechanised system consisting of a tracked feller-buncher, whole-tree skidders, a delimber, and loader to process the merchantable trees >12.7 cm dbh.
   (b) Sub-merchantable trees less than 12.7 cm dbh were hand felled, scattered, and lopped. This pre-commercial activity was sub-contracted out to a local sawyer operator.

(2) Hand felling of all trees (HD):
   (a) This scenario considers the hand cutting, limbing, and bucking of trees >12.7 cm which are then forwarded to the landing using an articulated rubber-tyred skidder with a log grapple.

(b) The merchantable activity is simultaneously accompanied by the cutting, scattering, and lopping of the very small, non-merchantable trees. This model assumes that a subcontractor completes all cutting and related processing, regardless of tree size.

(3) Cut-to-length mechanised harvesting (CTL):

(a) This scenario includes felling, delimbing, and cutting-to-length of all unmarked trees, followed by the forwarding of trees >12.7 cm dbh by tractor with log grapple to trucks or a landing.

The different operators worked on different stand types. The WT operator treated the blackjack stands (Units 1, 2, and 4). The HD operator contracted to complete the work on the blackjack/yellow pine (Units 5, 6, and 7). The CTL operator treated Units 10, 11, and 12. The reader is reminded at this point that three different harvesting systems on three different stands were modelled. The study was not replicated with respect to the harvest systems due to study design decisions that the authors had no control over. The appropriate comparisons are among prescriptions, not between harvest systems. A summary of each model is provided below and a comprehensive detailing of assumptions and specifics has been given in the report by Larson & Mirth (1999).

WT Harvesting

The four-step process used to model the whole-tree merchantable operation with the follow-on pre-commercial treatment consisted of:

(1) Determination of operational costs for a basic cutting-skidding-delimbing equipment set;

(2) Proportioning of other mechanised system costs according to a known set of cost ratios;

(3) Estimation of costs for the pre-commercial hand cutting operation; and

(4) Incorporation of this information into a spreadsheet cost model.

The hourly operational costs of Step 1 were based upon standard construction accounting procedures such as those detailed by Miyata (1980). Step 1 incorporated: a straight-line, 8-year depreciation schedule with 20% salvage value; opportunity costs; insurance and taxes; fuel, lubricant, and maintenance costs; and an operator wage structure that included 20 hours of overtime per week. The mechanised cost assignment procedure of Step 2 used cost ratios developed from an analysis of the Coconino National Forest (unpubl. data), a previous but similar thinning project located within the Fort Valley Experimental Forest where many of the implementation costs were well-defined. The distance to mill for calculation of trucking costs was taken to average 189 km one-way. It was assumed that the pre-commercial activity of Step 3 was accomplished with minimal costs where accounting for office overhead, profit, equipment depreciation, or supervisory staffing is neglected.

The last step, Step 4, consisted of building the spreadsheet model to integrate all costs with the projected cutting activity over Units 1, 2, and 4. The model created for this whole-tree operation was segregated into two stages: the mechanised commercial activity, and the follow-on pre-commercial thinning. This model is based upon production capacities—the potential number of trees processed per activity per hectare. The mechanised stage was constrained by the feller-buncher processing capacity of 150 trees/h adjusted by a 88% efficiency factor (also known as percentage utilisation) to account for 7.2 min/h for operator personal time (Conway 1978). Similarly the cut, scatter, and lop times constrained the hand-cut model. A 50% sawyer utilisation factor was assumed, allowing for long walking distances between very small trees in the previously managed areas.

Hand Harvesting

The modelling approach to the HD harvesting operation differs fundamentally from that of the previous WT method. We modelled this process as a direct-cost-only operation, neglecting overhead, profit, ancillary logging-related expenses, equipment depreciation, etc. This assumption is in contrast with the modelled WT system that incorporated all ideal business expenses (mobilisation, office overhead, profit margin, road work, trucking, loading, delimbing, slash handling, etc.).

As a consequence of the direct-cost approach, the estimation procedure used here is simpler and a function of only:

(1) Hourly equipment costs for a fully depreciated forwarding and loading set-up;
(2) Tree processing rates and associated labour;
(3) Trucking costs;
(4) Estimating the pre-commercial hand-cutting costs in the same manner as that assumed in the WT model; and
(5) Incorporation of this information into a computer spreadsheet model.

