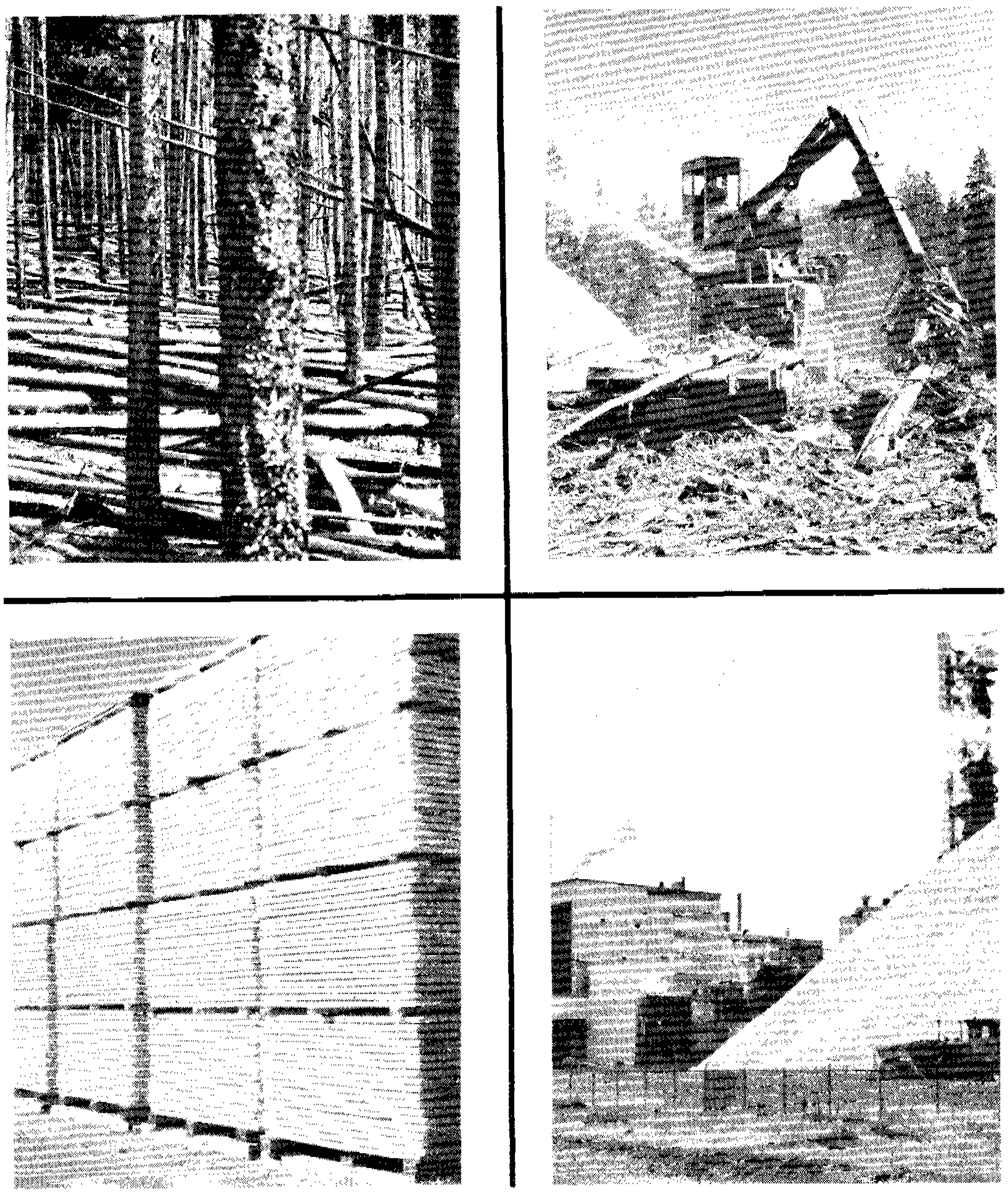
HARVESTING AND UTILIZATION OPPORTUNITIES FOR FOREST RESIDUES in the northern rocky mountains



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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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FOREWORD

Timber utilization practices have improved dramatically in recent years, but there is still a large volume of unused wood residues and salvageable material in the Rocky Mountain area. The need to achieve more complete and efficient utilization of this resource poses a major challenge. National projections predict substantial continued increases in demand for wood and wood fiber-based products. Environmental considerations also favor extending (or at least maintaining) the use of wood, a renewable natural resource that can be processed with less energy and less attendant pollution than alternate materials. Increasing interest in biomass fuels for supplementary power generation further emphasizes the undeveloped potential of the wood residue resource.

Excessive volumes of forest residues result in significant management problems, creating a fire hazard, inhibiting wildlife use, detracting from esthetic quality, interfering with regeneration, and requiring costly disposal treatments. Harvesting and utilization practices that facilitate more complete use of these residues can help meet national needs for wood products, and solve critical forest resource management problems.

Research reported in this Symposium investigates alternative timber harvesting and processing practices that can achieve more intensive timber utilization. Major subjects include detailed evaluation of the resource; investigation of product, processing, and market opportunities; and development of harvesting and handling methods. University researchers have been deeply involved as collaborators in all aspects of the research program.

Most of the research has been conducted in the lodgepole pine, larch, and Douglas-fir forests of Montana, Idaho, and Wyoming, and within the economic and industrial context common to that area. Investigations have covered an array of resource and operational situations, and have emphasized harvesting and utilization alternatives appropriate for old-growth, unmanaged stands. The results have broad implications for utilization of softwood species in general.

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Ernest Corrick

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ABSTRACT

The full utilization of residual material left in the woods following logging and thinning operations, and disease, insect attack, and windthrow has long been a source of concern and frustration to the forest manager. Recently there has been tremendous interest in increasing the use of residuals to combat projected energy and raw material shortages. The economics of harvesting increased levels of residuals must receive careful scrutiny. While many recovery ideas may be technologically and biologically possible, all utilization ideas will have to undergo thorough financial evaluation and will have to measure up against alternative uses of monies.

KEYWORDS: wood residues, residue utilization

Wood residuals by definition are what is left after valuable products have been removed by harvesting or manufacturing processes. It has been called slash, unmerchantable stem and branchwood, cull logs, foliage, and roots by the logger, and slabs, edgings, chips, sawdust, bark, and hogfuel by the mill manager. By its nature it has been viewed more as a problem to be dealt with than as an opportunity to be exploited.

The full utilization of residual material left in the woods following logging and thinning operations, and disease, insect attack, and windthrow has long been a source of concern and frustration to the forest manager. Recently there has been tremendous interest in increasing the use of residuals to combat projected energy and raw material shortages.

When asked to prepare this paper, I obtained a computerized listing of the literature available on wood residuals. The utilization of residuals has received much attention. A quick review of some of the subjects addressed in relation to residuals easily shows just how broad the subject really is. Some of the subjects are familiar, many are new: whole tree chipping (WTC), stump puller, pollution, fuel-energy, synthetic crude, biomass energy machine, gasohol, chemicals, ethanol, site deterioration, livestock feed, bread additives, mulch, and firewood. All of these subjects represent projects either underway or slated for future research.

Forest Industries magazine has recently instituted a monthly section on wood energy as it pertains to the use of sawmill and logging residuals. A sample of other articles concerning the use of or possible use of residuals is as follows:

- Missoulian - October 28, 1979, "Can a Wastewood put Dinner on the Plates?"
- Tobacco Valley News - Eureka, Montana, "Mills More Efficient."
- Across the Board - October, 1979, "Gasohol."
- Timber West - October, 1979, "Firewood Cut Increases 75%."
- The Logger and Lumberman - October, 1979, "Speak Out." (an editorial)

From the number and variety of these articles it is apparent that wood residuals represent a high-interest area to a broad cross section of our population.

My own perspective on residuals has been shaped by over 30 years of forest management and logging experience in the Northern Rocky Mountains, for the most part, in Montana. During these three decades the use of wood residuals has increased in both harvesting and manufacturing activities. In order to provide some background to our program, I would like to outline some of the changes that have taken place and some of the reasons they came about.

One of the most important changes, which led to greater utilization of timber, was the construction of stud mills in the 1950's and early 1960's. These mills permitted the logging of previously undesirable stands of lodgepole pine and other whitewood species. Incidentally, the advent of a dependable power saw around 1950 probably had more to do with increasing utilization than any other factor. By using a power saw, a faller could make the many extra cuts required to manufacture logs from smaller timber, and do it quickly and efficiently. Cross-cut saws were retired with few mourners, especially among those poor souls who had to use them.

Minimum merchantability requirements for trees and logs decreased over the years until today a minimum merchantable tree is 7-or 8-inches in diameter at breast height (d.b.h.), and a minimum merchantable log is 8 feet in length to a 6-inch top. These new merchantability requirements have significantly reduced the volume of residuals remaining after the logging operation.

Another large change in the use of "waste" wood in the Missoula area occurred when a pulp mill was constructed here and commenced operation in 1957. As a result, sawmill residuals, slabs and edgings that were formerly burned in tepee burners were suddenly being converted into profitable pulp chips. The decrease in the number of tepee burners, with the resultant decrease in air pollution, was noticed immediately.

Planer shavings were the next residual product to be utilized when, in the late 1960's and early 1970's, particleboard plants were constructed both in Missoula and Columbia Falls, Montana. These plants used planer shavings as the main material in their particleboard and so, once again, industry had increased the use of residuals from lumber and plywood operations.

The use of hogfuel, which is produced by grinding up bark, has steadily increased in all forest product facilities. Some of the hogfuel is used for the production of steam, and the steam is used in drying lumber and plywood, in driving machinery, and in heating buildings. A wood products firm in Libby, Montana, uses hogfuel to produce steam that, in turn, is used to generate electricity. That company uses a portion of the electricity for its own use and sells the surplus to the local power company.

Pulp mills have now developed processes that permit the use of a percentage of sawdust in the pulping process. This further reduces the volume of sawmill and plywood plant residuals. In fact, we're rapidly approaching the point in the use of manufacturing residuals that we have "even used the squeal of the hog."

There have been two short periods in the past ten years when local pulp mills used roundwood for chips. These logs were cull for lumber or plywood, but had enough sound material to use for chip purposes. Undoubtedly the time is fast approaching when roundwood will be a permanent source of pulp mill furnish.

A public utility in Washington recently conducted feasibility studies to determine if it is practical and economical to build a steam electrical generating plant which would use hogfuel as its energy source. The tentative location of the plant would be in the eastern part of the state of Washington.

I think it is important to point out that the increased use of residuals has been possible due to new or changed manufacturing facilities that could economically use these residuals. It is evident that any proposal to increase the use of residuals must be economically favorable to the user or manufacturer, or else it will not occur.

So, it is apparent that the use of residuals has increased dramatically in the last 30 years, and it is obvious from the size of this conference that there is a great deal of interest in how to further increase residual utilization. At the same time, there are still many questions to be answered before we commit ourselves to even greater use of residuals. To me, some of the more important questions would be: What are the biological limits of residual removal? If more of the biomass is removed during logging operations, what effect will this have on site quality and site potential? Should a portion of all residuals be left on the area to return to the soil? Will the removal of more logging residuals have a detrimental effect on future growing capacity?

We also need to develop technology to permit the economic removal of more of the residuals. In my opinion, most of the future increase in residual volumes will come from noncommercial thinning operations. Presently, we do not have the technology to use these thinnings, particularly on steep slopes.

Another important area to consider is the political implication of more residual use. It would appear that the general public would heartily approve of the use of more residuals. However, we must fully explain to all publics what the removal of more residuals will entail.

Finally, the economics of harvesting increased levels of residuals must receive careful scrutiny. While many recovery ideas may be technologically and biologically possible, all utilization ideas will have to undergo thorough financial evaluation and will have to measure up against alternative uses of monies.

THE FOREST RESIDUES UTILIZATION R&D PROGRAM

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ABSTRACT

Since 1974 the Intermountain Station has directed an integrated program of research toward developing methods to achieve more efficient timber utilization, consistent with responsible management of the forest ecosystem. This research combines the efforts of scientists in utilization, engineering, economics, marketing, and the biological sciences. Research in residue characterization has defined the volume, character, and product potential of residues in various timber types and harvesting situations. Research in products, processes, and markets has included work relating to solid wood and chip and fiber products. Particular emphasis has been given the processing and use of dead timber, by far the largest residue component in the Intermountain West. Other research has explored the feasibility of achieving closer utilization with conventional cable and ground skidding harvesting systems under different silvicultural and management prescriptions. Related research is developing new harvesting system concepts and practices, with emphasis upon systems that can function more efficiently in handling small timber, residue material, and small volumes per acre. More efficient utilization of the wood resource represented by forest residues can substantially extend the resource base.

KEYWORDS: forest residues, wood utilization, timber harvesting, forest practices

FOREST RESIDUES--PROBLEM AND OPPORTUNITY

A major challenge in the Intermountain area is the need to achieve more complete and efficient use of our available wood resource. Although utilization practices have improved dramatically in recent years, the aggregate volume of unused residues and potential salvage material is still very large. There are two immediate and related needs. The first need is to improve the recovery and utilization of the total wood resource, leaving less material as residue. National projections predict substantial increases in demand for wood and wood-fiber-based products, especially softwood housing construction materials. Environmental considerations also favor extending (or at least maintaining) the use of wood, a renewable resource that can be processed with less energy and less attendant pollution than alternative materials. Harvesting practices that facilitate more complete utilization of the available wood resource in the Northern Rocky Mountain States can contribute significantly to meeting this demand.

The second and concurrent need is to reduce the adverse esthetic and environmental impacts of timber harvesting, associated road construction, and other onsite activities. Present utilization standards and logging practices leave large amounts of residue--small trees, cull and broken logs, tops, and dead timber--on the ground following harvesting operations. Road right-of-way clearing and thinning operations result in additional volumes of unused wood. These residues can contribute to the forest's nutrient reservoir, reduce erosion, protect seedlings, and provide wildlife cover. In the quantities that frequently occur, however, they create a fire hazard, inhibit regeneration, detract from area esthetic values, and represent waste of a scarce fiber resource. Harvesting and transportation practices that improve the economic feasibility of using more of this material can remedy a major source of undesirable impacts on the area.

Since 1974 the Intermountain Experiment Station has directed a coordinated program of research, the Forest Residues Utilization R&D Program, toward investigating alternative timber harvesting practices that may facilitate more intensive, environmentally compatible, timber utilization. Major objectives of this program have been:

(1) To develop resource information--present and predicted--defining the location, quantity, and physical characteristics of material considered residue, as a means of strengthening utilization opportunities;

(2) To evaluate harvesting and transportation systems that can improve the technical and economic feasibility of recovering and using more of the total wood resource;

(3) To evaluate product, process, and market alternatives that will facilitate more complete and efficient use of material commonly left as residue;

(4) To evaluate the biological and environmental effects of residue reduction, and the influence of residue reduction on postharvest forest management needs and activities.

The principal subjects of this report and of the "Harvesting and Utilization Opportunities for Forest Residues in the Northern Rocky Mountains" symposium are the first three areas of investigation--research and related industrial experience in resource evaluation, harvesting, and utilization. The fourth area, environmental and management consequences, was the subject of a separate symposium in September 1979 (USDA Forest Service 1980).

THE RESEARCH PROGRAM

To meet specified objectives, program research has necessarily involved a wide variety of subject matter and associated disciplines. The core program staff has included researchers with skills in engineering, wood technology, economics, meteorology, microbiology, entomology, and biometrics. Other Station research work units in such subject areas as silviculture, fire management, economics, hydrology, and wildlife habitat have participated extensively in studies of biological and management impacts. Other major participants in the research have included researchers at other Forest Service units, researchers at several universities, and industrial timber harvesting and processing firms in the region. The Bureau of Business and Economic Research, University of Montana, and the forest products industry are especially worthy of note because of their extensive involvement.

Early program planning was developed around three basic concepts: recognition that wood utilization objectives and practices must extend from, and be compatible with, broad forest management objectives; belief that the best approach to residue utilization is through more efficient initial harvesting practices, rather than salvage operations; and recognition that residue reduction has significant and direct effects upon the forest ecosystem and subsequent management activities. The typical procedure followed in planning and implementing program research is illustrated in figure 1. First consideration was given to defining the total forest resource management objectives for a particular timber stand and site situation. Harvesting specifications were then developed for tree removal and other stand or site character modifications (usually an array of possible alternatives) to meet management objectives. Harvesting systems, utilization levels, and postharvest treatments that could achieve the selected treatment effects were applied. Finally, technical and economic feasibility were evaluated, and the environmental and management consequences of tested alternatives were determined. A central concern, of course, was to apply and test harvesting alternatives that have the capability of recovering much of the wood material commonly left onsite as residue.

Assessing the Resource

The term "forest residues" is commonly applied to all woody material that for one reason or another remains in the forest. Major components of this residue resource in the Northern Rocky Mountain area are: (1) logging slash and cull material from harvested trees; (2) standing and down dead timber; and (3) submerchantable trees cut in the process of thinning, postharvest site treatment, or right-of-way clearing. For most primary raw materials, the term "residues" implies an unusable waste byproduct. By contrast, wood residues have the same basic physical and chemical characteristics as the primary resource and are differentiated only by size, shape, or condition. They can be used (within the limits imposed by size, shape, or condition) by the same sawmill, pulpmill, or particleboard plant that uses the so-called "merchantable" part of the resource. Residue is simply that part of the total wood resource that cannot be used at a given time, because of constraints imposed by technology or economics--largely economics.

A first step in evaluating the utilization potential of the residue resource is to develop some estimate of quantity and physical characteristics. Although an accurate assessment would be extremely difficult, expensive, and probably not warranted, reasonable estimates are needed and have been obtained through various inventories and studies. A brief review of some of these inventory figures will serve to illustrate the scope of the residue resource.

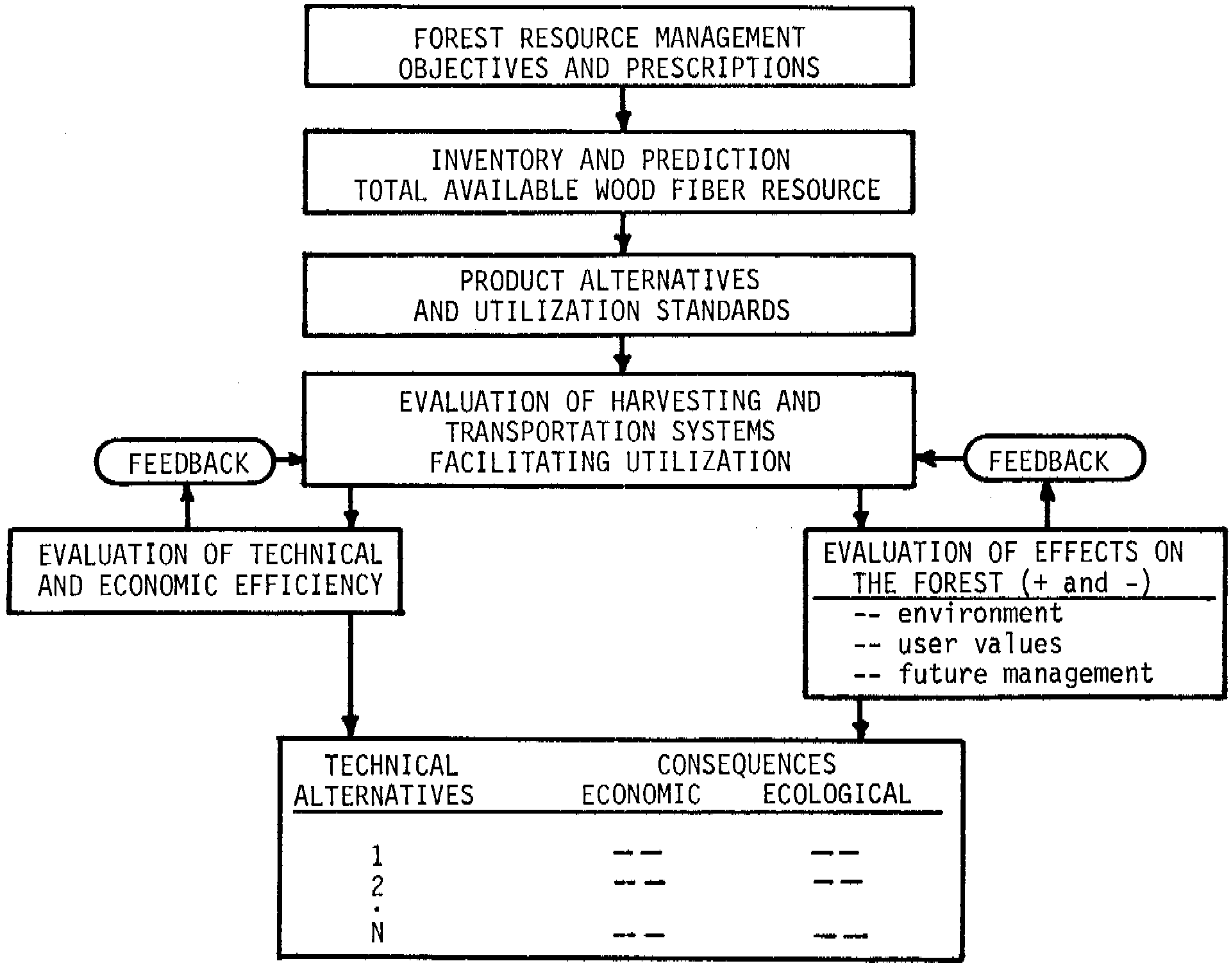

Figure 1.--Research program schematic depicting sequence of key phases. The program emphasized developing and testing harvesting and utilization alternatives that are compatible with, and facilitate, total forest resource management on the site.