The related operational costs for the old forwarder included maintenance, fuel, lubricants, tyres, and storage fees. The operational costs used by Miyata (1980) were not used for this piece of equipment. Like that used in the WT model, the HD model assumed a 60-hour workweek and a trucking rate of US$55/hour (A.Ribelin pers. comm.) with a 90% utilisation rate. The HD operator's main fibre buyer was located approximately 96 km away, but an accounting was also made for those loads of logs >35.6 cm dbh trucked 224 km to a pole buyer. A sub-contracting arrangement was assumed for the sawyers with a cost to the primary operator of $12/hour.

Cutter efficiency was taken at 80% to reflect the relatively flat terrain, high density of trees, and 12 minutes per hour of personal time (Arizona State University 1986). Some analyses assume cutter efficiencies of 50% based on difficult terrain, saw refuelling, service, and maintenance but others report efficiencies more in the 71–81% range, particularly where the terrain is not difficult (Johnson 1979; Lortz *et al.* 1997).

CTL Harvesting

The approach taken here was similar to than in the direct cost model used in the previous HD model where indirect costs, such as profit and overhead and any ancillary logging-related expenses, were not accounted for. As a consequence, the CTL model is a function of:

(1) Hourly equipment and operator rates for the CTL machine to simultaneously process both the merchantable and pre-commercial trees;
(2) Equipment and operator costs for forwarding the merchantable trees to the landing and loading to trucks;
(3) Trucking costs;
(4) Sawyer rates for felling, delimbing, and bucking the >40.6 cm dbh trees, if available; and

(5) Incorporation of this information into a computer spreadsheet model.

Except for the CTL machine and its use for both pre-commercial and commercial work, the model assumptions regarding trucking and haul distances, sawyer rates, forwarding and loading procedures, and other basic processes were the same as those used in the HD model.

TREATMENT COST

Upon the completion of each model, it was possible to project treatment costs by incorporating previously collected stand data for each unit on a per hectare basis. The results of applying each model to the appropriate units are summarised here in tabular form. Thinning costs using the WT system—a feller-buncher, whole tree skidding operation for trees >12.7 cm dbh, followed by a hand-cutting process to cut, fell, lop, and scatter trees <12.7 cm dbh—are summarised in Table 2. A summary of the thinning costs for the HD sawing operation is given in Table 3, and the CTL implementation costs are given in Table 4.

Within the blackjack units, Unit 4 with the 3–6 minimal restoration prescription was the cheapest to treat in terms of US$/m³. What appears to be an irregularity, is not. Unit 4 merely reflects the assertion that logging costs decrease as the available fibre per tree increases. Under the WT scenario in Table 2, Unit 4 yielded, on average, 64.00 m³/ha and 0.22 m³/tree. Units 1 and 2, with more aggressive prescriptions but with larger proportions of smaller trees, yielded 123.95 and 111.36 m³/ha, and 0.19 and 0.19 m³/tree, respectively.

On average, the pre-commercial cost to treat Units 1, 2, and 4 equated to US$0.28/tree. It is important to note, however, that these costs did not include any future handling of the potentially large piles of landed slash. These piles were the result of the feller-buncher, whole-tree skidding operation in which trees >12.7 cm dbh were topped and delimbed at the landing.

Unit 7 (Table 3) was a very productive unit, potentially yielding five truckloads of 12.7 to 55.9 cm dbh logs per hectare, 1½ to 2 times as much fibre as seen in other units. The average volume per tree equated to 0.35 m³/tree. As a consequence, logging costs were

TABLE 2–Implementation costs for the whole-tree harvesting operation projected over blackjack Units 1, 2, and 4 of the Fort Valley Research and Demonstration Project

	Units 1	2	4	Total or averaged over the three units
Treatment	1.5–3	2–4	3–6	
Whole-tree harvesting				
12.7 to < 55.9 cm dbh trees				
Merchantable m³/ha	123.97	111.36	64.00	101.36
US$/unit	$45,077	$44,743	$21,793	$111,613
US$/ha	$3,504	$3,144	$1,644	$2,766
US$/m³	$28	$28	$26	$28
Pre-commercial				
< 12.7 dbh trees				
Trees/ha	67.5	82.5	142.1	75.9
US$ total for unit	$219	$312	$322	$852
US$ total/ha	$17	$22	$24	$21

TABLE 3—Implementation costs for the hand felling harvesting operation projected over blackjack/yellow pine Units 5, 6, and 7 of the Fort Valley Research and Demonstration Project

	Units 5	6	7	Total or averaged over the three units
Treatment	3–6	1.5–3	2–4	
Hand felling operation				
12.7 to <55.9 cm dbh trees				
Merchantable m^3/ha	64.70	68.27	147.10	93.10
US$/unit	$27,823	$26,671	$47,035	$101,528
US$/ha	$1,840	$1,806	$3,192	$2,279
US$/$m^3$	$28	$26	$22	$26
Pre-commercial				
< 12.7 cm dbh trees				
Trees/ha	1,984.0	987.9	823.3	1,271.0
US$ total for unit	$4,463	$2,179	$1906	$8,548
US$ total/ha	$294	$148	$128	$193

affected positively where the cost to harvest and transport was at a very low value of US$21/$m^3$.

On a total dollar basis, pre-commercial thinning of Units 5, 6, and 7 was more costly than that observed in the previous blackjack units due to the large number of very small trees. On a per tree basis, however, the cost to treat the blackjack/yellow pine block was US$0.15/tree, US$0.13/tree less than that in the blackjack block. This per unit price difference reflected the difference in assumed sawyer efficiencies as a function of distance between trees. Walking time between trees decreased as density increased. Only 12 minutes per hour were given to the cutters for personal and walking time in the blackjack/yellow pine units *v.* the 30 minutes per hour allocated in the blackjack units.

Unit 11 (Table 4) was a very low yield unit (in terms of available, merchantable fibre), which resulted in high US$/$m^3$ treatment costs. It suffered from a combination of prescription

TABLE 4—Implementation costs for the cut-to-length harvesting operation projected over yellow pine Units 10, 11, and 12 of the Fort Valley Research and Demonstration Project

	Units 10	11	12	Total or averaged over the three units
Treatment	1.5–3	3–6	2–4	
Cut-to-length harvesting				
12.7 to < 55.9cm dbh trees				
Merchantable m^3/ha	68.52	11.93	57.33	45.47
US$/unit	$20,424	$8,659	$28,703	$57,786
US$/ha	$1,295	$517	$1,712	$1173
US$/$m^3$	$19	$43	$30	$26
Pre-commercial				
< 12.7 cm dbh trees				
Trees/ha	456.4	666.4	2,126.3	1,096.1
US$ total for unit	$2,583	$4,001	$12,792	$19,376
US$ total/ha	$164	$239	$763	$393

(3–6) and stand character, a relative bimodal distribution with large numbers of small (0 to 20.3 cm dbh) and very large (>55.9 cm) trees. Correspondingly, the average fibre yield per available tree was a very low 0.05 m^3/tree. In contrast, Unit 10, with a majority of the yield from the 12.7 to <40.6 cm dbh trees, was the least costly yellow pine unit to treat with a predicted cost to the mill of US$19/$m^3$. Average fibre yield per tree was 0.20 m^3/tree.

Close examination of the pre-commercial costs (Table 4) suggests that it is not cost-effective to use the CTL unit for cutting the very small trees. On a per tree basis, this operation costs US$0.36/tree, or about 2¼ times more than the contract crew modelled in either the HD or WT processes.

COMPARATIVE ANALYSIS OF MODELLED OPERATIONS

Efficiency analysis of fuels reduction or forest restoration projects requires an understanding of the cost-effectiveness of each type of merchantable tree operation modelled in this report. This information is not readily available from the previously presented analyses due to differing logging assumptions and stand characteristics, necessitating the completion of a new analysis that compares each operation appropriately.

To complete this comparative analysis, we applied each logging operation to each unit to collect direct cost data for a standard stand (merchantable trees in the 12.7 to 55.9 cm dbh sizes). More specifically, the comparative logging costs for each operation were calculated at the landing and the data included:

(1) Cost to fell, delimb, and buck the merchantable trees;
(2) Cost to handle the slash generated from the delimbing and topping of the merchantable trees;
(3) Cost to move the merchantable material to the landing and load on waiting trucks;
(4) Direct operational costs for the equipment and labour, neglecting overhead, profit, roadwork, and mobilisation.

This analysis did not include the pre-commercial activity as the intent was to compare and contrast, from an economic perspective, the three basic procedures for merchantable trees. Result summaries are provided in Tables 5, 6, and 7.