The largest and most conspicuous residue component in Northern Rocky Mountain forests is dead timber (fig. 2). Dead timber, resulting largely from a long and continuing history of insect and disease damage, can remain sound for many years on the relatively cold, dry sites common in this area. Forest Survey information indicates that approximately 6.7 billion ft^3 (190 million m^3) of salvable, dead sawtimber exists within the nine Rocky Mountain States (table 1). Montana alone contains an estimated 3 billion ft^3 (85 million m^3), roughly equivalent to 12 years' allowable cut at present harvesting levels. In addition, the annual sawtimber mortality for the same States is estimated to be 2.5 billion bd. ft. (71 million m^3), of which about two-thirds occurs in Montana and Idaho.

Figure 2.--Old-growth lodgepole pine stands contain a large proportion of dead material, both standing and down.

Table 1.--Net volume of salvable dead timber on commercial forest land in the Rocky Mountain States (source: Green and Setzer 1974).

State	Salvable dead timber		Percent of total
	Million ft³	(Million m³)	
Idaho	940.0	(26.6)	14
Montana	3,000.7	(85.0)	45
Wyoming	577.1	(16.3)	9
South Dakota	47.0	(1.3)	<1
Arizona	133.4	(3.8)	2
Colorado	1,340.7	(38.0)	20
Nevada	10.4	(0.3)	<1
New Mexico	346.5	(9.8)	5
Utah	303.9	(8.6)	5
Total	6,699.7	(189.7)	100

Residues remaining after a conventional saw log harvesting operation include dead timber rejected as unmerchantable, slash and cull material, and small stems either accidentally or purposely downed (fig. 3). Recent research studies, discussed in some detail by researchers participating in this symposium, indicate volumes of residue ranging from 2,000 to over 4,000 ft^3 per acre (140-280 m^3/ha) (Benson and Johnston 1976; Foulger and Harris 1973). Residues remaining following conventional clearcut logging in old-growth lodgepole pine, for example, averaged 4,333 ft^3 per acre (303 m^3/ha) (Foulger and Harris 1973). Material 3 inches (7.6 cm) and larger in diameter accounted for 82 percent of the residue (table 2).

Figure 3.--Residues remaining following conventional saw log harvesting operations in old-growth stands frequently exceed 100 tons per acre (224 tons/ha).

Table 2.--Wood and bark residues remaining following clearcut logging to conventional saw log utilization standards in mature lodgepole pine--Teton National Forest (source: Foulger and Harris 1973).

Diameter size class		Residue volume					
		Wood		Bark		Total	
in.	(cm)	- - - - - Ft^3 per acre (m^3 per hectare) - - - - - -					
<0.3	(<0.8)	2.4	(0.2)	5.7	(0.4)	8.1	(0.6)
0.3-0.6	(0.8-1.5)	69.3	(4.8)	41.2	(2.9)	110.5	(7.7)
0.6-3.0	(1.5-7.6)	562.7	(39.4)	84.8	(5.9)	647.5	(45.3)
>3.0	(>7.6)	3,274.5	(229.1)	292.5	(20.5)	3,567.0	(249.6)
Total		3,908.9	(273.5)	424.2	(29.7)	4,333.1	(303.2)

Gross inventory figures do not imply that the entire residue resource is economically or physically available. Harvesting costs, access problems, and the randomly scattered nature of much of the resource are likely to limit economic availability indefinitely. Nevertheless, the figures indicate that with even slightly improved harvesting and utilization practices, the currently unused wood could provide a substantial basis for industry expansion and added product manufacture with no added drain on the timber supply.

Harvesting Research

Much of the research investigating the feasibility of intensive levels of wood fiber recovery was conducted on three primary sites. These include:

(1) The Coram site--typical of old-growth western larch/Douglas-fir stands on steep slopes.

(2) The Lubrecht site--dry site Douglas-fir, with intermixtures of ponderosa pine and larch, on gentle terrain; broadly representative of a major segment of the more productive commercial forest land in the region.

(3) The Teton site--typical of higher elevation old-growth lodgepole pine in the Central and Northern Rocky Mountains.

These study sites are described in detail, including harvesting systems and utilization standards tested, in this publication under "Intensive Utilization with Conventional Harvesting Systems" (Barger 1980). On these major sites, harvesting systems research was closely integrated with pre- and postharvest studies evaluating the biological and environmental consequences of intensive utilization. On a number of other sites, researchers cooperated with industrial logging firms to study the physical and economic feasibility of specific harvesting systems and practices (fig. 4).

Figure 4.--An experimental salvage operation recovers pole-size timber, establishing a measure of the costs and productivity of the practice.

Program research in harvesting systems has taken two directions--evaluation of the efficiency of existing systems and practices when used to achieve close utilization standards, and development of new harvesting practices and equipment better suited to handling smaller, low-value material. Field studies have included the use of in-woods chipping systems; use of conventional tracked and wheeled skidding equipment in relatively gentle terrain; and use of cable systems in steeper terrain. Low capital investment systems evaluated in small timber have included horse skidding as well as use of farm tractors (Host and Schlieter 1978). In each study, utilization prescriptions have generally extended from standard saw log utilization down to total utilization of available fiber.

The development of new systems has concentrated on systems for steep slopes, primarily smaller, more versatile cable systems. Of particular interest are systems that can reduce the density of roads; reduce sensitivity to road location; and gather or bunch smaller material to make larger yarding payloads. A number of these concepts are discussed at length in this publication under "Outlook for New Harvesting Technology" (Gonsior 1980).

Related research has been directed toward developing improved methods of evaluating proposed harvesting operations, laying out sale areas and units for cable logging, and evaluating economic operability. Determination of economic feasibility becomes more critical for high investment systems such as cable systems and whole tree processing systems, where substantial hourly amortization costs must be covered. The increased use of cable systems also requires greater care and precision in laying out sale areas, particularly in areas that are borderline in terms of topography and operability.

Products and Process Research

Program research in products and processes has been oriented toward defining product and process opportunities that can achieve economically viable utilization of forest residue material. The utilization of dead timber and small stems has received the greatest attention, because these components make up a large share of the residue resource. Forest residues include material that can be used for virtually every product manufactured from the merchantable timber resource. Given favorable economic conditions, material normally considered residue has been used for lumber, commercial poles, house logs, and a full array of products with less demanding specifications. Near-future opportunities for utilizing significant volumes of residue seem to be brightest in four basic areas: (1) extended utilization for conventional roundwood and sawn products; (2) use for pulpwood; (3) use for particleboard and fiberboard manufacture; and (4) use as an industrial fuel.

Practices that achieve extended utilization of residue for conventional sawn and roundwood products include revising sawtimber merchantability standards to accept smaller tree and log diameters, manufacturing lumber or treated products from older dead timber, and relaxing quality standards used to identify cull material. Smaller chipping headrigs and more efficient small-log processing plants have succeeded in reducing the size of the minimum merchantable log in many situations. Finger-jointing and end-and-edge gluing have become relatively common practices, facilitating use of small pieces and nonstandard widths. Still in a development and trial stage are mills specifically designed to utilize cull logs. Roundwood product manufacturers are less reluctant than they have been in the past to make use of dead timber. Some have discovered distinct advantages in dead material for their particular application.

Extended utilization is especially sensitive to market conditions. During depressed market periods, products and processes nearest the manufacturing margin are the first to be discontinued. Given the long-term upward trend in demand for all wood products, however, it seems inevitable that more intensive utilization for conventional products will increase. Much of the material currently considered residue will become an economically available resource for these products.

Forest residues also include a large volume of material suitable primarily for chip, particle, or fiber-based products. Major foreseeable uses for such material are likely to be for pulp, particleboard or fiberboard, or fuel.

In the Northern Rocky Mountain area, there appears to be a relatively close balance between chippable mill wastes and pulpwood demand, with little room for expansion. As demand for pulp chips increases, and competing uses appear, the price of mill-waste chips can be expected to increase. In addition, as greater conversion efficiencies are achieved in plywood and lumber manufacture, available chip supplies may actually decline. When the cost of mill-waste chips approaches the cost of handling and chipping forest residues, the forest residues will become an economically viable source of pulpwood (fig. 5).

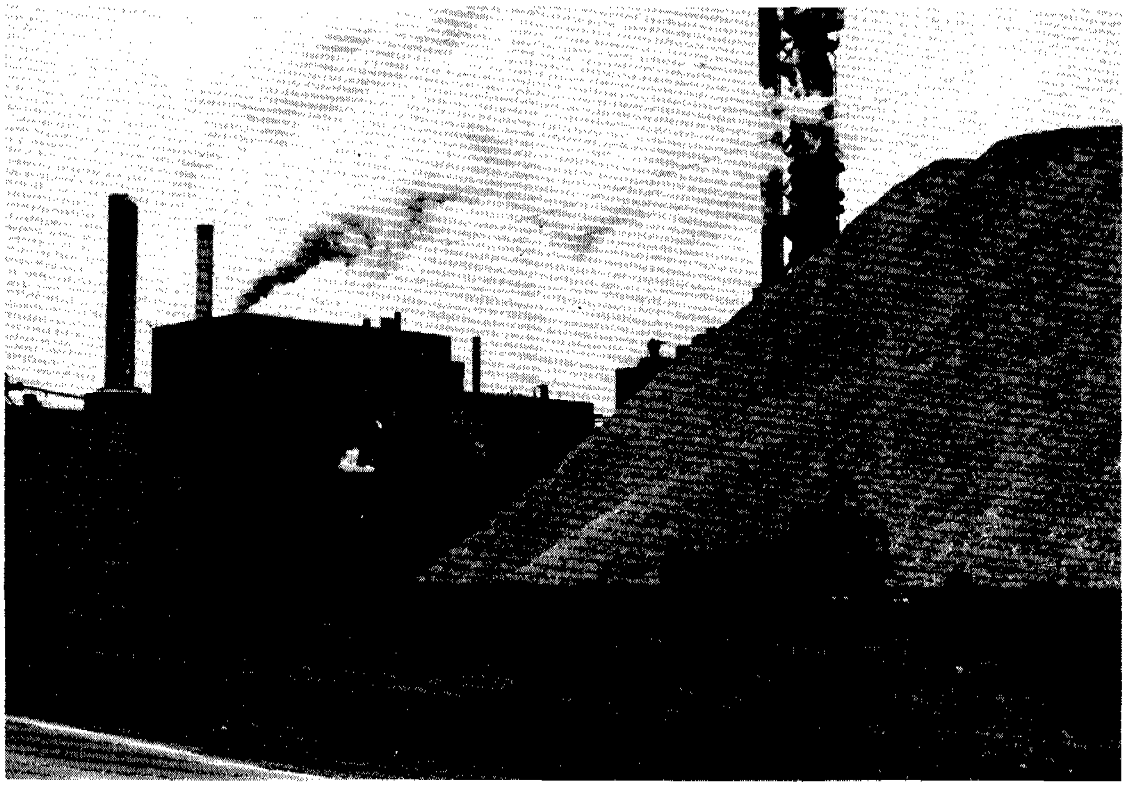

Figure 5.--Forest residues include large volumes of material suitable primarily for chip or fiber products, such as paper.

The development of a new class of particleboard products, referred to as structural particleboards, may offer more immediate promise for utilizing forest residues. Structural particleboards are designed to provide the strength and weather resistance necessary for exterior and structural applications such as wall and roof sheathing. To obtain the added strength, the boards are manufactured from relatively long, thin flakes of uniform size and shape. The flakes or particles may be alined in one direction, cross-banded, or combined with veneer face plies. With the exception of large residues such as veneer cores, mill residues are not suitable for the production of acceptable particles. Roundwood or forest residues will be required.

Structural particleboards are in the developmental stage, but their success and rate of market growth are difficult to predict. Historically, the construction industry has been slow to adopt new concepts and projects. If it can compete with plywood, structural particleboard could utilize significant volumes of forest residues within a few years. Assuming that pricing will be comparable to that for exterior plywood, the particleboard industry should find forest residues within economic reach.

Recent concerns about soaring energy costs and shortages of fossil fuels have directed renewed interest toward wood as an industrial fuel. Many industrial firms are facing potential restrictions on the availability of fuels and electrical energy, and at best are operating with interruptible energy sources. One obvious solution is to reconsider the role of wood residues as fuel.

Wood wastes have long been used as fuel by the wood products industry, however, and recent trends within the industry are toward expanding capability to use wood fuel. Residues burned in manufacturing plants can produce both process steam and electricity, with much of the energy used in the form of steam and heated air. Recent developments in wood combustion technology have dramatically improved the efficiency of wood-fired furnaces. Increasing alternative energy costs, physical unavailability of other fuels, and the need to develop self-sufficiency will all contribute toward making forest residues an economically available industrial fuel.

Program studies have included the investigation of product potential represented by residues; processing characteristics affecting drying, treating, chipping, gluing, and other manufacturing treatments; the physical characteristics of products produced from residues; and the economic availability and probable cost of residues delivered to processing facilities. Specific research results are discussed in detail in subsequent sections of this publication. Representatives from wood products firms also discuss the practical considerations that influence the utilization of low-quality wood.

REPORTING THE RESULTS

The purpose of this publication is threefold:

--To report the results of research conducted by the Residues R&D Program in harvesting and utilization opportunities for forest residues;

--To provide a record of proceedings of the 3-day symposium exploring both research and industrial experience in residues utilization;

--To provide a compendium of information useful to those involved or interested in improving the recovery and utilization of forest residues.

Improved resource utilization depends upon better resource information, improved harvesting alternatives, identified product and market opportunities, and knowledge of the economic and management consequences. The information presented in the remainder of this publication covers all of these subjects to some degree. The material is organized in four sections entitled "The Resource," "Harvesting Opportunities," "Utilization Opportunities," and "Economic and Management Considerations." The results and information presented in any particular paper, however, may include aspects ranging all the way from resource considerations to economic implications.

More efficient utilization of our wood resource can substantially extend the available wood fiber resource, providing a base for industrial expansion and economic growth. It is the most effective way to add to timber supply in the short run. Improved utilization practices can also contribute to resolving some of the more difficult environmental and management problems associated with timber harvesting. It is toward these goals that the research program and the symposium have been directed.

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UNIVERSITY RESEARCH IN RENEWABLE RESOURCES: A COMING OF AGE?

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ABSTRACT

The universities, especially those with forestry schools, have been active in residue research for the last two decades. This interest has intensified in recent years as we have firmly recognized the vital importance of reducing waste and stretching our raw material resources. This interest ranges from the ecomomics of residue recovery to the viability of biomass for chemical feedstock. To tap the university's interest and talent, support from the federal government and especially industry will be needed more than ever before to keep our universities the "creators of the future."

KEYWORDS: residue utilization, research, funding

Some time ago, I was asked to address the role university research plays in the resolution of problems in harvesting and utilizing forest residues. Upon reflection, I took it upon myself to broaden that topic to present to this symposium a more general picture of university research in renewable resources. Specifically, I thought it would be informative to say a few words on (a) how universities look at research, (b) how that research is done, (c) where the funds come from, (d) what are some of the issues facing the academic community in research, and (e) where we might be headed as the enrollments begin to stabilize and perhaps even decline over the 1980's. Each of these factors, of course, will have an impact on research in general, including that done on various aspects of residue recovery and utilization.

How do the universities look at research?

A traditional image held by the public over the last two centuries is best described by the English mathematician and philosopher Alfred North Whitehead. "The task of a university is the creation of the future," he wrote in one of his many essays encompassing a wide range of fields. This statement, albeit brief, sets a high but realistic goal for our institutions of higher education. To me, it refers to the three basic service functions of the universities--teaching, research, and extension.

The research function, in its broad sense, includes not only the type of studies where data are collected and analyzed, but also all other types of creative activities, such as those in the fields of sculpture or music. The research interest of the universities--particularly the older and more established institutions--is strong and very basic. Research is indeed considered a primary function in such institutions, especially in the land-grant universities. You recall the Morrill Act of 1862, the Hatch Act of 1887, the second Morrill Act of 1890, and the Smith-Lever Act of 1914, framing the land-grant concept establishing research as a prime function of the universities. Both basic and applied research have traditionally been carried out by university professors who undoubtedly wrote the definition of research in the Webster's Third New International Dictionary:

> . . . critical and exhaustive investigation or experimentation having for its aim the discovery of new facts and their correct interrelationships, the revision of accepted conclusions, theories or laws in the light of newly discovered facts, or the practical application of such new or revised conclusions, theories, or laws. . . .

In fact, this definition is utilized in policy statements of many universities as applied to the research function of those institutions. Note that both basic and applied research are encompassed within the definition. Many universities now aspire to ". . . imbue the human mind with knowledge, tolerance, and vision and stimulate a lasting attitude of inquiry." Furthermore, the mission of the universities is to serve the people as a center of learning for the advancement, preservation, dissemination, and use of knowledge. The advancement of knowledge obviously requires involvement in research.

FORESTRY RELATED RESEARCH

Forestry research has a long history in our universities. Early research on using native and exotic trees for windbreaks and various aspects of wood utilization, among others, goes back to the early decades of this century. The research was of necessity low key; it occupied that portion of the professor's time which was not needed for teaching. With the exception of some surge occurring after World War II, slow but gradual increase in research took place over the half-century from about 1910 to around 1960. Then in 1962, a significant event occurred: the enactment of the McIntire-Stennis Act which authorized federal funds for research at universities. This act, coupled with several other developments, brought about a quickening pace in forestry and utilization research. These developments included a phenomenal growth in student enrollments, including graduate programs, over the decade following the Act; the prospect of increased reliance on forest resources in meeting our material and recreational demands; an increased environmental awareness and the attendant need for better information; and finally general increases in federal research and development dollars.

The McIntire-Stennis Act was a major landmark legislation. This was the first time that the Congress of the United States recognized the role that the forestry schools can play in research and encouraged that role by authorizing federal dollars on a regular basis. The Act, appropriately, recognizes both research and training aspects of the program. Today, some 62 institutions, both land grant and non-land grant, participate in some 500 totally or partially funded projects. Many of these projects deal with various aspects of forest residue recovery and use. Nationally, some 600 scientists and about as many students participate in the program. The total budget for the program is about $9.5 million, with institutions receiving funds ranging from small sums to several hundred thousand dollars. The funds are allocated on a formula basis to each state, taking into consideration the timber harvest, the forest land base and non-federal dollars available for research. A significant advantage derives from the regularity of these dollars, which permits some degree of planning in addressing research problems.

Many of you are well aware of the phenomenal enrollment growth occurring in the forestry schools over the last 15 years. Departments handling a few dozen students suddenly found themselves faced with burgeoning enrollments; in some cases, student numbers quadrupled. Supply of these graduates, however, clearly exceeded demand. Many graduates, failing to find the desired job, found entering graduate school a viable option. The result: enrollment growth in graduate programs, providing a good source of research workers.

This audience needs no elaboration on the increasing importance this country and indeed the world is placing on forest resources. These resources are being "rediscovered" and sometimes referred to as the "renewable quads" in an energy hungry society. Greater demands on these resources, however, must be coupled with greater sophistication in the way we deal with them. Judicious use of existing information as well as new knowledge being developed through research will be necessary to enable us to produce and recover more per acre. This symposium is an example of people presenting information so that we may be able to recover economically the large quantities of available residue.

In a recent meeting in Lewiston, Idaho, I noted the statement made that the residue from the Clearwater National Forest alone can supply the fuel for two 25-megawatt power plants for many years to come. How about competing demands for more pulp and board production and other forest products? How about the impact of such residue recovery on site impaction, on nutrient cycling? Answers to these questions are not easily obtainable in every location and require careful research and analysis.

We have come to a stage in our societal development when the public demands reasonable environmental care in extracting more material and services from our forest acreage. This sort of demand will continue over the decades ahead. It will continue to guide our research along a course which will yield greater rewards: not just how to get more on less land, but how to do it harmoniously with nature, protecting the land base for optimum production in the years ahead.

HOW IS RESEARCH DONE AT UNIVERSITIES?

Doing research is not unlike cooking a good meal. Thoughts must go into it as to what is to be served and how it is to be prepared. Then logistics and ingredients must be combined and the results served in a palatable manner so that it looks good and tastes and digests well. Should any of the major elements in logistics or ingredients be missing, then the quality suffers and the results are not as appealing.

The universities do have trained manpower willing and eager to participate in research. Support dollars, however, are not always available. Participation in research is indeed expected of the university faculty, as the basic philosophy of "publish or perish" prevails on most campuses to varying degrees. A variety of scenarios occur in doing research at our universities.

The Brave Professor Scenario

Here is a situation when the professor is fully committed to teaching but still manages to "steal" some time from his office or family to engage in a "pet" project. The Brave Professor scenario is characterized by virtually no formalized budgeting and indeed no budgets. The department head might even jump on him if he makes "too many" long distance calls or uses the copying machine "excessively." This research often involves a different interpretation of published material, or taking "another look" at something already known. For the productive person who aspires to research, this scenario will soon become frustrating. Aggravation is compounded when he finds that promotions, merit raises, and the like are still significantly influenced by publications, books, etc. He continually argues for more time and money to do research, with little result. He is good at talking because that is what he does all day long in his many classes. At times he feels like a tape recorder, since he has been assigned several sections of the same course and repeats the same lecture time and time again.

The Low Budget Scenario

The low budget professor has been allotted some of his time (perhaps 20-40 percent) to research and has managed to secure a small budget (several thousand dollars) from the limited university funds to work on a project. He is not sure how many years the budget will be maintained; thus, if he is wise, he periodically informs his administrators of the payoff from the project. From the small budget, he is able to hire a student or two at minimum hourly wages (or through the federal Work-Study program) to collect data, do library search, man a monitoring device and the like. He might even manage to pay for a little computer time. He and his administrators know the budget is less than what he really needs, but the work goes on at a level of productivity below what the professor is capable of delivering.

The Pay-it-Yourself Scenario

In this scenario, the professor is serving as the major advisor to one or two graduate students. The student was accepted on the proviso that he provide his own financial support. This is fine until it comes to meeting the research requirements for the degree. Then, the challenge sets in when he must select a research topic that is (a) acceptable to the major advisor and the advisory committee, (b) timely, (c) feasible, and (d) doesn't cost money! The challenge confronts both the student and the professor. There are those in the academic community who argue that it is indeed unwise to admit a student to graduate studies when funds are not available to facilitate a reasonably good research environment. The argument continues that it is simply too expensive to do research and very few students have the financial resources to meet their research requirement. Under these circumstances, the professor and the student still manage to come up with a low-budget project for the student which often does not result in any publications.

The T.A. Scenario

Many departments, especially those with heavy teaching commitments, are often provided with one or more teaching assistants (TA's). The TA is given a stipend which covers his basic food/shelter expenses. If the major professor can manage the support costs through a small grant, this team is able to work on a project with reasonable success. This is especially true if the support funds can provide wages for one or more undergraduates who can be assigned to various routine tasks, i.e., data collection, lab maintenance, and the like. The TA is still limited as to the amount of time he can devote to the research as he has some basic and at times heavy responsibility in teaching.

The More-Like-It Scenario

In this scenario, the professor supervises one or more funded graduate research assistants and has control over adequate support dollars. Good field data followed by careful analysis can be produced under this arrangement. Travel and publication dollars permit participation in professional meetings and symposia, and journal articles permit dissemination of the results. Copies of more detailed reports can also be made and submitted to those agencies likely to benefit from the findings. Traditionally, this scenario has proven to be successful in carrying out research at universities.

The Master Grantsman Scenario

This scenario often involves a well-known professor who either happens to be in a highly fundable area and/or is a master grantsman. He is able to secure resources, sometimes well in excess of $100,000 per year, with which he hires one or two research associates, a technician, and has basic responsibility for some four to ten graduate research assistants. He is officially involved in some two to six major projects and has had to delegate responsibility to his associates. He, himself, has turned into what is sometimes referred to as the "bio-politician" with a strong scientific background. Several publications per year bear his name. He travels extensively, consulting, lecturing, and continuously looking for new sources of funds. The scenario can become very productive, generating high quality research information with good potential tie-in with the users of that information.

The Multi-Disciplinary Scenario

In this case, the overall project involves a broader array of scientists encompassing a variety of fields. The project is divided into manageable subprojects which are, in turn, handled by a professor and his support staff (research associates, technicians, students). An overall coordinator or director "brings it all together" and prepares the overall report. This scenario requires special skills and experiences in working with a variety of people and disciplines, but has the reward of making sizable contributions to the problem area. The universities are now attempting to strengthen their interdisciplinary efforts in research, as there is a general belief that such teams not only can be put together readily in a university, but they can strengthen the university's research posture by involving a significant section of faculty and students.

The Cooperative Scenario

In my experience, one of the most exciting scenarios involves cooperation among several agencies and organizations in teaming up with university researchers in a continuing researcher-user partnership. In this scenario, the overall effort is subdivided in a similar fashion as that pointed out for the multi-disciplinary scenario, with some of the team members employed by outside research agencies such as the Forest Service and the industry. This partnership gives a real-world touch to the program and has the reward of seeing the information used soon after it becomes available. The industry, the government, and the universities can be natural partners in the field of forestry and wood utilization, providing both the financial and manpower needs for projects. The cooperative scenario is now taking shape in the fields of tree improvement and forest fertilization in several parts of the United States. In these situations, the universities often produce a portion of the research information and also serve as an integrative means of receiving information from all cooperators and analyzing it so that it will be useful to the users.

FUNDING RESEARCH

Doing research costs money--and plenty of it! But if it is done right, the returns are substantial. Where do the universities get the funds to carry out their research function?

Briefly, state and federal governments provide a major portion of the needed dollars in their regular budgetary process. The state portion largely provided the dollars allocated to the faculty salaries. If Professor Brown's job description indicates, for example, 50 percent research, and if Professor Brown is entirely paid from state dollars, then those dollars are, in reality, being provided by the state for research purposes. Many do not realize that the state governments are in this manner underwriting a substantial amount of dollars for research at our universities. Also, many institutions are budgeted by the state for additional funds for temporary salaries and operating expenses. For example, to meet matching requirements for the Hatch and McIntire-Stennis Act funds, the states often need to allocate dollars for research in addition to the salary dollars. This brings me to the federal funds which are budgeted on a regular basis for research at our universities.

The Hatch Act and the McIntire-Stennis Act provide a regular source of funds for forestry-related research as indicated earlier. As you know, the Hatch Act funds have provided the financial backbone for agricultural research at our land grant universities. Other budgeted federal funds in mining and in energy are now gradually becoming available.

Gifts and scholarships are an additional source of funds. Most gifts and scholarships have certain restrictions as to how and in which areas they are to be spent but some provide student stipends and operating dollars for research.

In recent years contracts and grants have provided a major share of funding for university research. In some forestry schools, these sources of funds could be as high as 50 percent or more of the total research dollars available to the school. These funds are generally soft, with possible substantial variations in amounts received from year to year. Many such grants and contracts are competitive, requiring special skills, time to develop proposals, and finesse in grantsmanship by the faculty and administrators. Since the universities are becoming increasingly dependent on such funds, they are an element keeping many in our universities "on their toes." Where do such funds go? To staff, salaries, materials, travel, graduate assistantships, computer time, publications, and the like. Where do such funds come from? By far, the federal agencies are the source of most such funds. My experience in research administration indicates that over 90 percent of such funds are federal funds either directly originating from the particular agency headquarters in Washington or more often filtering through other federal or state organizations. In the renewable resources areas, industry provides a very small percentage (perhaps 2-5 percent) of research dollars to the universities in the western United States.

To respond to the increasing demand for research, many of our forestry schools have hired staff on such soft funds, and some have moved ahead in placing a portion of the salary of their regular staff also on such dollars. It is now common to see faculty in our forestry schools on 9-month appointments, with the responsibility of securing salaries for the 3-month summer period falling on the individual professor. Indeed, some faculty members may also have to secure a portion of their regular 9-month salary by writing research proposals and attempting to secure grant funds for the proposal. This process, although lessening job security, has contributed significantly to an expanded research program by the universities.

CURRENT ISSUES FACING UNIVERSITIES

It is now being predicted that the universities will encounter enrollment drops in the 1980's. The Census Bureau estimates that the number of 18-year olds in the United States will drop by more than 18 percent between now and 1990. This is expected to result in smaller faculties as fewer students will enter universities. Will it also imply a smaller research role for the universities? Will it affect the quality and the vigor of research as the younger Ph.Ds are less able to secure university faculty positions? Will it discourage our talented undergraduate students from entering graduate schools as the job market outside the universities improves and the prospect of securing faculty positions decline?

No one has a firm answer to these questions. A recent Harvard study generally paints an optimistic picture as regards research in our universities. The study, authored by Professor Robert E. Klitgaard, an associate professor in the John F. Kennedy School of Government, concludes that the decline in output of university research jobs will be much smaller than decline in university teaching jobs. He claims that the aging faculty will not be less productive than the young Ph.Ds. A study by Professor Stephen Cole at State University of New York at Stony Brook found that "scientists are slightly more productive during their forties" and that "in most of the fields studied, the scientists over the age of 60 were not much less productive than those under 35." Thus, Mr. Cole writes, "It is unlikely that an increase in the mean age of our scientists will, and of itself, bring about a meaningful decline in our scientific capacity." Some of us in higher education even advance the possibility that the quality of overall research may increase as the less serious researchers drop out of the picture, shifting dollars to stronger and more committed scientists. This is a possibility that Klitgaard also advances. How about promising undergraduate students bypassing graduate schools? This is indeed a realistic possibility.

To keep research in our universities vigorous, increasing funds from all sources, particularly the federal government and the industry, will be needed. It is time that the forest products industries recognized the substantial talent which exists in our universities and find the means of tapping that research talent. Indeed, industry/university partnership is a significant challenge which has the potential of combining the substantial financial resources of the industry with the highly trained manpower at our universities in addressing such issues as forest residue use, intensive forest management, integrated pest management, energy, even new product development. These are substantial challenges requiring sizable resources and talent. It is indeed a national challenge to facilitate this industry/university partnership. Currently, the Carter Administration is in the process of taking several steps to encourage technological innovation. One of these involves increased support for university-industry cooperative research and development programs. The federal government also proposes the creation of university-based technology-research centers and adoption of a liberal, government-wide patent policy which would give the inventors exclusive licenses to commercialize their inventions resulting from federally sponsored research.

The universities are ready to cooperate in maintaining and improving the technological backbone of the forest products industry. The question involves whether the industry has recognized the opportunity and seizes it to benefit itself and the society as a whole.

THE RESOURCE

Only during the past few years have forest residues been elevated to the status of a "resource." In fact, the term "residue" is relatively new; historically, the tops, small trees, and cull and dead material remaining after logging were termed "brush" or "slash," strictly a disposal problem. The sheer volume of wood contained in residue material commands attention, however, and current emphasis upon improving wood utilization focuses upon the product potential of the residue resource.

National projections predict continuing increases in the demand for wood and fiber-based products. In the face of a declining land base available for timber production, concerns about environmental impacts, and constraints in harvesting activities, better use must be made of the available resource. In the short run, more complete recovery and use of the total available wood resource is the most effective way to add to supply.

Interest in residue utilization raises some significant questions about the character and potential of the resource:

--How much residue material is there in our forests, and how does measurement of this material fit into the broader framework of resource inventory?

--What are the characteristics of this material in terms of volumes per acre, quality, size, and variation from one forest type to another?

--What are the costs of harvesting this material?

The information presented in this section addresses these three perspectives on forest residues as a viable wood resource.

RESOURCES EVALUATION AND RESIDUE: WHERE WE'VE BEEN AND WHERE WE'RE GOING

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ABSTRACT

In the past, analyses conducted by regional Resources Evaluation (Forest Survey) Units have considered forest residues only in passing. Recent political and economic developments have caused more attention to be focused on forest residues both for conversion to forest products and as a source of energy. This will undoubtedly lead to improved methods of assessing the forest residue situation and improving its utilization potential.

KEYWORDS: forest inventory, utilization, residues

In this paper, I would like to briefly outline how Resources Evaluation has treated forest residue in the past, what changes have been made recently to more adequately address the forest residue issue, and finally to consider what changes will have to be made in the future to provide basic input into a forest residue decision model.

Before we can evaluate the residue situation in the Rocky Mountains we must first define what we mean by residue. In the dictionary, residue is defined as "something that remains after a part is taken, separated, or designated." The brochure announcing this Symposium stated that forest residues include small trees, cull and broken logs, tops and dead trees with the latter being the largest single component. Resources Evaluation, however, is much more restrictive in its definition of residue.

First, the only trees that can be considered are live trees of commercial species except those that are cull because of form, rot or other defect. Second, only the portion of these trees, between a one foot stump and a four inch top, left in the woods after or killed during a logging operation is considered to be residue. Slash, that is, tops and limbs, cull trees, dead trees, etc., are not included in our estimates of logging residue. Nor do we include any material on lands classed as unproductive. It is, therefore, obvious that our estimates of residue or--more precisely--logging residue are conservative.

This is not to say that small trees, cull trees and dead trees are not taken into account. Quite the contrary, every effort is made to sample for this material. It is just that these items are displayed elsewhere and are not included in our estimates of residue or removals.

Estimates of logging residue are obtained through the use of various factors developed from utilization studies. These studies, conducted at approximately five year intervals, are designed to provide information about the source of material that is converted to various industrial products. Once an active logging operation for a particular product, such as sawlogs, has been selected, a crew will visit the site to take a series of standing tree measurements. These measurements reflect National or regional merchantability standards and include such items as stump diameter, d.b.h., height to a fixed top and total height. Additionally, the species and product are also indicated. After the tree is felled, a second set of measurements is taken to reflect the degree to which the tree was utilized. These include stump height, and diameter, log length and diameter at small end, length of material from small end of log to a fixed top diameter, if left behind, and those sections between a one foot stump and the fixed top that are bucked out because of breakage or rot.

Also measured is the amount of material falling outside the merchantable limits that will be converted to industrial products, including material from cull trees and other nongrowing stock sources.

These measurements are then converted to ratios or factors to predict the utilization or lack of it by product and species. These ratios provide the adjustments necessary to convert total industrial harvest to an estimate of annual removals.

To illustrate this process, consider first the case of overutilization. Assume that we have determined that 1,000,000 board feet of sawlogs have been delivered to a sawmill and we need to relate this to our standing inventory. From our utilization study, we find that on the average, sawlog harvesting operations left 6-inch as opposed to one foot stumps, went to a 7-inch as opposed to 9-inch top, utilized major limbs and obtained some logs from cull material. Our estimate of sawtimber removals then would be 1,000,000 board feet gross removals minus the stump volume, minus the additional volume above the 9-inch top, minus the volume in the major limbs utilized, minus the volume of cull material utilized. If all of the deductions amounted to ten percent, then for every one million board feet of reported harvest, we would only show a 900 thousand board foot reduction in inventory. In this example, there would not be any residue material.

On the other hand, if the loggers are leaving three foot stumps, stopping at a 12-inch top and not utilizing any other material, the inventory adjustment would be in the other direction. That is, if this underutilization amounted to 10 percent, then every one million board feet of reported harvest would take 1,100,000 board feet of inventory. The additional 100,000 board feet of material would be reported as logging residue, and the reduction in inventory would be reported as 110 percent of sawtimber volume removed.

Recent estimates of harvest for the Rocky Mountains may put these factors into proper perspective. In 1976, 95 percent of the roundwood material converted into industrial products came from growing stock trees, more than 4 percent came from salvable dead trees, and the remainder--less than one half of one percent--was evenly divided between cull tree and nongrowing stock sources.

In terms of total removals, some 88 percent went for conversion into industrial and domestic products, nearly eleven percent was left in the woods as logging residue. The remainder went into "other removals." "Other removals" represents the volume of material removed in cultural operations--timber stand improvement, precommercial thinning, and other nonproduct harvesting operations--land clearing for agriculture, roads, lakes, etc., and the volume of material left standing on forest land that has been set aside or otherwise withdrawn from the timber growing base but still supports standing trees. The volume in this category will be discussed later.

Before going into needs for the future, we would like to briefly discuss our treatment of mortality, cull, and small trees. Mortality and cull trees are selected for tally using the same sampling rule that is applied to all live trees. A prism with a basal area factor of 40 is used to determine whether or not a tree qualifies for selection. Once selected for measurement, it is usually obvious whether the tree is alive or dead. Up until recently, however, a dead tree was classified as mortality and/or salvable dead, and a tree class, i.e., growing stock or cull, at time of death was assigned. No attempt was made to further describe this material.

Recent developments in the forest products industry, namely advancing technology in pulp conversion and the house log industry, have made certain dead trees, both standing and down, economically feasible for conversion into products. As a result, our definitions and classifications of mortality have been broadened. For example, we currently record the amount and kind of defect on salvable dead material, and we indicate whether the tree is standing or down. In the case of a large windthrow, the inventory crew will actually attempt to "resurrect" each tree to determine whether or not it would have qualified for tally. We are also recording nonsalvable dead trees, both standing and down.

A live tree is considered to be cull if one or more of the following criteria are met:

1. Live sawtimber tree having more than two-thirds of its gross board foot volume in cull material including rot, crook, sweep and other defects such as excess limbiness or open grown (wolf tree).

2. Sound live sawtimber trees that do not contain at least one twelve foot log now or prospectively.

3. Live poletimber tree with more than two-thirds of its gross cubic foot volume in cull material including multiple stems, excessive crook or a butt section with less than 8 feet of usable wood.

4. Sound live poletimber trees that are excessively limby or open grown (wolf trees).

5. Seedlings and saplings which are unlikely to grow into growing stock because disease, crook, animal damage, or supporession.

And finally,

6. Off-site species.

Cull trees are further classified as rough or rotten depending on the amount of rot, serious fire or basal scars, and dead bole sections. If these defects account for more than one-third of the volume lost in a cull tree then the tree is coded as a rotten cull.