The modelled WT operation was the most cost-effective operation within the blackjack and blackjack/yellow pine areas. The WT operation cost approximately US$0.40/tree and US$0.88/tree less than the respective CTL and HD operations. These cost savings were a direct function of processing (fell, limb, buck, land, and load) speed. From an equipment and operator rate perspective, the WT model was the most expensive of the three operations. However, its capacity to process 132 trees/h more than compensates for the expense. In

TABLE 5–Whole-tree harvesting logging costs at the landing by stand type

Costs/Tree volumes	Blackjack	Blackjack/Yellow pine	Yellow pine
Total cost, US$	$44,778	$42,370	$41,005
Total cost, US$/$m^3$	$11	$10	$18
Total cost, US$/tree	$2.16	$2.16	$2.16
Average volume (m^3/tree)	0.19	0.21	0.12

TABLE 6–Hand logging costs at the landing by stand type

Costs/Tree volumes	Blackjack	Blackjack/Yellow pine	Yellow pine
Total cost, US$	$61,834	$60,516	$45,302
Total cost, US$/m^3	$15	$15	$20
Total cost, US$/tree	$2.99	$3.09	$2.39
Average volume (m^3/tree)	0.19	0.21	0.12

TABLE 7–Cut-to-length logging costs at the landing by stand type

Costs/Tree volumes	Blackjack	Blackjack/Yellow pine	Yellow pine
Total cost, US$	$52,633	$52,095	$40,382
Total cost, US$/m^3	$13	$13	$18
Total cost, US$/tree	$2.54	$2.66	$2.13
Average volume (m^3/tree)	0.19	0.21	0.12

contrast, the CTL and the HD models, with much lower capitalisation structures and labour rates, were severely limited by the forwarding unit. The spreadsheet calculations suggest that the forwarder's capacity is between 9.6 and 14.4 trees/h. Both operations could realise cost reductions if the forwarding capacity was better matched to the capacity of the cutting rate.

Within the yellow pine area, the CTL system was a bit more economical than the WT, demonstrating a US$0.03/tree advantage. In addition, the difference in cost between the HD and the WT was only US$0.23/tree, a much smaller difference than that observed in the black jack and blackjack/yellow pine areas. Within the yellow pine area, the CTL and HD operations were not limited by forwarding speeds, but by cutter rates. Since forwarder capacity is function of tree size and tree density, the yellow pine units with fewer available large trees and more closely spaced small trees yielded better forwarding times. Without this limitation, the CTL unit per tree costs were less than the WT costs. This occurred because the CTL unit processed nearly the same number of trees per hour as the WT system (110 *v.* 132 trees/h), but with significantly lower equipment and labour charges.

POTENTIAL BIOFUEL MARKETS

The success of the local WUI fire-risk reduction programme is a function not only of treatment costs, but also of the partnership's ability to convert the thinned fibre into suitable products. For the 134-ha Fort Valley Research and Demonstration Project reported on herein, we examined the economic potential of firewood and ethanol, contrasting these users' ability to purchase fibre to the operators' costs to bring the fibre to market. Only fuelwood and ethanol were considered in this analysis because of limited opportunities in the district heating/cooling plant and industrial process steam plant sectors.

Firewood

There currently exists a viable firewood market that is based in Northern Arizona. Local distributors, such as Canyon Wood Products in Verde Valley, Arizona, purchase raw logs that are converted into small bundles of split wood wrapped in plastic for the retail markets in Los Angeles, California, and Phoenix, Arizona (Temple *et al.* 1999). This particular biofuel producer pays the equivalent of about US\$22/m^3, and can at times purchase two to four truckloads per day. Canyon Wood Products, not unlike other firewood manufacturers, frequently becomes over-supplied and stops purchasing wood from the local loggers on a regular basis (J.Perkins pers. comm.).

The HD and CTL operators traditionally sold logs into a combined market of firewood, pallet stock, and high-value poles. In contrast, the WT operator historically sold his logs to a newsprint manufacturer and a large-diameter sawmill. Because of this historical preference, an analysis of the firewood potential was completed for the only the HD and CTL situations where:

(1) All logs <35.6 cm dbh (outside-bark, small-end) went to firewood and pallet stock at US\$22/$m^3$with a haul distance of 96 km, and

(2) The larger material went to a pole producer located 224 km away paying US\$71/ m^3.

These analyses neglect the cost of operator downtime when all three markets became oversupplied from the 134-ha project.

Recall that both the HD and CTL models considered direct costs only and did not include expenses for overhead, profit, depreciation, insurance, and opportunity loss due to new equipment purchases. In this regard, these models may not be sustainable with higher production demands, as increases will require a larger infrastructure to support more employees, equipment purchases, and financial tracking.