Small trees; that is, trees from 1.0-4.9-inch d.b.h., are tallied using a 1/300 acre fixed radius plot on every point of our 10-point cluster. These small trees are measured in essentially the same manner as their 5.0+ inch d.b.h., counterparts, and are included where appropriate in our computation procedures. Until recently, however, there were no volume estimates computed for this segment of the inventory.

It should be quite apparent from the above, that in the past Resources Evaluation was primarily timber oriented. The McSweeney-McNary Act of 1928, our enabling legislation, authorized the Secretary of Agriculture to make and keep current a comprehensive survey of the present and prospective requirements for timber and other forest products in the United States, and of timber supplies including a determination of the present and potential productivity of the Nation's forest lands. Thus, our primary objective was to relate everything to that component of the forest that could produce industrial timber products. We only took detail tree and area data on commercial timberland, that, by definition, was land that could produce a crop of industrial wood at an annual rate above 20 cubic feet per acre per year at culmination of mean annual increment. Our tree measurements were confined to growing stock trees that, by definition, were those trees that would be featured in management. Our measurements were confined to that portion of the tree that had the highest probability of yielding an industrial product. In other words, we were what some refer to as timber beasts and we were pretty good at it.

In August of 1974, however, the Congress passed and the President signed the Forest and Rangeland Renewable Resources Planning Act (RPA). The Act amended our enabling legislation to the extent that timber is no longer the driving force behind Resources Evaluation activities. Timber hasn't completely taken a backseat, it is just sharing the driver's seat with the other renewable resources such as wildlife, rangeland, water, and so forth. As a consequence, we have had to change our way of thinking and one area receiving considerable attention lately is forest residues. Current economic conditions have also added impetus to the desire to know more about the residue situation.

How will this shift in program direction affect how we evaluate forest resources in general and forest residues in particular? First, we will have to rethink our concept of forest residue. That "cull" tree standing in the middle of the forest may be home for some rare woodpecker; that slash left on the forest floor may be what will determine the survival of the seedling that will be planted there five years hence; and that pile of wind thrown lodgepole may be the security blanket for various and sundry critters that we don't see. If this is the case, then perhaps what we consider to be forest residue may not be residue at all. Second, to make these kinds of determinations will require a better or more detailed information base which in turn will require improvements in our current inventory procedures and the development of new methodology.

Predicting total woody biomass is one of the more important gaps yet to be filled. This problem is not unique to the Rocky Mountains. In fact, in 1977 a National level task force was appointed by then Forest Service Chief McGuire to develop a process for determining the amount of woody fiber that might be available for conversion to products or used as an alternative energy source. As a result of the recommendations of the task force, a study team was commissioned to draw together information currently available in the field of biomass prediction and to develop a National biomass handbook. The final product should consist of a series of equations and/or tables and should be available in the very near future.

Once these results become available we may have to modify how we sample the forest resource. For example, stem diameter at the base of the crown is one parameter used to predict total crown volume--a measurement we are not taking at the present time.

To more adequately assess what is happening to the standing inventory we will have to conduct more frequent and comprehensive utilization studies. Our measurements will have to be somewhat more flexible and will certainly have to be more detailed. For example, we will have to have the capability to shift from one merchantability standard to another. We will also have to develop the ability to predict or assess the slash situation for various types of logging operations. This is one area that has long been of concern to those who are interested in the energy potential from harvesting operations, and our current estimates of logging residues do not adequately address this problem.

The whole area of "other removals" will require additional study. As a minimum we will have to separate that portion of "other removals" that is still standing from the component that is actually severed. At present some of the volume that is on lands that have been administratively designated as a park or wilderness is being included as cut material that is potential biomass for energy conversion, when in fact the stands on these lands are probably no different from those which occur on adjacent lands. By providing estimates of the forest resource on reserved lands we can accomplish two objectives.

First, the fiber base will be more adequately described and, second, the potential from these lands can be assessed. This could become quite important in view of recent international energy developments.

Timely remeasurement surveys that include detailed measurements on all forest lands would also increase our ability to deal with shifting resource concerns. The target cycle for Resources Evaluation is about 10 years. If this cycle could be achieved in the Intermountain Region, we would be able to determine more accurately when a tree died, for example. We would also have time series information which could be used to model the dynamics of forest stands on an extensive basis.

One area that deserves serious consideration is the refinement of our inventory process to indicate how much residue is currently in the woods and to predict where large volumes of residue may occur in the future. We also need the measurements of certain descriptive parameters that will indicate the proximity of these stands to developed markets. In other words, the manner in which a manager treats a stand with high mortality potential could very well be tempered by the stands nearness to an all-weather road, the steepness of the slope on which it falls and its elevation. Thus, at a minimum, these parameters should measure the degree of physical accessibility.

Partner to determining accessibility is determination of the availability of the present or potential residue resource. This will require research outside the normal inventory process. Generally speaking, residues are available anywhere they occur on public lands that have not been withdrawn from timber production. The private sector, on the other hand, presents a completely different set of issues. Residues on these lands may be physically accessible, but because of owner attitudes they may not be available to the market. This issue has also been receiving considerable attention at the National level in recent months.

In conclusion, changing our approach to inventory should provide better estimates of the total forest resource situation including forest residue. We must keep in mind, however, that inventories conducted by Resources Evaluation are extensive in nature and, in the West, usually cover only the state and private lands. These inventories can only provide sample derived estimates of the amounts of various forest resources by some categories that may reflect their utility for conversion to various wood products, but we cannot tell you where the resources are. Therefore, any thoughts of being able to capture and use the salvable material within a given geographical location has to be tempered with economic considerations. Moreover, future analyses of our forests and the outputs they produce will have to consider both timber and nontimber values for the residue resource as well as the growing stock inventory.

RESIDUE CHARACTERISTICS IN THE NORTHERN ROCKY MOUNTAINS

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ABSTRACT

In the northern Rocky Mountains, 350-450 million cubic feet (9.9 to 12.7 million m^3) of logging residue is generated each year. This residue consists of dead standing and down trees, green unmerchantable trees, broken pieces and the tops and branches of those trees removed in logging. Up to 60 percent of the residue material is technologically suitable for wood products, but condition, size and product potential vary among forest types. Other factors which influence residue utilization are level of harvest, trends in wood processing, industrial uses and economic conditions.

KEYWORDS: forest residue, logging residue, utilization

INTRODUCTION

During the past 5 years, the Forest Residues Utilization research unit has made an extensive study of forest and logging residues in the principal forest types of Montana, Idaho and Wyoming. The purposes of this study were to develop wood biomass data as a baseline for evaluating impacts of alternative residue treatments and to estimate the utilization potential of forest residues. Over 3,000 samples were taken at various research sites and in undisturbed stands in National Forests throughout the area.

Residues were measured using standard fixed or variable plot techniques for standing trees and the planar intercept (line transect) method for down material (Brown 1974). Characteristics such as piece size and condition were determined by measurement or estimation. The principal forest types included in these studies were lodgepole, larch, grand fir, spruce-alpine fir and Douglas-fir. Most timber harvest and residue management problems occur in mature and overmature forests of these types.

This paper summarizes residue characteristics that affect harvest and utilization potentials. The characteristics of woody material were reported earlier (Benson and Schlieter 1980a).

CHARACTERISTICS OF FOREST RESIDUES

Old-growth conifer forests typically contain a sizable volume of material--such as dead, cull, rotten and undersize stems--not normally suited for sawlogs or veneer logs. Because disease, insects, bad weather and fire suppression occur neither regularly nor evenly throughout stands, the amount and condition of residues vary widely. One stand, because of reasonably good spacing, may have escaped serious disease or insect problems and have very little residue. The trees in another stand in the same forest type may have experienced extensive crowding and fire suppression that produced many small defective stems; similarly, stands that have suffered heavy rot or insect mortality may have more residue than merchantable material. The data that follow should be interpreted as averages for each type.

Volume and Condition

When considering utilization of residue material, the volume per acre and the condition of residues are of key importance. Furthermore, even if no utilization is planned, the physical presence of residues affects the costs both of logging and of subsequent activities such as fuel management and regeneration.

The volume of all wood 3 inches diameter (7.6 cm) and larger on our study sites is shown in table 1. Forest inventory and sale cruise data normally present smaller volumes because they tend not to include all the types of material reported here.

Table 1.--Volume of wood in mature stands, in residue study areas, by component.[1]

	FOREST TYPE					
	Lodgepole	Larch	Douglas-fir Moist site	Douglas-fir Dry site	Grand fir	Spruce-Alpine fir[2]
	ft^3/acre					
Green Trees						
Merchantable log	2225	3401	2546	1658	4283	2000
Cull	119	222	334	52	564	391
Top	457	132	105	75	208	300
Small stems	244	663	527	300	156	380
Sub total	3045	4418	3512	2085	5211	3071
(m^3/ha)	(213)	(309)	(246)	(146)	(364)	(215)
Standing Dead						
No defect	436	86	180	0	24	153
Sound defect[3]	291	30	49	78		
Solid rot	139	493	36	22	256	68
Crumbly rot	0	302	55	0		
Sub total	866	911	320	100	280	221
(m^3/ha)	(61)	(64)	(22)	(7)	(20)	(15)
Down						
No defect	356	108	267	43	281	455
Sound defect[3]	310	66	52	19	7	43
Solid rot[4]	213	124	137	181	309	106
Crumbly rot[4]	233	1196	398	527	1903	262
Sub total	1112	1494	854	770	2500	866
(m^3/ha)	(78)	(104)	(60)	(54)	(175)	(61)
TOTAL, ft^3/a	5023	6823	4686	2955	7991	4158
(m^3/ha)	(351)	(477)	(328)	(207)	(559)	(291)

[1]Top volumes and stem volumes for small trees were compiled from recently published formulae based on species, d.b.h., and height (Faurot 1977).

[2]Breakdown of totals into component is estimated.

[3]Sound defect includes crook, sweep, fork, splits and drying checks that prevent use for solid wood products but not for fibers.

[4]Solid rot includes pieces with rot that can be handled in logging; crumbly rot is material that will not hold together in logging.

Total stand volumes ranged from about 3,000 ft^3/a on dry Douglas-fir sites to nearly 8,000 ft^3/a on grand fir sites. In most forest types about half the total volume consisted of green merchantable logs (fig. 1), and the condition of other standing residue material varied. In lodgepole pine and spruce-alpine fir, much of the residue was sound dead material. These forest types occur at high elevations with dry, cool conditions that do not favor rapid decay. On the other hand, in grand fir and western larch (which favor moister, warmer sites) rotten dead material predominated. Cull green material with rot also was substantial in moister forest types.

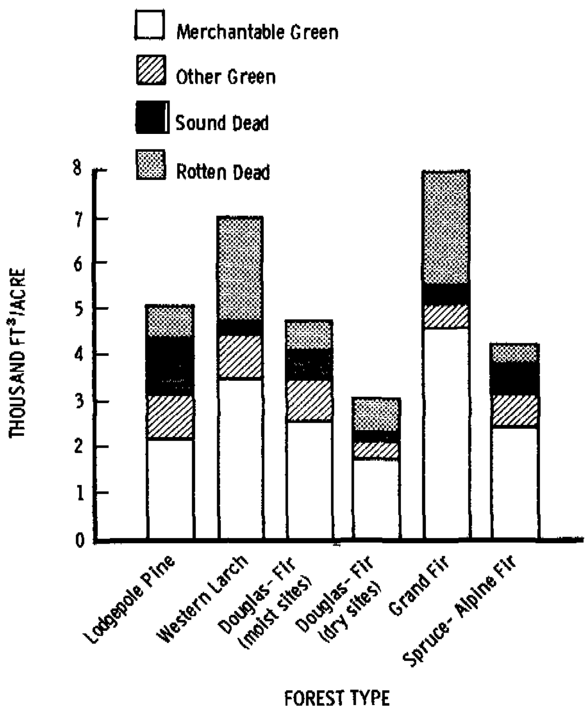

Figure 1.--Volume of wood 3 inches (7.6 cm) and larger in diameter in principal forest types.

The condition of down material appears to be related to decay conditions. In grand fir and larch most of the down material was crumbly rot that could not be removed from the site with conventional logging equipment. In lodgepole and spruce-alpine fir about three-fourths of the material was sound or had only limited defects that would not preclude harvesting (fig. 2).

Figure 2.--Most of the dead and down material in lodgepole stands is suited for product utilization.

Size and Number of Residue Pieces

Because utilization potentials and the costs of harvesting both relate to the number and size of the residue pieces involved, these characteristics were measured in detail for some of our samples.

In lodgepole pine and Douglas-fir sites representing a range of residue conditions, we estimated the following distribution of residue piece sizes:

Condition, diameter, length	Percentage of harvestable residue	
	Lodgepole pine	Douglas-fir
Sound, 6"+, 18'+	43	53
Sound, 6"+, 9' to 18 '	8	9
Sound, 3" to 6", 9'+	29	19
Sound, all diameter, less than 9'	5	9
Solid rot all diameters and lengths	15	10

(Source: Outlook for Utilization of Forest Residues, Northern Rocky Mountain Area, Unpublished Report, USFS Forestry Sciences Laboratory, Missoula)

These estimates indicate that about half the volume of usable residue material was in fairly large pieces or whole trees. Pieces greater than 6 inches in diameter by 18 feet in length averaged 15 ft^3 per piece. In most cases, small green and standing dead trees were intact and of full length; down material was often broken, however, which meant more pieces with smaller volumes. There was also considerable variation among forest types in the number and size of sound, usable, down pieces. Lodgepole pine averaged 127 sound down pieces per acre; western larch 65; and dry Douglas-fir sites 18.

When all sound standing and down material is taken into account, there are potentially 500-800 pieces per acre (1235-1975/ha) in a typical lodgepole pine stand and 200-400 pieces/a (495-990/ha) in Douglas fir (estimates were derived from Benson and Strong 1977; Benson and Keck[1]; Benson and Schlieter 1980a). About 200 stems per acre (495/ha) in lodgepole stands, and 100-150/a (245-370/ha) in Douglas-fir stands, are merchantable green trees. The remainder are residue pieces--300-500 pieces per acre (740-1235/ha) in lodgepole, and 100-250 (245-615/ha) in Douglas-fir.

Product Potential

Potential products were estimated for several forest types. The number of product pieces that could be recovered from each standing or down dead piece was determined, beginning with the product of highest value (table 2). In lodgepole pine over 350 product pieces per acre (865/ha) were recoverable; in Douglas-fir about 70 (170/ha), and in larch about 40 (100/ha).

Specifications for these products vary from one location to another but the size requirements used in the study were typical. Dead material of certain species is not currently used for some of the products listed in table 2. In the larch and Douglas-fir types, for example, only a few pieces are suited for solid wood products, and most have defects that prevent use for anything except pulp wood.

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[1]Benson, Robert E., and Kenneth Keck. 1979. Forest residues on the Targee National Forest. Mimeo. Rept. Forestry Sciences Laboratory, Drawer G, Missoula.

Table 2.--Number of potential products from standing and down dead pieces, selected forest types.

Product and type piece[1]	Lodgepole pine	Western larch	Douglas-fir moist sites
	- - - - - - - - - - - - pieces/acre	- - - - - - - - - - - - -	
Houselogs			
standing	9 (22)	1 (2)	2 (5)
down	13 (32)		
Sawlogs			
standing	21 (52)	3 (7)	7 (17)
down	20 (49)		
Corral rails			
standing	43 (106)	3 (7)	5 (12)
down	46 (114)		
Posts			
standing	36 (89)	1 (2)	2 (5)
down	44 (109)		
Pulp bolts			
standing	51 (126)	30 (74)	57 (141)
down	75 (185)		

[1]Minimum specifications used were as follow:

Houselogs-- 9 inches diameter, 8 feet long; no crook, sweep, rot, or checks that would preclude use as houselogs;
Sawlogs-- 6 inches diameter, 8 feet long, 1/3 sound;
Corral rails-- 3 inches diameter, 10 feet long; reasonably straight, no rot or major checks;
Posts-- 3 inches diameter, 7 feet long; no crook, rot or major checks;
Pulp bolts-- 3 inches diameter, 8 feet long; sound enough to hold together in yarding.

LOGGING RESIDUES

The amount and characteristics of residue material that actually remains after logging may or may not be closely related to predictions based on pre-harvest conditions. Often residue material becomes broken in the logging operation so the post-harvest potential is reduced.

In one study of 33 cutting units, between 1,800-2,600 ft^3/acre (126-182 m^3/ha) remained in units that received conventional utilization; only about 20 percent of this material was over 9 feet (2.7 m) long. In unlogged stands, however, about 80 percent of the residue material was over 9 feet (2.7 m) long, which indicated much of the residue potential was lost due to breakage in logging. On the other hand, where removal of all pieces over 9 feet (2.7 m) long was required in utilization specifications, only about 15 percent of the total preharvest volume remained as residues. This suggests that when logging is intended to remove residue material it can be done without excessive breakage.

In our study about half the volume remaining after conventional utilization was green material. With close and intermediate residue utilization levels, virtually all the green material was removed, with only the unsound or broken small pieces of dead material remaining.

In another study, six timber sale units logged to conventional sawlog standards had from 1,800 ft^3/acre to over 3,800 ft^3/acre (126 m^3 to 266 m^3/ha) of residue remaining. Two of these units were relogged to recover pulpwood and any other products that could be made. This resulted in a 44 percent reduction of residues in one area and a 59 percent reduction in the other (Chase 1979).

In typical mature or overmature stands, where about half the total volume is residue material, the proper combination of utilization standards and logging could remove most of this material for utilization (fig. 3). Based on our case studies, it appears that close utilization at the time of initial sawlog removal recovers more of the material than relogging. This, however, would depend on stand conditions and other factors not considered in these study areas.

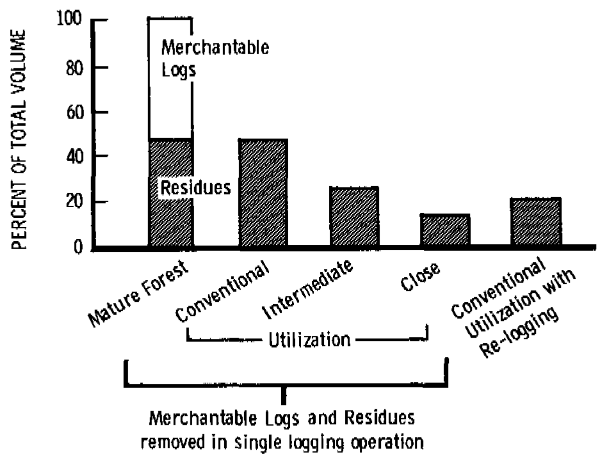

Figure 3.--Proportion of residue material in mature stands remaining under alternative utilization practices.

FACTORS INFLUENCING POTENTIAL UTILIZATION

Other papers in this proceedings examine the potential for residue utilization from both technical and economic perspectives. The total potential in terms of wood volume and use depends on three general factors: level of harvest, trends in utilization standards, and large scale uses.

Level of Harvest

Currently about 465 million ft^3 (13.1 million m^3) of residues are generated annually in the northern Rocky Mountains. About 355 million ft^3 (10 million m^3) of these residues accumulate in the six major forest types discussed in this summary. The level of harvest is projected to remain at present levels for the next decade or so, which means that if residues are removed at the time of regular harvest there is potentially available 0.3 to 0.4 billion ft^3 (8.5 million m^3 to 11.3 million m^3) of additional material.

If, as has been speculated, land use designation or restrictions on logging reduce the level of harvest, the volume of residues would be reduced accordingly. On the other hand, two potential sources of residues not included are: (1) material from thinning in young stands, which could add a modest amount, but is generally considered to be costly as fiber at this time; and (2) extensive salvage of dead or high risk trees. There are options to salvage log or prelog dead or high risk trees over large areas. This would essentially be the same as taking out all the residues in a short period of time rather than a continuing smaller annual volume removed along with the regular harvest. Two major problems would need to be solved: first, financing the extensive road system needed to reach scattered dead or high risk trees in a short time period; and second, providing equipment to successfully and economically remove these trees without adverse impacts on the remaining forest system.

Trends in Utilization

There has been a continuing trend toward greater utilization of wood fiber from any given logging unit because of increased demands for wood and improved methods of utilizing material formerly left as residue. When our studies began more than 6 years ago, we defined residue as material not meeting usual sawlog or veneer log specifications. Since then, material we originally classed as residue has been utilized to a greater degree. This has not been quantified in our studies, but several examples will illustrate the situation.

In western Wyoming and southeastern Idaho several mills were forced to adapt to using dead lodgepole pine. Bark beetle epidemics had almost eliminated green sawtimber.

A relatively new industry which produces house logs and log homes has been established in western Montana. Dead lodgepole is preferred, and often the value of this one-time residue is higher than that of green trees.

Throughout the western states, areas near forested land have seen a dramatic increase in the use of wood as a home heating fuel. In one area of southeastern Idaho it is estimated that from 25 to 40 percent of the total wood removed is for home heating fuel.

These trends indicate that a substantial portion of the region's 350 to 400 million ft^3 (10 to 11.3 million m^3) of residue material is already being utilized. The "residue" base actually shrinks, as mechantability standards are redefined.

Large Scale Use

The harvesting of northern Rocky Mountain timber for lumber and veneer production creates a seemingly inexhaustible supply of residue that has potential value. During the past few years important, but incremental, changes in residue utilization have occurred. In contrast to these small improvements, major increases in residue removal through industrial use appear possible. These possibilities include the expanded use of forest residues for pulp or fiber, as surplus sawmill and veneer mill residues decline; harvesting of forest residues for chemicals and wood alcohol; manufacture of densified fuel pellets for home or industrial use; and large scale use of all fiber material--wood, straw, whatever--for energy production.

If such large scale uses develop, guidelines will be needed to aid the land manager in determining the kinds and amounts of residue that should be left on an area to protect and enhance the forest ecosystem.

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APPLICATIONS OF A COST MODEL TO NORTHERN ROCKY MOUNTAIN RESIDUES

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ABSTRACT

Whatever decisions are to be made concerning the possible use of forest residues, questions always arise about the costs of collecting and transporting them to a place where they might be used. The residue cost model consists of a series of seven tables, which allow the estimation of the collection costs of the types of residues common to the northern Rocky Mountains. The cost tables were developed from published studies of both conventional logging and residue collection.

KEYWORDS: residue collection, residue utilization

Over the past several years, there has been much research directed at the potential uses of forest residues. The results have generally indicated that there are no technical problems in using residues, but we still find that they are not being used. The primary reason they are not is that the costs of obtaining the residues is greater than their value. In the spring of 1978, a cooperative study between the USDA-Forest Service Intermountain Forest and Range Experiment Station Forestry Sciences Laboratory and the University of Montana Bureau of Business Research was begun, with the goal being to develop a model for estimating the cost of collecting forest residues, and then using the model to estimate the cost availability of residues in this area.

The source of data for development of the cost model was published information related to conventional logging. Interviews with a number of operators who had experience in collecting residues indicated that it was really not much different from commercial logging, so that there was no need to develop a new data base just for residues.

The cost data collected from the many sources were summarized into a series of seven tables, which are given at the end of this report.

ORGANIZATION OF THE TABLES

The construction and organization of the cost tables represent a compromise between the need for the tables to be relatively easy to use, and the need to provide reasonable accuracy in the final cost estimate. To simplify the tables, some of the variables which one would expect to influence the cost of residue collection are not included, such as the species, or the slope of the ground. A number of variables, however, have such a strong influence on the cost that the tables include them. Some of the variables which must be considered are the size of the residue pieces, the skidding distance, the haul distance, and whether the material is to be chipped in the woods or hauled in whole.

Figure 1 shows the various combinations of tables that should be used to estimate the collection costs of various types of forest residues.

IMPORTANT VARIABLES

By far the most important variable in the cost of residue collection is the size of the residue pieces. The cost per piece of handling residues is smaller for smaller pieces, but the smaller pieces contain less material, so that the cost per unit volume is greater for smaller sizes. This relationship holds true in nearly every phase of residue collection, from falling of dead trees to the hauling of residues. Figure 2 shows the cost of ground skidding a distance of 300 feet (91 m). At volumes per piece above 10 cubic feet (0.3 m^3), the cost is relatively constant, but at smaller sizes, the cost rises very sharply, and goes off the scale of figure 2 at sizes less than one cubic foot (0.03 m^3) per piece. As a basis for comparison, a stick of wood four inches (10 cm) in diameter and 16 feet long (5 m) would contain about one cubic foot (0.03 m^3) of wood, and would weigh about 70 pounds (32 kg) green. A stick 12 inches (30 cm) in diameter and 16 feet (5 m) long would contain about 10 cubic feet (0.3 m^3) and would weigh about 700 pounds (317 kg).

The costs of falling and limbing, skidding or yarding, and loading all follow the same pattern of sharply rising costs with smaller sizes. The practical result of this relationship is that we cannot use average sizes of residues when estimating the cost of collection, as that would seriously underestimate the cost.

As an example, consider a quantity of logging residues where half of the total volume was contained in tops and small stems with an average size of one cubic foot (0.03 m^3), and the other half is contained in cull logs with an average size of ten cubic feet (0.3 m^3). The average size of all residues is then 5.5 cubic feet (0.16 m^3). From table 3, the cost of ground skidding a distance of 500 cubic feet (152 m) is $16.40 per cunit ($5.80 per m^3) (read at the closest table value of 5 cubic feet). However, the small material will really cost $82.10 per cunit ($29 per m^3) for skidding, and the larger material will cost $8.20 per cunit ($2.9 per m^3). The average cost is really ($82.10 + $8.20) /2 = $45.15 per cunit ($15.94 per m^3). By averaging the piece size, the cost estimate is only about one third of what it should be. Some averaging will be necessary in estimating costs, but care should be taken that the averaging does not include a wide range of sizes, especially of the smaller sizes. If the residues source is not relatively uniform in size, it should be divided into several size categories so that the cost can be estimated separately for each one.

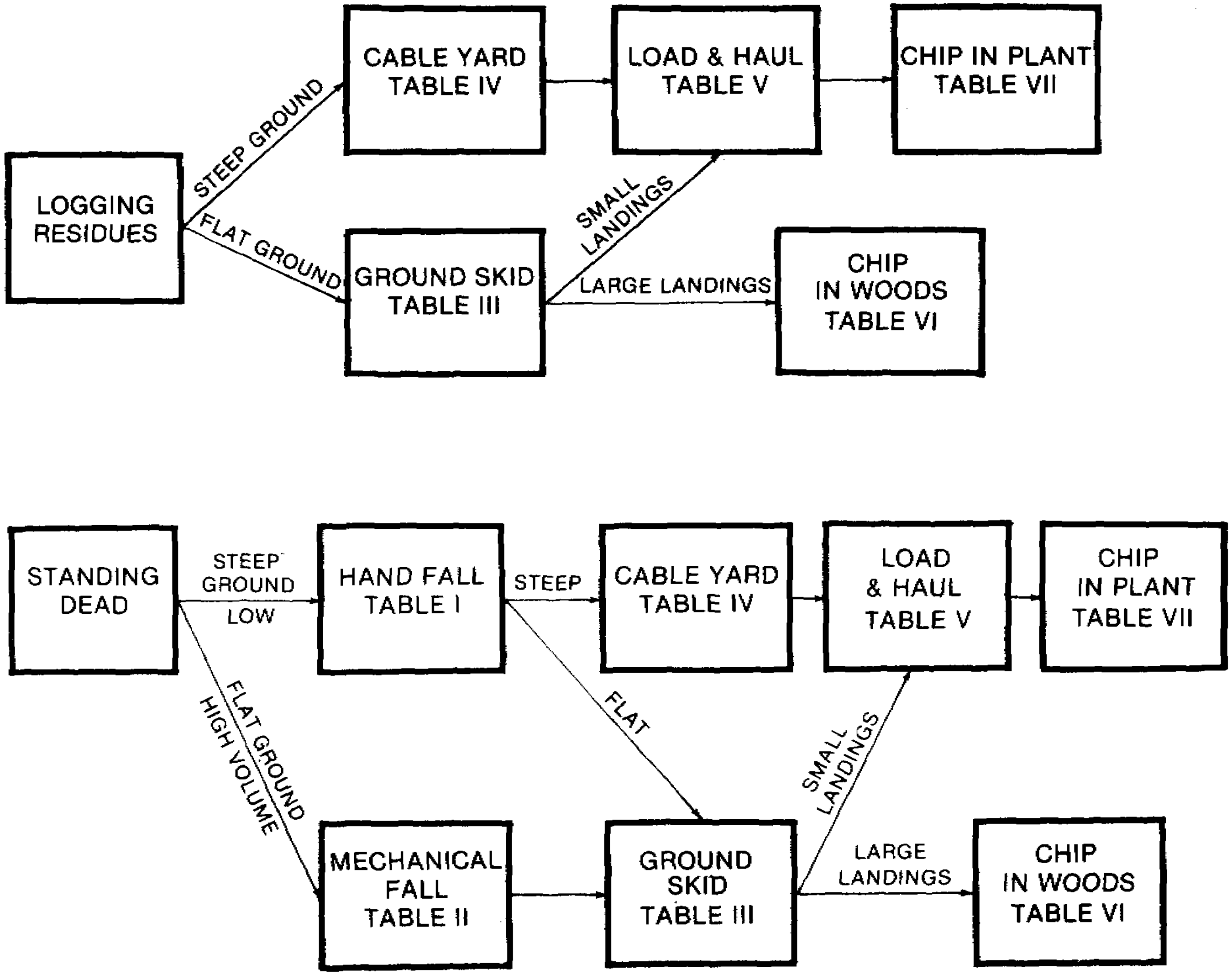

Figure 1.--Cost table selection guide.

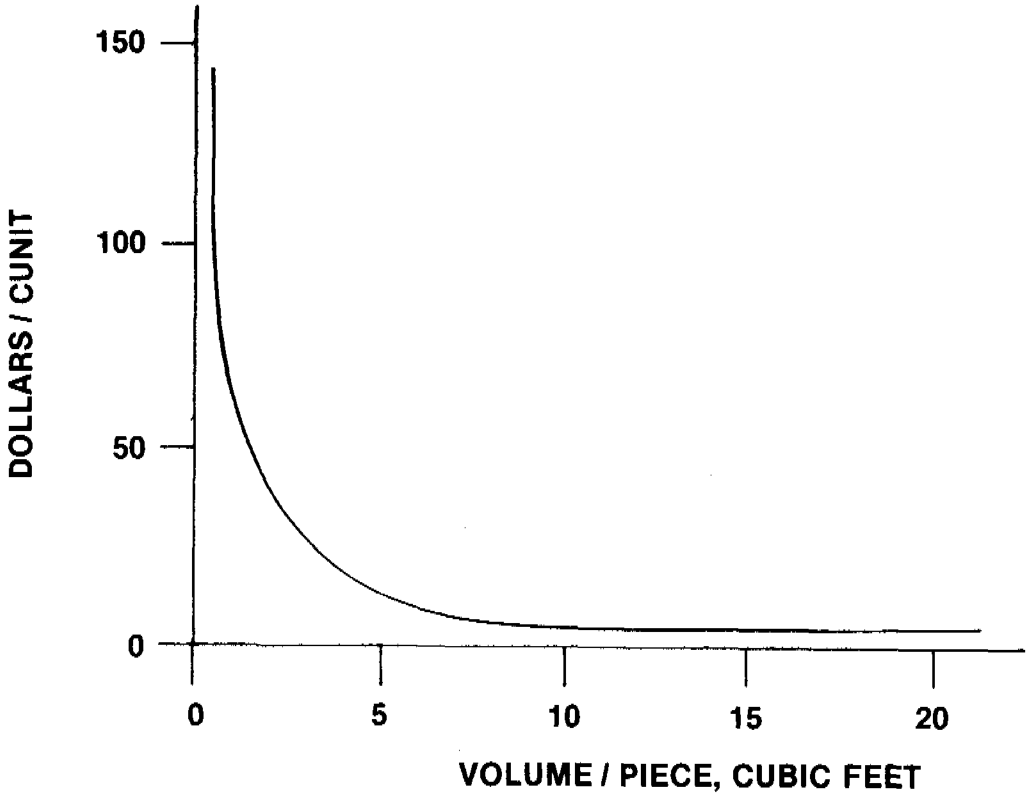

Figure 2.--Ground skidding cost, 300 feet, one way.

Distances for ground skidding, and for hauling to a central location also affect the cost, but the relationship is nearly linear, so that averaging does not cause a problem as it does with piece size. The amount of detail needed to obtain cost estimates can thus be reduced by using average skid distance and average haul distance.

The two remaining primary variables are the choice between ground or cable yarding, and the choice between chipping in the woods or centralized chipping. Ground skidding is always preferable to cable yarding because of the lower cost, but it can be used only where the ground is not too steep. As a general rule, if the average slope is greater than 30 percent, some form of cable yarding must be used. The per cunit cost of cable yarding is shown in table 4, and it should be noted that the cost is quite high. What this really means is that, except for some very large pieces, residues that must be cable yarded are not really economically available.

The choice between in-woods chipping or centralized chipping can be made partially according to the piece size. For piece sizes above about 5 or 10 cubic feet (0.14 or 0.28 m^3), it is cheaper to haul the pieces to a central location. For smaller pieces it appears to cost less to chip in the woods. However, the cost tables assume that conditions will allow efficient operation of in-woods chipping. The necessary conditions include sufficient volume to sustain a steady output, large flat landings, and good roads. These conditions are not often available in the Rocky Mountains, so that care should be used before assuming that in-woods chipping will be used.

Table 1.--Hand felling cost

d.b.h.		Felling only	Limbing only	Fell and limb
inches	cm	------------	$/cunit[1/]	--------------
4	10	37.20	57.10	94.30
6	15	15.30	23.90	39.20
8	20	8.00	9.60	17.60
10	25	4.00	6.30	10.30
12	30	2.70	4.20	6.90
14	36	2.10	3.20	5.30
16	41	1.70	2.60	4.30
18	46	1.40	2.20	3.60
20	51	1.20	1.90	3.10
24	61	.90	1.50	2.40
28	71	.80	1.20	2.00

1/ to obtain $\$/m^3$, multiply tabled values by 0.353

Table 2.--Mechanical felling cost

d.b.h.		Fell only	Fell and limb
inches	cm	----- $/cunit[1/]	-----
4	10	69.00	81.80
6	15	26.80	31.80
8	20	11.10	13.20
10	25	5.90	7.00
12	30	3.50	4.20
14	36	2.40	2.90
16	41	1.70	2.10
18	46	1.30	1.50
20	51	1.00	1.20

1/ to obtain $\$/m^3$ multiply tabled entries by 0.353

Table 3.--Ground skidding cost

Volume per piece ft3	Volume per piece m3	Volume per load[1/] ft3	Volume per load[1/] m3	50 feet / 15 meters	100 feet / 30 meters	150 feet / 46 meters	200 feet / 61 meters	300 feet / 91 meters	400 feet / 122 meters	500 feet / 152 meters	600 feet / 183 meters	800 feet / 244 meters	1000 feet / 305 meters	2000 feet / 610 meters	3000 feet / 914 meters
				One way skidding distance — $ /cunit[2/]											
0.5	0.01	5	0.1	125.6	130.0	134.2	138.4	147.0	155.6	164.2	172.8	190.0	207.2	293.2	379.2
1.0	0.03	10	0.3	62.8	65.0	57.1	69.2	73.5	77.8	82.1	86.4	95.0	103.6	146.6	189.6
1.5	0.04	15	0.4	41.9	43.3	44.7	46.1	49.0	51.9	54.7	57.6	63.3	69.1	97.7	126.4
2.0	0.06	20	0.6	31.4	32.5	33.6	34.6	36.8	38.9	41.1	43.2	47.5	51.8	73.3	94.8
3.0	0.08	30	0.8	20.9	21.7	22.4	23.1	24.5	25.9	27.4	28.8	31.7	34.5	48.9	63.2
4.0	0.11	40	1.1	15.7	16.3	16.8	17.3	18.4	19.5	20.5	21.6	23.8	25.9	36.7	47.4
5.0	0.14	50	1.4	12.6	13.0	13.4	13.8	14.7	15.6	16.4	17.3	19.0	20.7	29.3	37.9
10.0	0.28	100	2.8	6.3	6.5	6.7	6.9	7.4	7.8	8.2	8.6	9.5	10.4	14.7	19.0
15.0 or over	0.42	150 or over	4.2	4.2	4.3	4.5	4.6	4.9	5.2	5.5	5.8	6.3	6.9	9.8	12.6

1/ Volume per load assumes 10 pieces per load to a maximum load of 150 cubic feet ($4.2 m^3$)

2/ to obtain $ /m^3 multiply tabled entries by 0.353

Table 4.--Cable yarding cost.[1/]
$ Per cunit

Average Piece size Ft^3	m^3	Yarding cost $/cunit	($/m^3)
.5	0.01	769	272
1.0	0.03	390	138
1.5	0.04	261	92
2.0	0.06	197	70
3.0	0.08	133	47
4.0	0.11	101	36
5.0	0.14	82	29
10.0	0.28	43.2	15.2
15.0	0.42	30.8	10.9
20.0	0.57	24.8	8.8
25.0	0.71	21.3	7.5
30.0	0.85	19.3	6.8
40.0	1.13	17.2	6.1
50.0	1.42	16.0	5.6
60.0	1.70	14.0	4.9
70.0	1.98	12.4	4.4
80.0	2.26	11.1	3.9
90.0	2.55	10.1	3.6
100.0	2.83	9.3	3.3

1/ The cost values shown are for yarding distances up to 1,000 feet. For yarding distances of 1,000 to 2,000 feet, increase the costs shown by 20 percent. Do not use this table for distances greater than 2,000 feet.