The results of a revenue analysis of Unit 7 of the blackjack/yellow pine stands (Table 8) clearly indicate that the high-value pole market subsidised the low-value firewood market, producing a very favourable return under the assumption that the markets can absorb the entire harvested supply. Those units with fewer available large trees, such as Units 5 and 6, will not fare as well. The total return to the operator under ideal market conditions was projected at, respectively, 22.5% and 39.4%. If overhead, mobilisation, and road costs were included—approximated at 13.8% of the logging costs (Larson & Mirth 1999)—then Units 5 and 6 would provide margins of 7.6% and 22.5% to cover depreciation, insurance, opportunity losses, and profit.

The revenue results for the CTL operator (Table 9) over the yellow pine units were not favourable. This particular combination of stand characteristics, operating assumptions, and

TABLE 8–Projected hand felling operator revenue (US\$) for Units 5, 6, and 7 with a firewood and pole market

Parameter	Unit 5	Unit 6	Unit 7	Total
Prescription	3–6	1–2	2–4	
Mill revenue				
Firewood	\$15,311	\$16,169	\$23,578	\$55,058
Poles (vigas)	\$19,708	\$19,050	\$77,102	\$115,860
Total mill revenue	\$35,019	\$35,219	\$100,680	\$170,918
Stumpage costs	–\$677	–\$698	–\$1,501	–\$2,876
Merchantable material costs	–\$24,393	–\$23,196	–\$37,830	–\$85,419
Pre-commercial costs	–\$4,463	–\$2,179	–\$1,906	–\$8,548
Total return	\$5,486	\$9,146	\$59,443	\$74,075

TABLE 9—Projected cut-to-length operator revenue (US$) for Units 10, 11, and 12 firewood and pole market.

Parameter	Unit 10	Unit 11	Unit 12	Total
Prescription	1–2	3–6	2–4	
Mill revenue				
Firewood	$23,676	$4,372	$16,968	$45,016
Poles (vigas)	$0	$0	$13,189	$13,189
Total mill revenue	$23,676	$4,372	$30,157	$58,205
Stumpage costs	–$748	$0	$0	–$748
Merchantable material costs	–$20,424	–$8,659	–$28,703	–$57,786
Pre-commercial costs	–$2,583	–$4,001	–$12,792	–$19,376
Pre-commercial service rate	$0	$1,861	$1,865	$3,726
Total return	–$79	–$6,427	–$9,473	–$15,979

market conditions yielded a total loss of nearly US$16,000. Where this loss could be absorbed is unknown, as this direct cost model does not incorporate indirect cost centres such as profit, overhead, depreciation, etc.

Ethanol

The production of ethanol, a clean-burning fuel, from woody (lignocellulosic) material is considered at this time an emerging use for the small-diameter wood removed in forest restoration and fuels reduction programmes. Ethanol is currently produced mostly from corn (Biofuels News 1998; Kryzanowski 1998), but new technologies developed by the National Renewable Energy Laboratory (NREL) are improving the prospects for wood conversion (U.S. Department of Energy 1993).

The Department of Energy believes that ethanol use may reduce oil imports, may slow the depletion of United States oil resources, and may in fact help the environment (U.S. Department of Energy 1993). For example, ethanol is blended with gasoline in many cities in the western United States to increase the octane of the fuel while reducing carbon monoxide levels (Kane & Leblanc 1989). A second environmental benefit is that there is no net release of carbon dioxide produced by the combustion of the ethanol (U.S. Department of Energy 1993). In coming years, automakers plan to produce vehicles that will use ethanol as an alternative fuel (Reitman & Christian 1997).

The process for producing ethanol consists of breaking up the wood fibre and treating it to promote a maximum amount of fermentation of the xylan and cellulose components of the wood. During this process, the lignin in the wood is separated out and is available for use as a burning fuel or for processing into other products.

The new technology to produce ethanol from wood has been tested on a laboratory scale, but has not yet been assembled in a working plant. A current project involving the NREL and the Quincy Library Group in California is seeking to construct a plant that would require clearing of the 0 to 15.2 cm dbh trees from about 20 235 ha/year as a feedstock for the plant (Yancey 1996). Yancey (1997) estimated that a 110 million litres/year plant could be built for US$39 million plus the cost of the power plant.