Table 5.--Loading and hauling cost

Average volume per piece		One way haul distance												
		miles												
		5	10	15	20	25	30	40	50	60	70	80	90	100
		km												
		8	16	24	32	40	48	64	80	97	113	129	145	161
ft^3	m^3	$ /cunit[1/]												
0.5	0.01	20.7	22.1	23.3	24.2	25.7	27.0	29.6	32.2	34.6	36.8	39.1	41.2	43.2
1.0	0.03	17.6	18.6	19.6	20.6	21.8	22.9	25.2	27.5	29.6	31.6	33.5	35.4	37.2
1.5	0.04	15.1	15.9	16.8	17.7	18.8	19.8	21.8	23.9	25.7	27.6	29.3	31.0	32.6
2.0	0.06	13.2	14.0	14.8	15.6	16.5	17.5	19.3	21.2	22.8	24.5	26.1	27.6	29.0
3.0	0.08	11.7	12.4	13.2	13.9	14.8	15.7	17.4	19.1	20.7	22.2	23.7	25.1	26.5
4.0	0.11	10.6	11.2	12.0	12.7	13.5	14.3	15.9	17.5	19.0	20.4	21.8	23.1	24.4
5.0	0.14	9.9	10.6	11.3	11.9	12.7	13.5	15.1	16.6	18.0	19.4	20.7	22.0	23.2
10.0	0.28	8.4	9.0	9.7	10.4	11.1	11.9	13.4	14.8	16.2	17.5	18.8	20.0	21.2
15.0	0.42	7.8	8.4	9.1	9.8	10.5	11.3	12.8	14.2	15.6	16.9	18.2	19.4	20.6
20.0	0.57	7.5	8.1	8.7	9.4	10.1	10.9	12.4	13.9	15.2	16.6	17.8	19.0	20.2
25.0	0.71	7.1	7.7	8.4	9.0	9.8	10.6	12.0	13.5	14.9	16.2	17.5	18.7	19.9
30.0	0.85	6.8	7.4	8.1	8.7	9.5	10.2	11.7	13.2	14.6	15.9	17.2	18.4	19.6
40.0	1.13	6.4	7.0	7.7	8.3	9.1	9.9	11.4	12.8	14.2	15.5	16.8	18.0	19.2
50.0	1.42	6.1	6.7	7.4	8.0	8.8	9.6	11.1	12.5	13.9	15.2	16.5	17.7	18.9
60.0	1.70	5.9	6.5	7.2	7.8	8.6	9.4	10.8	12.3	13.7	15.0	16.3	17.5	18.7
70.0	1.98	5.8	6.4	7.0	7.7	8.4	9.2	10.7	12.2	13.5	14.8	16.1	17.3	18.5
80.0	2.26	5.6	6.2	6.9	7.5	8.3	9.0	10.5	12.0	13.4	14.7	16.0	17.2	18.4
90.0	2.55	5.4	6.0	6.7	7.4	8.1	8.9	10.4	11.9	13.2	14.6	15.8	17.0	18.2
100.0	2.83	5.3	5.9	6.6	7.2	8.0	8.8	10.2	11.7	13.1	14.4	15.7	16.9	18.1

1/ to obtain $ /m^3 multiply tabled entries by 0.353

Table 6.--In-woods chipping and hauling cost[1/]

One-way haul Distance		Barked chips[2/]	Not Barked chips[2/]
miles	km	---- $ /cunit[3/] ------	
5	8	13.18	11.37
10	16	14.05	12.24
15	24	15.04	13.23
20	32	15.98	14.17
25	40	17.09	15.28
30	48	18.19	16.38
40	64	20.35	18.54
50	80	22.51	20.70
60	97	24.49	22.68
70	113	26.41	24.60
80	129	28.28	26.47
90	145	30.03	28.22
100	161	31.78	29.97

1/ Chipping only costs are: barked -- $9.04/cunit
not barked -- $7.23/cunit

2/ If the residues are to be barked prior to chipping, tables 1 or 2 (if used) must provide for limbing. If the residues are not to be barked, and thus contain bark in the chips, limbing is not required.

3/ to obtain $ /m^3 multiply tabled entries by 0.353

Table 7.--In-plant chipping cost

	$ /cunit	$ /m^3
1) Chip only[1/]	6.25	2.20
2) Handling costs[2/]	6.25	2.20
Total	12.50	4.40

1/ Chip only costs include chipper, labor, power, and limited yard handling.

2/ Handling costs include barking, bark and chip handling and storage, and screening of chips.

EXAMPLE COST ESTIMATION

Example A: High Volume Harvest of Dead Lodgepole Pine

Assume, for this example, that the residues are dead lodgepole, which is relatively uniform in size, with an average diameter at breast height (d.b.h.) of 10 inches (25 cm). It is on relatively flat ground with large landings available, so that mechanical falling and in-woods chipping are to be used. The average skidding distance is 400 feet (122 m). The trees will be chipped without barking, and hauled 40 miles (32 km) to a central location. The average volume per tree is 16.3 cubic feet (0.46 m^3). The relevant costs are:

Table 2:	Mechanical fall, without limbing	$5.90	($2.08/$m^3$)
Table 3:	Ground skid	$5.20	($1.84/$m^3$)
Table 6:	In-woods chip and haul, not barked	$18.54	($6.54/$m^3$)
	Total Cost	$29.64 per cunit	($10.46/$m^3$)

Example B: Logging Residues on Steep Ground

For this example, assume that the logging residues have the following size distribution:

a) 3 to 5 inch diameter, 8 feet long (8 to 13 cm, 2.4 m) 20 percent of total
b) 6 to 10 inch diameter, 16 feet long (15 to 25 cm, 4.9 m) 50 percent of total
c) 14 to 22 inch diameter, 24 feet long (36 to 56 cm, 7.3 m) 30 percent of total

The material is on steep ground, so that cable yarding must be used. It must be hauled 60 miles (96 km) to a central chipper, where it will be chipped for fuel, so that barking is not required. Because of the large difference in the piece size of the three categories, the cost must be estimated separately for each and the average cost found by using the percentage of the total as weights. The results are:

	Table 4	Table 5	Table 7	Total	% of Total
	$ per cunit				
a) .5 ft^3	$769.00	$34.55	$6.25	$809.80	20
b) 4.4 ft^3	$101.00	$19.01	$6.25	$126.26	50
c) 35.9 ft^3	$17.20	$14.20	$6.25	$37.65	30

Weighted Average Cost: $236.39/cunit

	Table 4	Table 5	Table 7	Total	% of Total
	$ per m^3				
a) 0.01 m^3	$271.46	$12.20	$2.21	$285.87	20
b) 0.12 m^3	35.65	6.71	2.21	44.57	50
c) 1.00 m^3	6.07	5.01	2.21	13.29	30

Weighted Average Cost: $83.45/$m^3$

These examples represent two of the extremes in the cost of collecting forest residues. There are residues that can be collected at costs which make them attractive sources of raw material for either products or fuel, but there are alos large volumes that are available only at exorbitant costs. When considering the entire forest residue resource, we must use care to remember that much of it is not economically available.

THE ECONOMIC AVAILABILITY OF FOREST RESIDUE IN THE NORTHERN ROCKY MOUNTAINS: A PRELIMINARY ANALYSIS

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ABSTRACT

The Bureau of Business and Economic Research and the Intermountain Forest and Range Experiment Station, Missoula, are involved in a cooperative research project to estimate the cost of harvesting and transporting forest residues to processing centers in the northern Rocky Mountains. Regionwide estimates are to be made based on detailed analyses of the volumes and types of forest residues available to selected individual manufacturing centers. The results of the analysis of the first manufacturing center are presented in this paper. The initial study area selected was Lincoln County, Montana, with Libby, Montana as the processing center. It appears from the analysis that substantial volumes of logging residue material would be available at a cost which would allow for its use in fuel and reconstituted wood fiber products as well as solid wood products.

KEYWORDS: residue availability, residue utilization, residue cost

The results presented in this paper are part of a cooperative research project by the Bureau of Business and Economic Research at the University of Montana and the USDA Forest Service Intermountain Forest and Range Experiment station in Missoula. The major objective of the project is to estimate the volumes of potentially utilizable forest residues in the northern Rocky Mountains, and the costs of harvesting and transporting this material to processing or manufacturing centers.

The task of making estimates for the northern Rocky Mountain area was approached on an individual manufacturing or processing center basis. The plan was to make a detailed analysis of the volumes and types of residue which could be delivered to selected manufacturing centers at various cost levels. The detailed analyses of the selected manufacturing centers will be used in conjunction with projections of future timber harvest levels and locations to develop broad estimates of the volumes and costs of forest residues available in the northern Rocky Mountain area. This paper presents the results of the first attempt to develop cost estimates for a manufacturing center.

MATERIAL CONSIDERED IN THE ANALYSIS

Forest residues encompass an enormous quantity and variety of material. Virtually all of it is physically suitable at least as a raw material to manufacture reconstituted wood products or as a source of fuel. The major consideration in the increased use of forest residue is the cost of delivering the material to plants capable of utilizing the wood fiber.

The most available portion of the forest residue resource both physically and economically is that material which can be harvested in conjunction with conventional logging operations. The emphasis in this analysis was, therefore, placed on the logging residue component. Logging residue itself includes a varied amount and condition of material, ranging in size from branches and twigs to the boles of large snags, and in condition from sawlog quality material to unsound material with crumbly rot.

The focus of the analysis was further limited to logging residue that is both sound enough and large enough to be handled in conventional logging operations. This includes dead material, both standing and down, that has no defect, that has sound defect, or that has solid rot, as well as green material that is not of sawlog quality.

The minimum piece size was originally set at 8 feet (2.4 meters) in length and 3 inches (7.6 centimeters) in diameter, and then further restricted to a minimum piece size of greater than 2 cubic feet (.057 cubic meters). This was done because it was apparent from a preliminary analysis that the cost of removing material smaller than 2 cubic feet far exceeds the potential value of that material.

THE BASIS FOR THE ANALYSIS: PREVIOUS WORK AND TIMBER HARVEST DATA

Benson and Schlieter have developed estimates of the volume of residues in old growth stands for the major forest types in the northern Rocky Mountains. Withycombe has developed a model for estimating the cost of harvesting and delivering forest residues to plant sites in the northern Rocky Mountains.1/

A computer program developed with the assistance of Jim Ullrich, of the University of Montana Computer Center, has made further analysis possible. It uses both the forest residue data and the cost model in conjunction with site specific timber harvest information to estimate the volume and type of logging residue which can be delivered to a designated manufacturing center at various price levels.

1/ See Robert Benson and Joyce Schlieter, "Volume and Characteristics of Forest Residues in the Northern Rocky Mountains," and Richard Withycombe, "Application of a Cost Model to Northern Rocky Mountain Residues," in this publication of the proceedings.

The development of site specific timber harvest information involves the site by site construction of the timber harvest activity in a potential supply area for a so-called future typical year. The site specific information includes:

1) merchantable volume harvested by species;
2) method of removal (either by cable yarding or ground skidding);
3) the average skidding or yarding distance for each site, and
4) the haul distance to the manufacturing center.

Benson and Schlieter's residue volume data are used to develop factors to estimate from green merchantable volume the volume of the residue generated, classified by its condition, and its potential use for each site. The material is then further divided into categories according to piece size. Withycombe's cost model is used in conjunction with the timber harvest information, to estimate the cost of delivering the residue. The site-by-site data are then summarized for the supply area and the volumes can be sorted by cost and type of residue material for analysis.

The area selected to begin the study was Lincoln County in northwestern Montana, with Libby as the designated manufacturing center. The study was initiated in Lincoln County for a number of reasons, but primarily because it is a high timber producing area with a highly developed forest products industry -- in fact, Lincoln County is the highest timber producing county in the state. Because of the harvest level and predominant forest types, large volumes of logging residue are generated annually in Lincoln County, much of which remains unutilized and at present, uncommitted.

IDENTIFICATION OF THE POTENTIAL SUPPLY AREA

The potential supply area for Libby was designated as the timber supply area for the primary wood products manufacturers currently operating in Lincoln County. The reader should keep in mind that the supply area was defined somewhat arbitrarily and though it does offer the potentially cheapest logging residue available, it was established irrespective of the annual volume requirements of a potential user. If the evaluation were for a sulfate pulp mill, the supply area would have to be expanded considerably. In fact, it might be advisable to expand the supply area for plants with considerably lower raw material requirements, rather than use the more expensive logging residue material from within the supply area. For example, logging residue with a piece size of 100 cubic feet (283 cubic meters) that is hauled 100 miles (161 kilometers) might very well be cheaper to use than a 3 cubic foot (.085 cubic meter) piece hauled only 10 miles (16 kilometers). This paper deals only with the designated supply area. In the overall analysis the potential for drawing from an expanded area will also be evaluated. The supply area for the analysis encompassed much of Lincoln County and parts of adjacent counties in Montana and Idaho with a maximum haul distance of approximately 100 miles (161 kilometers).

THE DEVELOPMENT OF THE TIMBER HARVEST DATA

The annual timber utilization for all mills in Lincoln County in recent years has been slightly less than 200 million board feet, Scribner (979 thousand cubic meters) of timber. Of this material approximately 90 percent came from two sources -- from national forest lands, specifically the Kootenai National Forest and fee simple lands of the St. Regis Paper Company. Both the St. Regis Paper Company and the Kootenai National Forest provided us with detailed timber harvest and sale information.

The Forest Service timber harvest data were obtained from timber sales for calendar year 1978. The St. Regis Company data were from actual removals for 1978. The remainder of the harvest was estimated based on data from the above two sources.

RESULTS

Within the supply area as defined earlier an estimated 190 thousand cunits (537 thousand cubic meters) gross scale volume of logging residue would be available annually to Libby, Montana, from the designated supply area, at a cost of about $7.5 million in 1978 dollars (table 1). This represents an average cost of about $39 per cunit ($13.78 per cubic meter) delivered to Libby.

The volume figures in this analysis are expressed as gross in-woods volume. Estimates of loss due to breakage and defect range from 25 to 50 percent of this gross scale volume for logging residue. Preliminary estimates indicate that given this level of loss for breakage and defect, the cost per cunit for the net utilizable volume delivered will be approximately 50 percent higher than the costs indicated in this analysis.

The utilizable portion of logging residue was divided into three categories based on potential end use as follows:

1) material with no defect -- sawlog quality material
2) material with sound defect -- material suitable for some solid products such as house logs
3) material with solid rot -- material suitable only as a source of wood fiber but sound enough to be handled in a conventional logging operation.

All of the material is of course actually suitable as a source of fiber. However, the solid product uses of the no defect and sound defect material generally represent a higher value use.

An estimated 67 thousand cunits (190 thousand cubic meters) of no defect or sawlog quality residue would be available annually at an average cost of $46 per cunit ($16 per cubic meter). The sound defect category included an estimated annual volume of 33 thousand cunits (93 thousand cubic meters) of logging residue with an average cost of approximately $43 per cunit ($15 per cubic meter). The largest volume is in the solid rot category with an estimated annual volume of 90 thousand cunits (254 thousand cubic meters) available at approximately $33 per cunit ($12 per cubic meter).

The difference in average delivery cost among the three categories is due primarily to different piece size distributions in each of the categories. As indicated earlier, the total volume estimates and cost per cunit in all categories were calculated based on gross scale volume. Depending on the desired end use, the net scale volume of the material delivered would be somewhat lower and the cost per unit of utilizable wood fiber would be somewhat higher.

The figures shown in table 2 represent average cost figures. Because of the wide variation in not only piece size of the material, but also in the other factors contributing to the cost of delivery, there was quite a wide range in cost for each cunit composing the 190 thousand cunits (537 thousand cubic meters). In fact, the per cunit costs ranged from just under $15 per cunit to several hundred dollars per cunit with cost per cubic meter ranging from about $5 to in excess of $200.

Table 3 gives a much more detailed breakdown of the estimated volume of material that can be delivered to Libby from within the supply area. One of the things the computer model made possible was the identification of the volume of material which could be delivered to a plant in Libby for various ranges of costs. The cost ranges

Table 1.--Estimated logging residue available annually to Libby, Montana

TOTAL VOLUME (cunits)	190,000 cunits	537,000 cubic meters
TOTAL DELIVERY COST IN ROUND FORM (1978 Dollars)	$7,500,000	$7,500,000
COST (1978 Dollars)	$ 39 per cunit	$14 per cubic meter

Sources: Derived. Based on unpublished data from Robert Benson, Research Forester, Intermountain Forest and Range Experiment Station, Missoula, Montana; Richard Withycombe, Bureau of Business and Economic Research, University of Montana, Missoula, Montana; and the Kootenai National Forest and St. Regis Paper Co., Libby, Montana.

Table 2.--Average harvest and transportation cost of logging residue, by type, Libby, Montana

	RESIDUE VOLUME (000 cunits)	RESIDUE VOLUME (000 cubic meters)	AVERAGE DELIVERY COST per cunit	AVERAGE DELIVERY COST per cubic meter
No Defect	67	190	$46	$16
Sound Defect	33	93	43	15
Solid Rot	90	254	33	12
Total	190	537	39	14

Sources: Derived. Based on unpublished data from Robert Benson, Research Forester, Intermountain Forest and Range Experiment Station, Missoula, Montana; Richard Withycombe, Bureau of Business and Economic Research, University of Montana, Missoula, Montana; and the Kootenai National Forest and St. Regis Paper Co., Libby, Montana.

Table 3.--Volume of logging residue available, by type and by delivery cost category, in thousands of cunits

Cost Range	Residue Type: No Defect	Sound Defect	Solid Rot	Total
$ 0 - $10.00	0	0	0	0
$10.01 - $20.00	16	5	33	54
$20.01 - $30.00	21	14	32	67
$30.01 - $40.00	5	3	8	16
$40.01 - $50.00	7	3	6	16
$50.01 -$100.00	13	6	8	27
$100.01 and over	5	2	3	10
Total available	67	33	90	190

Sources. Derived. Based on unpublished data from Robert Benson, Research Forester, Intermountain Forest and Range Experiment Station, Missoula, Montana; Richard Withycombe, Bureau of Business and Economic Research, University of Montana, Missoula, Montana; and the Kootenai National Forest and St. Regis Paper Co., Libby, Montana.

used here are per cunit costs of $0-$10; $10-$20; $20-$30; $30-$40; $40-$50; $50-$100; and over $100 per cunit. The figures in the various cells are in thousands of cunits. The metric equivalents are shown in table 4.

For example, based on this analysis, no logging residue material of any kind is available to Libby for a cost per cunit of less than $10. For a cost per cunit of between $10 and $20, 16 thousand cunits of no defect material, 5 thousand cunits of sound defect material, and 33 thousand cunits of solid rot material would be available from within the supply area. Again, for between $20 and $30 per cunit, an additional 21 thousand cunits of no defect material, 14 thousand cunits of sound defect material, and 32 thousand cunits of solid rot material, and so on, would be available.

The high proportion of the total volume of the three residue types available in the lower cost categories (under $50 per cunit) seems to offer some encouragement for the increased utilization of logging residue material. Again, however, the reader should be aware that volumes are expressed in gross scale volume and may underestimate the cost per cunit of utilizable fiber by 50 percent. In the course of the overall project a major emphasis will be placed on expressing these volumes and the related costs per unit volume in units of utilizable wood fiber.

Table 4.--Volume of logging residue available, by type and by delivery cost category, in thousand cubic meters

	Residue Type			
	No Defect	Sound Defect	Solid Rot	Total
$ 0 - $3.53	0	0	0	0
$ 3.54 - $7.07	46	14	92	152
$ 7.08 -$10.60	59	40	91	190
$10.61 -$14.13	14	8	23	45
$14.14 -$17.66	20	8	17	45
$17.66 -$35.33	37	17	23	77
$35.33 and over	14	6	8	28
Total available	190	93	254	537

Sources: Derived. Based on unpublished data from Robert Benson, Research Forester, Intermountain Forest and Range Experiment Station, Missoula, Montana; Richard Withycombe, Bureau of Business and Economic Research, University of Montana, Missoula, Montana; and the Kootenai National Forest and St. Regis Paper Co., Libby, Montana.

A DEMONSTRATION OF A POTENTIAL APPLICATION OF THE COST MODEL

This section will focus on the solid rot logging residue to demonstrate how this analysis might be used. Table 5 includes an incremental and cumulative analysis of the solid rot logging residue material from within the designated supply area (Table 6 is the metric equivalent).

Column 1 again is composed of cost categories. Column 2 is the volume deliverable in thousand cunits in the various cost categories, and column 3 is the average per cunit cost of delivering the material in each cost category. Column 4 represents a cumulative total and illustrates what cumulative volume of material would be available at a cost equal to or less than the upper limit of the designated cost category. For example, for $20 or less per cunit, 33 thousand cunits are deliverable from the supply area; for $30 or less per cunit, 65 thousand cunits are available, and so on.

The fifth column represents a weighted average cost per cunit for the cumulative volumes. In other words, the average cost per cunit of delivering the 65 thousand cunits available for less than $30 a cunit is $20.

Table 5.--Incremental and cumulative analysis for solid rot logging residue

Cost Category	-- Incremental Analysis -- Volume (000 cunits)	Cost per cunit	-- Cumulative Analysis -- Volume (000 cunits)	Average Cost per cunit
$ 0 - $10.00	0	$ 0	0	$ 0
$10.01 - $20.00	33	17	33	17
$20.01 - $30.00	32	24	65	20
$30.01 - $40.00	8	35	73	22
$40.01 - $50.00	6	45	79	23
$50.01 -$100.00	8	65	87	27
$100.00 and over	3	191	90	33

Table 6.--Incremental and cumulative analysis for solid rot logging residue

	-- Incremental Analysis -- Volume (000 cubic meters)	Cost per cubic meter	-- Cumulative Analysis -- Volume (000 cubic meters)	Average Cost per cubic meter
$ 0 - $3.53	0	$0	0	$0
$ 3.54 - $7.07	92	6.00	92	6.00
$ 7.08 -$10.60	91	8.48	183	7.07
$10.61 -$14.13	23	12.36	206	7.77
$14.14 -$17.66	17	15.90	223	8.12
$17.67 -$35.33	23	22.97	246	9.54
$35.34 and over	8	67.49	254	11.66

This model might aid a firm in making several kinds of decisions. The following examples have been chosen to illustrate potential applications of the model.

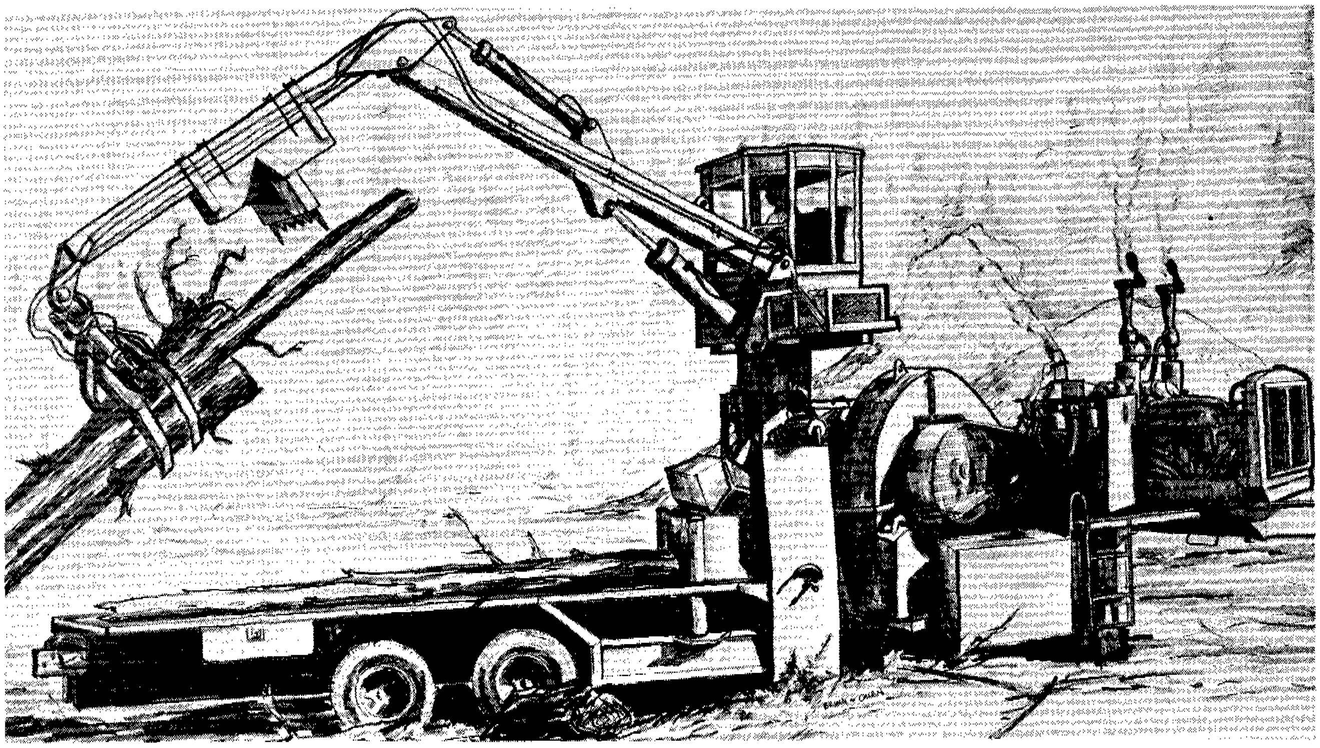
The first case assumes that a firm currently operates a power plant which allows some flexibility in the fuel mix; an example, would be one based on a solid fuel system that allowed the substitution of forest residue for a more conventional fuel such as coal, in greater and greater increments. In this case the firm would use the incremental cost analysis to evaluate the rate at which forest residue might be used as a fuel in place of a portion of the coal. If, as a substitute for coal, forest residue were worth more than $17 per cunit, the firm might consider using those first 33 thousand cunits and providing the remainder of its fuel needs with coal. If the cost of coal rose enough that as a fuel, forest residue were worth in excess of $24 per cunit, the firm would consider substituting the additional 32 thousand cunits with a marginal cost of $24 per cunit, and again providing the remainder of its fuel needs with coal.

A firm might also be faced with the decision of building a fuel generating facility for its plant. The cost of more conventional fuels would allow the firm to pay so much per cunit for forest residue as a fuel in a wood fired boiler -- let us say now $20 per cunit delivered in round form. This is a figure which, given recent and projected increases in the price of natural gas and fuel oil, is not at all unreasonable. The question facing the firm would then be whether sufficient quantities of forest residue were available at an average cost of $20 per cunit to supply a facility of this type. We see from our weighted average price that an estimated 65 thousand cunits of suitable material would be available annually from the supply area, for a weighted average price of $20 per cunit. This would be enough material to supply a rather substantial industrial fuel system.

The same type of analysis would, of course, be possible with the other types of logging residue. For example, this procedure could be used to determine what stumpage price and cost of green sawlogs would warrant adjustments in a firm's facilities, or investment in new facilities to use more dead material.

The model described here will have a number of potential uses. One of the major objectives for this model's development is to make possible broad range estimates of the volumes of forest residue available to processing centers throughout the northern Rocky Mountain area for various delivery costs.

In addition, the model is being constructed so that it can be easily adapted to facilitate more precise estimates of residue cost and availability on a localized level. The model is structured so that the cost factors and the residue volume factors can be modified to conform to local situations, and any suggestions for modifications to fit more localized cost and supply situations would be greatly appreciated.



HARVESTING OPPORTUNITIES

Wood residues on logged areas continue to create significant management and protection problems. YUM yarding, piling, burning, and other disposal activities are being practiced daily by timber operators and land management agencies. The most promising approach to utilizing this residue resource is through more efficient harvesting systems and practices, capable of recovering more of the total fiber resource at time of initial harvest. With few exceptions, relogging to recover material left as residue is neither technically nor economically attractive.

Research in improved harvesting system efficiency has taken two directions: (1) evaluation of the efficiency of existing systems when used to achieve close utilization standards, and (2) development of new harvesting systems and practices better suited to smaller, lower-value material. Research reported in this section includes field tests of conventional systems under a wide variety of Rocky Mountain timber conditions and operating situations; development of in-woods processing alternatives; and development of new concepts in harvesting technology.

The costs of recovering residue material constitute a primary barrier to improved utilization. The development and application of harvesting techniques that are physically and economically more efficient is a critical need. The research reported here, and continuing research of the same nature, addresses that need.

HARVESTING EFFICIENCY--A HISTORICAL PERSPECTIVE

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ABSTRACT

Many significant and far-reaching changes have taken place in the logging industry since its inception in the mid-17th century. But technological advances aimed at improved timber utilization have not come about quickly. It has been an incremental and continuous process, but progress can often be noted only by looking backward.

KEYWORDS: logging, harvesting, history

Although historical documents do not reveal the exact time, man probably began using wood at or about the same time he developed a taste for apples--no doubt first as a tool and shelter and later as a raw material for refined, durable goods. Why? Because wood, millions of years ago, had the same desirable qualities as it has today. Namely, it produces heat when burned, it is easy to work, its strength/weight ratio is excellent, and it is renewable. Because of my admiration and respect for loggers of all eras, please note I did not say wood was easy to obtain.

"Harvesting" of timber is a term applied to many sequential activities. It begins with the designation of what timber is to be removed and what is to be left and ends with reforestation. The actual cutting of timber and its movement from the woods to the mill is one of the harvesting activities. This I refer to as logging--and it is the activity at which most of my comments will be aimed.

Because many changes have been made in logging equipment and techniques, I think it is proper for us to pause at this time and look back, if for no other reason than to allow a redefinement of perspective. Many years ago, a farsighted individual named Renan predicted "that the 20th century will spend a great deal of time picking out of the wastebasket the values the 19th century threw into it." So during the next few minutes, let's take a look through the logger's wastebasket.

When the United States formally declared its independence, our country consisted of 13 States, many more wild animals than people, and seemingly limitless tracts of forests. Philadelphia was the largest city, with 34,000 people. Nine out of 10 new Americans lived in the country, scattered along the eastern seaboard from Maine to northern Florida. Yet, because of the high birth rate and large influx of immigrants from the Old World, the population of both town and country was increasing rapidly.

Still, in 1776 the original states contained mainly expansive wilderness and very few farms. To the colonists, vast eastern forests of more than a million square miles represented a dark and impenetrable place that harbored wild animals and "dangerous" Indians. But these colonists were determined and tough. They would remove this obstacle and then plant their crops. True, they used trees for ships, houses, fuel, tools, etc., but there were more than they could use. They had to "let daylight in," and this they accomplished with unrelenting determination.

Most settlements had a "lumbering" industry because of the abundance of timber, but these were on a small scale, used primitive methods, and supplied mainly local needs. In the beginning, logs were split with a froe or sawn on a pitsaw.

Supposedly, the first power-driven sawmill in America was established in 1633. Depending on which book you read, it was in Maine, New Hampshire, Pennsylvania, New York, or Virginia. The number of sawmills grew quickly. Most were waterpowered and were therefore located along streams which also provided transportation for the logs. Soon, gangsaws were developed that could cut many more logs per day and the problem of keeping logs at the mills arose.

Because of increasing populations and growing export markets, lumbering became a rapidly expanding enterprise. By 1682, Maine alone had 24 sawmills. Consequently, logging operations had to expand as well to keep the mills supplied with logs.

The lumbering industry as we know it today began in the Northeast. White pine was the "king tree." Almost all of the northeastern states had an apparently never-ending supply of this great species, but the region we know as Maine today was particularly suitable for large-scale commercial logging. This was because of the desirable combination of uninterrupted expanses of timber and the preponderance of rivers and streams to float logs to the mills.

Men with money and vision began buying up timberland in Maine. Much of it was purchased at the rate of 12.5 cents per acre. It is reported that a Philadelphia banker and politician by the name of William Bingham purchased 2.1 million acres of pine and spruce in one tract in the Penobscot country in 1790.

Immigrants from Scotland and Ireland as well as skilled French-Canadians provided the bulk of the manpower needed to cut and move this timber.

The method of logging was pretty much standard. It was called "white water logging." With the coming of the "fall freezeup," small armies of loggers took to the woods. Logging camps were located up the streams from the mills. Trees were felled with axes and bucked to length with crosscut saws. The logs were then manhandled onto a crude skidding device called a go-devil to yard to the main road. The go-devil was a section of a forked birch that had a crosspiece fastened midway of the V; it was pulled by a team of horses. At the main road, the logs were loaded with the help of gravity onto sleds and pulled by oxen to the streambank. Throughout the bitter cold winters, sled loads of logs were hauled to the river's edge and stashed there in gigantic piles. To make the sleds move with greater ease, water was sprinkled on the snowpacked road during the night. By morning it was frozen hard and slick. Snubbing lines attached to stumps were used to slow the sleds when going down hills.

Although the bitter cold and deep snow provided miserable working conditions, winter logging was conventional for many years. Available technology permitted few options.

When spring finally arrived and the streams began flowing, the piles of logs were pushed into the rushing waters by loggers with long, steel-tipped pike poles. Thus began the spectacular log drives downstream to the mills. Along the way the logs would inevitably jam and have to be freed by the daring drivers. This was one of the most dangerous jobs of the white water logger. Yet most survived the drives to "blow in" their wages of about $20 a month in the mill towns where wine, women, and song were always in plentiful supply.

The basic tools and equipment used in early logging consisted of the ax, one-man crosscut saws for bucking, sleds, a type of cant hook, and pike poles. Power was supplied by man, oxen, and horses aided by gravity.

Axes have been in use since the stone age--but refined over time into finely balanced and very effective tools.

Saws are of more recent times, although used in Europe as early as the middle of the 15th century. Crosscuts became widely used in this country in the early 1800's. Almost all of them were manufactured in America because imports from Europe were expensive and difficult to obtain. Crosscut saws increased log production considerably and reduced wood losses from chips previously produced by axes. For reasons difficult to imagine, until 1880 saws were used for bucking only. Why it took 40 years for fallers to realize that saws could be made longer and used by two men to fell a tree is not understood. But when axes gave way to felling saws, production climbed with a resultant decrease in safety hazards. The direction of fall of a sawn tree was more predictable than a tree felled with an ax. The ax was still used to put in the undercut.

Several tools and devices that made logging easier, safer, and often more productive were invented and put into use in the Northeast. The Peavey was invented and first manufactured by Joseph Peavey near Bangor, Maine, in 1858. A large boom for sorting logs was devised in 1825, and this idea has been used widely. The Bangor snubber, a device for controlling the speed of sled loads of logs on steep hills, was invented by Bangor men sometime in the 1830's. In the late 1800's, sluiceways and steampowered conveyers were introduced that speeded log delivery to mills tremendously.

It must be mentioned that new developments in logging practices were often spurred by new developments in milling and processing techniques. As the mill capacity increased, more logs were needed. This is still true today.

The first real increase in lumber production came with the first steampowered sawmill. The Bath Steam Mill Company of Bath, Maine, supposedly built its first mill in 1821. By 1850, 36 steampowered sawmills were in operation in the State of Maine.

The development of the circular saw greatly increased production over the old sash or up-and-down saws. They were in wide use in Maine by the middle of the 1800's. Saw filing became an art shrouded in secrecy. Gang-saws that used 20 and more blades on the same rig soon appeared on the scene, again to boost production at the mills.

Each of these innovations increased the appetite of the mills--one that had to be satisified--and the loggers would do it!

After about a century of intensive logging, it became obvious to most lumbermen that the forests of Maine were really not inexhaustible. Enterprising people began looking around for new timberlands as early as the 1830's. Some operations were moved to upstate New York and western Pennsylvania, where lumbering was already proceeding at a rapid pace. The Erie Canal, which was completed in 1825, would subsequently move thousands of loggers westward and millions of feet of lumber eastward. Albany, New York, was the biggest lumber market in the world for 40 years.

The expansion of the logging frontier continued westward until its next major stop in the vast white pine forests surrounding the Great Lakes.

This migration from the Northeast had its beginning in 1836 with the purchase of a tract of timberland on the St. Clair River in Michigan. The purchaser was Charles Merrill of Lincoln, Maine. Many more such purchases were soon made by eastern lumbermen--all at the going rate of $1.25 an acre for public domain lands.

The timber in the Lake States was bigger and thicker than anything ever seen in the East--surely more than could be cut in 1,000 years. And these were great streams for driving logs--the Saginaw, An Sable, the Bad, the Rifle, etc. Plenty of snow, too, for winter logging, still the conventional way.

The first sawmills were established in the Lake States about 1832, but the region did not become the center of lumbering activities until after the Civil War. By 1870, the Lake States became the leader in lumber production and remained so until 1900 when the South took over. By the early 1880's there were 112 mills along the Saginaw River, cutting a combined total of slightly more than a billion board feet of lumber annually.

The demand for lumber was constantly increasing, pushed upward by the rapidly rising population in America. Between 1820 and 1870, the United States population quadrupled. Thus, the associated demands for forest products and new homes had risen in priority to those for export products such as ship masts and staves.

Again, technological advances in sawmilling led to demands for more logs. Lumber making in Maine had been slow compared to that of the Lake States. Although a bandsaw had been invented in England in the early 1800's, it took 75 years for it to reach America. The first bandsaw headrig appeared in the Lake States in the 1880's. This saw could easily outproduce the old circular saws and, in so doing, left less sawdust.

Other developments followed to complement the bandsaw. Log handling devices that loaded logs onto the carriage and the bull chain that moved logs from the log pond to the mill were developed by Michiganers. The log pond was rendered ice-free by running steam lines from the mill into the pond. Now mills could cut all winter.

People with inventive abilities had a field day. Someone devised a rig known simply as "the big wheels." This was a pair of wooden wheels, each 10 feet in diameter, set on an axle connected by a long tongue or pole. A log was straddled by the big wheels and chained to it. When the pole was pulled by oxen or horses, the front end of the log would be lifted slightly off the ground. This became the first wheeled skidder. Roads were not needed because the axles had sufficient height to clear stumps, rocks, etc. The biggest effect was to make summer logging practical. If the mills would work all winter, then the loggers would work all summer.

All of these increased activities and new processing developments hurried things along in the woods as well, for it was the logger's sole job to keep the log ponds at mills full of logs.

Logging activities in the Lake States started in lower Michigan, moved to the upper peninsula, to Wisconsin, and finally, to Minnesota.

Winter logging was conventional in the Lake States, also. Sleds were the primary means of moving logs from the woods to the streams. A common load for one sled drawn by a team of horses was 60,000 pounds. Stewart Holbrook describes a fantastically large sleigh load of logs in his book entitled "Holy Old Mackinaw." The load was put together in northern Michigan to show off at the Columbian Exposition of 1893 held in Chicago. The load, made up of logs 18 feet in length, was 33 feet 3 inches high and scaled 36,055 board feet. One team of horses pulled it with ease from the woods to the shipping point, but it took nine railroad flatcars to move the logs and sleigh to Chicago.

Logging camps expanded rapidly in size and number of workers. Unable to hire enough workers from local areas or the Northeast, thousands of Canadians from the maritime provinces were recruited by the timber barons. They also imported Scandinavians from Norway, Sweden, and Finland with great success.

Conditions improved in logging camps, also, with a resultant increased output of logs. Camps became cleaner; hence, less sickness and disease. Above all, the variety and quality of the food improved steadily. Good cooks became almost as important as good bosses. The introduction of canned foods helped greatly to improve the bill of fare. The number of items in the camp stores steadily expanded to provide loggers with their needed personal items.

Railroad logging came to Michigan in the 1870's, but the early locomotives were practical only on fairly level ground. The first successful logging railroad in the United States was the Lake George and Muskegon River Railroad built in 1876-77 in Michigan. Reportedly, there were 89 logging railroads running more than 450 miles of track in Michigan by 1889.

The year 1881 brought two highly significant developments to the logging industry. In this year new technology that utilized steam revolutionized logging forever. Steampower had been used at sawmills for 40 years, but loggers still depended on brute force provided by man or animal, water, or gravity to move logs.

Now in 1881, Ephraim Shay of Michigan developed the steampowered, gear-driven, railroad locomotive. With the advent of the railroad, sawmills were located inland along the rail lines. The railroads provided transportation for the lumber and made possible the expansion of Lake States logging into Wisconsin and Minnesota.

And out in the West, a Californian named John Dolbeer invented the steam donkey. Horses and oxen could rest at last. The donkey, with first rope on its capstan-like drums and later wire cable, was used to yard and load logs. Both the donkey and the locomotive served as the power of the forests until gradually replaced by the internal combustion engine.

Maine loggers were still contributing to logging progress. In 1886, Horace Butters, then living in Ludington, Michigan, invented the Horace Butters' patent skidding and loading machine. This gigantic and complicated system was the fore-runner to cable logging rigs used today in more refined forms. Butters' setup consisted of two spar trees with guy ropes and a trolley strung between the spars. A carriage was pulled along the trolley by a line from a steam donkey. Logs were lifted out of the woods and pulled to one of the spars. There, another donkey and rigging loaded them onto railroad cars. This skidding device never really caught on in the Lake States, but it was used effectively in the South to log the bayous, and it was used extensively in the West in various forms and configurations.

Lumbering in the Lake States continued at a frantic pace until the turn of the century. Chicago was the center of lumber merchandising and use. Immense quantities of wood were needed to rebuild Chicago after the disastrous 1871 fire.