To better understand the economics of a wood-to-ethanol manufacturing facility located in northern Arizona, Yancey completed two analyses of our local WUI situation (M.Yancey pers. comm.). Using his previously developed ProForma System model, he examined the costs and the internal rate of return (IRR) for a 26.5 million litres/year facility with a yearly raw material supply of 127 900 bone-dry Mg costing US$18 and US$36/Mg, respectively. His results, which were based upon many assumptions that could be fine-tuned if warranted, suggested that the respective IRRs were 7.5% and –0.8%, neither of which prove to be good investments. Further study of ethanol as a viable product use is probably not warranted based upon these results. A summary of the raw material inputs and Yancey's model are provided in Table 10.

TABLE 10–Raw material inputs and plant model for ethanol production, based on Unit 7 tree distribution, whole-tree logging, and a 144-km one-way haul distance

Plant parameter	\$20/Mg raw material costs	\$40/Mg raw material costs
Plant ethanol capacity	26,495,000 litres/year	26,495,000 litres/year
Plant life	20 years	20 years
Ethanol yield per Mg (dry)	206.9 litres/Mg	206.9 litres/Mg
Ethanol selling price	US$0.34/litre	US$0.34/litre
Total capital investment	US$26,847,000	US$27,088,000
Annualised loan payment	US$2,806,000	US$2,831,000
Net production costs/year	US$8,188,000	US$9,522,000
Feedstock costs/year	US$2,820,000	US$5,640,000
Cost of raw materials (percentage of selling price)	16.7%	31.2%

The feedstock supply estimate of 127 900 Mg/year was based upon projecting Unit 7 inventory yields over 4654 ha. In this projection, all harvested trees 12.7 to <27.9 cm dbh, and the tops and branches of the trees >27.9 cm dbh, went as feedstock. The fibre costs of US$36 and $18/Mg reflect two different scenarios: with and without additional subsidies. The US$36/Mg (equivalent to US$17/m^3) represents the Unit 7 projected logging costs for a WT logging system with a 144 km one-way haul distance to an envisioned ethanol facility co-located at an existing coal-fired power plant.

Although a 26.5 million litres/year wood-to-ethanol manufacturing facility could consume most of the small-diameter fibre harvested within the Coconino and Kaibab National Forests of northern Arizona, the realistic cost of this fibre is currently too expensive to warrant further study. The analyses conducted and reported here suggest that the cost to harvest and transport the raw woody materials must be reduced to less than US$9/m^3 (US$18/Mg) to make the manufacturing economics more attractive to potential investors. Depending upon the stand and the type of harvesting operations, the fibre costs will exceed this figure many times over. For example, the fibre from the 2–4 blackjack unit (Unit 2) and the 2–4 yellow unit (Unit 12) using a WT system is projected to cost US$25/m^3 and US$42/m^3, respectively.

IN CONCLUSION

The representative WUI project analysed here is not economical under a biofuel fibre market of either solid fuel wood or ethanol. This negative prognosis worsens when low-production yellow pine stands that are choked with large numbers of very small trees are thinned using old and ill-suited harvesting systems. Ethanol, which can consume large quantities of thinned small-diameter trees, demands a fibre cost that cannot currently be obtained by the local harvesting operators. Depending on stand and processing procedures, their actual fibre costs can be as much as 2 to 5 times more expensive than what may be acceptable to a potential ethanol investor. Surprisingly, the solid fuel wood market can pay 2.6 times more for fibre, and is a viable market for local harvesters if supplemented with another higher-value use such as architectural poles. It is a market, however, that frequently becomes over-supplied as it uses only a very limited quantity of small-diameter logs.

The local harvesting technology modelled here is not well matched for fuels reduction and forest restoration programmes. Even though the more modern WT system was found to be the most cost-efficient in two out of the three stand types, it is a system developed for large-tree work. The WT system becomes less efficient in the yellow pine stands where the work is concentrated in groupings of very small-diameter trees. In addition, the WT system generates large piles of slash that are located at the landing and require further processing. In terms of slash, the HD and CTL systems are better, leaving the limbs and tops scattered throughout the forest floor. The efficiency of both of these modelled systems, however, is severely limited by a slow and old forwarding system. Unfortunately, the HD and CTL models reflect the current state of the harvesting industry in northern Arizona. The remaining operators cannot account for indirect costs and make do with out-dated equipment that is not well-suited for the type of thinning tasks characteristic of proposed fuels reduction and forest restoration programmes.

In terms of material input characteristics, biofuels represent an attractive use for thinned fiber. It generally requires fiber at a cost, however, that is not readily attainable in the currently proposed northern Arizona WUI programmes.

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