Then, as it happened in the East, the magnificent stands of white pine were exhausted, and it was again time to move on--this time to the South and to the Far West. About one-fourth of the migrating loggers from the Lake States moved to the South; the rest went West.

Lumbering activities had been underway for some time in the South and in the West, but at fairly low levels of intensity. Accelerated logging in the vast pine forests of the South began in the 1870's. Soon after the Civil War, several sawmills were built along the Gulf Coast. Mobile, Alabama, became a major lumber port. Since the South was already settled and populated, a local labor supply was already available.

Only the most accessible places in the South were logged at first. Techniques used were much the same as in the Lake States. Rivers and ditches were used to float and move logs to the mills. Oxen pulled logs, hooked together or on carts, to these waterways.

The coming of the railroad opened up markets in the North for southern pine lumber. Lumber production rapidly increased throughout the South. The region supplied 39 percent of the total United States production in 1900; in 1920 this jumped to 52 percent.

Timber production in the South was different from that in the East and Lake States. Because of comparatively rapid growing conditions, second-growth stands succeeded the virgin stands in a relatively short time. This, coupled with excellent protection and other intensive management practices, accounts for the fact that the South today still produces about 30 percent of the Nation's lumber.

Logging and sawmilling began on a limited scale in the Northwest some time in the late 1820's. Lumber was first sawn on pitsaws powered by two men at the rate of 150 board feet per day. Later, a mechanical saw powered by water produced 3,000 feet per day.

California began producing some redwood lumber a few years later, but West Coast logging remained at a low level because a substantial local market for lumber did not exist. No more than 25,000 people lived along the entire West Coast in 1847. To the East there was only wilderness for some 2,000 miles.

The market problem was solved in 1848 with the discovery of gold--appropriately enough at a sawmiller's site in California's Sierra foothills. The migration of people from around the world to mine the gold created a demand for wood far above the local wood producers' capability.

Sawmills and logging operations quickly sprang up along the California coast and on up to Oregon and the Puget Sound in Washington. The methods were crude at first, but steady progress was made, and new developments such as the circle saw and steampower were eagerly adopted. With soaring demands for lumber and increasing mechanization, logging operations were conducted in all seasons of the year.

The opening of transcontinental railroads to Portland in 1882 and across the Cascades to Puget Sound in 1887 again greatly expanded the markets for western lumber. By 1880, western producers were cutting about 700 million board feet per year.

The Indians along the northwest coast of Washington and in southern Oregon were the first loggers to cut timber in these regions. They used the huge cedars, spruces, and pines to build canoes and large cargo boats.

The gigantic western conifers presented new challenges to the western loggers' ingenuity. A single fir tree could be 10 feet in diameter and weigh 100 tons. Redwoods and cedars were much larger.

At first, hand logging was done, but this was feasible only where trees grew next to rivers or streams. It was also slow and backbreaking. Oxen were later used to skid strings of logs to streams. Big wheels pulled by oxen were used on somewhat flat, dry land. Various kinds of chutes and flumes were devised to move logs down the hills.

The skidroad came into use on the Puget Sound in the early 1850's. This was a wide, well-engineered and cleared trail over which strings of logs were skidded by oxen and horses. Skids made from thick timbers laid crosswise on the trail like rail ties reduced the drag of the logs. Grease was applied to the skids to make the going easier. Effective as it was, the skidroad could not be used on hills too steep for oxen nor at greater distances than what the animals could endure.

The term skidroad later took on another meaning. When used as two words, both capitalized, Skid Road referred to the streets in any logging town that were brightly lit and lined with saloons, honky-tonks, restaurants, and lodging houses. This was the place the loggers went to "blow 'er in" after the long months in the logging camps. The term was eventually changed to Skid Row by some unknowing writer.

The log chute was the first device that enabled the loggers to reach up onto the steep slopes for the large, quality timber. Furthermore, it did not demand sheer muscle power from men or beasts. Gravity did most of the work. Chutes were basically long troughs made from peeled trees. The inside surface was generally greased to ease the movement of the logs. A chute built above the Klamath River in Oregon was 2,650 feet long and reportedly carried logs at speeds up to 90 miles per hour.

Flumes were also used, although mainly for lumber. They were made of lumber to carry sawn boards to the bottom land for shipping or reloading. Flumes were much longer than chutes--sometimes 40 or 50 miles. They were really small manmade rivers, since moving water was used to carry the lumber.

But it took the steam donkey and the Shay locomotive to get western logging highballing. With the coming of improved wire cable in the 1890's, the steam donkey was used to lift, pull, and haul logs in just about any imaginable configuration. Dolbeer's donkey was, of course, the necessary ingredient for successful ground-lead logging. It also spawned the development of high-lead logging which required spar trees and a daredevil high climber.

The steam donkey had a definite economic effect on logging. Skidding costs on one operation along the Columbia River reportedly dropped from $4.50 to $2.10 per thousand board feet when donkeys were used instead of oxen. Production almost doubled when the high-lead took over.

Commercial logging came to the Inland Empire in the mid-1840's. The importance of this region was based on the production of western white and ponderosa pine. The first mill on record in Idaho was built in 1840 at Lapwai. It primarily supplied the growing lumber needs of the mining industry.

The first mill reportedly built in Montana was at Stevensville in the late 1840's. These were combination gristmills and sawmills powered by water. Logging methods were similar to those used in the Lake States. Logs were hauled by animals to stream banks and floated down to mills in the spring. On more level land, big wheels, which were the forerunners to the more improved skidding arches and log flumes were used. Steam donkeys combined with locomotives accelerated the logging pace near the turn of the century.

The pine loggers of the Inland Empire were again prodded by the sawmillers. Someone filed teeth on the rear edge of a bandsaw blade so it cut when moving both forward and backward. The double cut band increased production noticeably and other equipment in the mill was streamlined to keep pace.

The logging and milling of pine developed rapidly. Lumber production in Idaho went from 65 million feet in 1898 to 500 million in 10 years. Loggers watching the highballing movement of logs on a high-lead setup were certain this level of mechanization would never be exceeded. But it wasn't long before someone put up two spars and skyline yarding was born.

Further developments revolutionized logging again and again. The application of the internal combustion engine to the woods in the 1920's spelled doom to the steam donkeys and locomotives. First, gasoline, and later, diesel engines, gradually took over the role steam had played so effectively. Mobile wheeled and track-type tractors became common and proved to be very efficient in skidding. Diesel-powered trucks pulling highly maneuverable log trailers came into use. They could go almost anywhere when combined with modern road-building equipment and techniques. Winches with wire rope were added to the tractors as a further refinement.

About this same time, the power saw was being developed by several different innovators. This proved to be the most important technological contribution to the logging industry since the steam donkey and the locomotive. They reportedly cut felling and bucking time in half.

The first power saws were steam operated, but electric saws came on the scene shortly thereafter. They were huge, heavy, and cumbersome, but improvements were continually being made. The earliest production saws with gasoline engines came from Germany, but this source dried up with the advent of World War II. The Titan 1/ saw, manufactured in Seattle, was supposedly the first power saw built in the United States. This was about 1940. Several followed closely, including Mall, Disston, McCullough, Lombard, and Homelite.

Extensive use of power saws began after the war and quickly retired the axes and cross-cut saws that had been the standard for so many years.

Log loading and unloading devices have been improved greatly over the years. Modern, self-propelled, hydraulic-powered machines now lift an entire truck or rail car load at one time.

1/ The use of trade, firm, or corporation names does not constitute an official endorsement of, or approval by the U. S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Rapid advancements have been made in the development of rubber-tired articulated skidders. With their great maneuverability, high clearance, and short turning radius, they have probably had the greatest impact on logging since the development of the chain saw.

The 1960's saw widespread use of felling shears, tree harvesters, and in-the-woods chipping. They continue to be used on relatively level ground and more extensively in pulp operations.

Cable yarding continues at a high level in the West and the Inland Empire. New, more sophisticated and smaller mobile yarders are becoming popular. Their use grows with increasing environmental concerns and the need for thinning overstocked stands.

Overall, giant strides have been made in recent years in the advancement of logging technologies. Helicopter and balloon logging is commonplace. Machines that cut, buck, delimb, and carry are in wide use, and fast-moving trucks haul large loads of logs to market on modern paved highways. And this is as it should be. A noted philosopher by the name of Bacon once said, "He that will not apply new remedies must expect new evils."

Now that we have looked back through the pages of logging history, we might properly ask, "have things really changed, or is it like the cynic said--'Change is something which is often identified with progress, like a woman moving furniture around, or an office manager shifting offices'?" In 1776, men were coping with the problem of how best to move logs from the woods to the mills. We're doing the same thing today. Maybe there is something to the cliche, "The more things change, the more they remain the same."

But there have been changes to be sure. The beginning and end result may be the same, but the ways of reaching it are quite different. Conditions have changed dramatically. Trees today are smaller than yesteryear--and they grow on some of the darndest places. Many of the logs brought in today would have been left in the woods as recently as 2 or 3 years ago.

Yet, changes have also occurred at the other end of the scale. Markets exist today for a much greater array of wood products than in earlier years. Opportunities for better utilization are arising. Pulp mills and particleboard mills, for example, use small roundwood of lower quality. Wood chips and sawdust are used widely to produce energy.

These are exciting times. New technology coupled with new markets and products provide the key.

The important thing to remember is that change is often not readily noticeable because it comes so slowly. It is usually an incremented and continuous process. It does not happen overnight. It is evolutionary many more times than revolutionary. Often we must look back to see progress. But it does occur with patience and perseverance and usually with everlasting beneficial effects.

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INTENSIVE UTILIZATION WITH CONVENTIONAL HARVESTING SYSTEMS

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ABSTRACT

Forest residues utilization research has included case studies of the efficiency of existing harvesting systems in achieving close fiber utilization. Field evaluations included the use of in-woods chipping systems in gentle terrain; crawler skidder systems in gentle terrain; and skyline systems in steep terrain. In each situation, utilization standards ranged from conventional saw log utilization to near-total utilization of available fiber.

Intensive utilization has been achieved concurrent with saw log harvesting, rather than through postharvest salvage. The total costs of harvesting merchantable material and residue together are partitioned to derive costs of residue recovery. Costs of recovery vary significantly among the case situations studied, and also vary with the method by which costs are allocated. Residue recovery costs commonly run \$30-\$60 per dry ton (\$33-\$67 per tonne).

KEYWORDS: forest residues, timber harvesting, wood residues utilization, logging systems, timber harvesting productivity.

THE HARVESTING TASK

Although timber harvesting practices have improved dramatically in recent years, large volumes of wood residues and salvable material remain unused in the Rocky Mountain area. More complete and efficient utilization of this resource poses a major challenge. National projections predict substantial continued increases in demand for wood and wood fiber-based products. Environmental considerations also favor extending the use of wood, a renewable natural resource that can be processed with less energy and less attendant pollution than alternate materials. Increasing interest in biomass fuels for supplementary power generation further emphasizes the undeveloped potential of the wood residue resource.

Excessive volumes of forest residues result in significant management problems: fire hazards, reduced wildlife use, degraded esthetic quality, difficult regeneration, and costly disposal. Harvesting and utilization practices that facilitate more complete use of these residues can help meet national needs for wood products and solve critical forest resource management problems.

Forest residues remaining on logged sites include small trees, cull and broken logs, tops, and dead timber. The most immediate opportunity to increase utilization of this material is to remove it in conjunction with conventional harvesting operations. A primary barrier to improving utilization, however, is the added cost of recovering residue material. Typically, the value of residues will not cover the costs of harvesting them. Harvesting systems and practices are needed that can more effectively and efficiently recover residue.

The residue utilization research program has included both the evaluation of existing harvesting systems and the development of new harvesting concepts for achieving close fiber utilization. This report covers the field testing and evaluation of harvesting systems in common use under various stand and terrain conditions and silvicultural systems encountered in the Northern Rockies.

EVALUATING EXISTING SYSTEMS

Recovering residue material with conventional harvesting systems, in conjunction with the harvest of merchantable material, offers potential advantages. Conventional logging systems are available, are in place, and involve no radical changes in technology. Further, they require no new or added capital investments, and no significant changes in job skills or training requirements. The costs of practicing intensive utilization with existing systems are largely unknown, however, as are the technical problems that may be encountered.

Research efforts reported here were directed toward defining costs of residue recovery with three conventional systems: skyline logging on steep terrain; tractor logging on gentle terrain; and in-woods chipping teamed with a ground skidding operation on gentle terrain. Because the silvicultural prescription has a significant effect on most harvesting costs, a range of silvicultural practices were included on two sites. Utilization standards for cutting units on each site included conventional saw log utilization and one or more intensive fiber utilization standards. Intensive utilization prescriptions specified the removal of material down to a defined size and quality class, and allowed the contractor to accomplish this jointly with removal of the "merchantable" portion of the timber. The three harvesting operations, and associated utilization standards, recovery, and costs, are described in following sections.

Skyline Harvesting--The Coram Site

The Coram study site is located on Coram Experimental Forest, on the Hungry Horse District of the Flathead National Forest. The site typifies old-growth western larch/Douglas-fir stands on steep slopes. Elevations range from 3,900 to 5,300 feet (1 188 to 1 615 m), and annual precipitation is in the 25- to 35-inch (64 to 89 cm) range. Western larch and Douglas-fir are the predominant tree species, although subalpine fir, Engelmann spruce, western hemlock, and birch also occurred in intermixture on the harvested units.

Steep slopes and operating constraints dictated the use of either aerial or cable yarding systems capable of relatively long reach (1,000 to 1,200 feet) (305 to 365 m) and at least partial suspension of logs being yarded. Skyline yarding systems were used--a running skyline system where both up- and downhill yarding were required (fig. 1), and a live skyline where uphill yarding alone was adequate. Silvicultural prescriptions included in the field tests, and the utilization standards practiced, are described in table 1.

Figure 1.--A running skyline system was employed on the Coram site to provide both up- and downhill yarding capability.

Table 1.--Harvesting treatment specifications for cutting units, Coram site

Silvicultural system	Cutting specifications	Utilization standards
SHELTERWOOD	All trees designated by utilization standard cut; approximately half the volume in 7"+ (17.8 cm) d.b.h. trees left, aiming for good height and species diversity.	(1) Conventional: logs to 8'x5½" (2.4 m x 14 cm) top, one-third sound, removed from all 7"+ (17.8 cm) d.b.h. trees cut, green and recently dead.
		(2) Intermediate: logs to 8'x3" (2.4 m x 7.6 cm) top, one-third sound, removed from all cut trees 5" (12.7 cm) d.b.h. and larger, and all standing and down dead timber.
		(3) Intensive: all cut green and recently dead trees 5" (12.7 cm) d.b.h. and larger removed tree-length; all green trees 1"-5" (2.5-12.7 cm) d.b.h. removed tree-length in bundles (FS crews cut & bundle); all standing and down dead timber 8'x3" (2.4 m x 7.6 cm) and larger removed if sound enough to yard.
GROUP SELECTION	All trees designated by utilization standard cut, in selected groups of 0.5 to 1.5 acres (0.2 to 0.6 ha) in size.	Same as (1), (2), and (3) above.
CLEARCUT	All trees designed by utilization standard cut.	Same as (1), (2), (3) above.

Six sale area blocks were logged, two under each basic silvicultural system. Each block was subdivided into treatment areas upon which the alternate levels of utilization were applied. Blocks were laid out to take advantage of existing and new system roads, and purposely included both up- and downhill yarding. Back-to-back yarding with the running skyline system allowed laying out the larger units up to 2,000 feet (609 m) in slope length. Utilization treatment areas designed for post-harvest broadcast burning were burned the season following logging.

Volumes of merchantable timber available for harvesting (table 2) ranged from 1,767 ft^3/acre (124 m^3/ha) in the conventionally logged shelterwood unit, to over 7,000 ft^3/acre (490 m^3/ha) in the group selection units. Volumes of nonmerchantable material included on intensively harvested units varied from 1,700 ft^3/acre (119 m^3/ha) to over 3,000 ft^3/acre (210 m^3/ha). Actual recovery of residue material, however, was generally no more than 25-50 percent of the gross volume potentially available. The remainder either did not meet the minimum size and condition specifications for removal, or was overlooked and left onsite.

Table 2.--Volumes of merchantable and nonmerchantable material available for harvest, and volumes of nonmerchantable material removed, under alternative treatment specifications, Coram site

Harvesting treatment	Volumes available for harvest				Nonmerch. volume removed
	Merchantable	Nonmerchantable			
		6"+ (15.2 cm)	3"-6" (7.6-15.2 cm)	<3" (7.6 cm)	
	Ft³/acre (m³/ha)				
Shelterwood:					
(1) Conventional	1,767 (124)	--	--	--	--
(2) Intermediate	2,299 (161)	734 (51)	966 (68)	--	425 (30)
(3) Intensive	2,057 (144)	813 (57)	918 (64)	48 (3)	906 (63)
Group Selection:					
(1) Conventional	7,083 (496)	--	--	--	--
(2) Intermediate	6,620 (463)	1,900 (133)	804 (56)	--	785 (55)
(3) Intensive	5,100 (357)	1,872 (131)	940 (66)	113 (8)	1,962 (137)
Clearcut:					
(1) Conventional	4,994 (349)	--	--	--	--
(2) Intermediate	5,520 (386)	2,408 (168)	631 (44)	--	860 (60)
(3) Intensive	3,515 (246)	1,702 (119)	530 (37)	23 (2)	783 (55)

Harvesting productivity and calculated costs of harvesting are described in table 3. The costs shown were developed on the basis of recorded production per hour and calculated system costs per hour. All turns yarded were scaled to determine the volumes of merchantable and nonmerchantable material produced per hour. Cost estimation was based on average industry costs (1974 dollars) for the equipment and crews being used.

Harvesting costs, such as the cost of a yarder and operating crew, can most conveniently be expressed per hour of operation. Other costs, such as the cost of felling and bucking timber, are commonly expressed per unit of volume produced. To develop a common base for combining costs, a "system cost per hour" was adopted. System cost per hour is comprised of the yarder and crew cost per hour, plus the costs of all other logging functions (fell, buck, bunch) required to produce the volume of material yarded in an hour. These costs can then be allocated against volume produced per hour in any desired fashion.

Table 3.--Harvesting productivity and calculated costs of harvesting, Coram site

Harvesting treatment	Yarder production/hour		Cost of hourly production			Total hourly cost	Cost per M bd. ft. merch.[1]	Cost per m^3, all volume
	Merchantable		Nonmerch.	Fell-buck-bunch		Yarding			
				Merchantable	Nonmerch.				
	Bd. ft.	*Ft^3 (m^3)*	*Ft^3 (m^3)*	Dollars (1974)					
Shelterwood:									
(1) Conventional	2,968	474 (13)	0 --	53	--	187	240	81	18
(2) Intermediate	2,355	379 (11)	114 (3)	56	17	187	260	110	19
(3) Intensive	1,267	204 (6)	488 (14)	31	91	187	309	237	15
Group Selection:									
(1) Conventional	3,276	524 (15)	0 --	59	--	187	246	75	16
(2) Intermediate	3,026	484 (14)	189 (5)	73	28	187	288	95	15
(3) Intensive	2,130	340 (10)	324 (9)	51	60	187	298	140	16
Clearcut:									
(1) Conventional	5,398	862 (24)	0 --	65	--	187	252	47	11
(2) Intermediate	4,654	745 (21)	134 (4)	74	13	187	274	59	11
(3) Intensive	3,138	506 (14)	100 (3)	50	15	187	252	80	15

[1]Total costs allocated to merchantable volume recovered.

Costs attributable to residue recovery (tables 4 and 5) can be calculated in either of two ways, depending upon the philosophy adopted. The first approach, illustrated in table 4, initially assigns all costs of harvesting to the merchantable saw log volume recovered (table 3). The differences in cost per M bd. ft. of merchantable volume between the conventional saw log units and the more intensively utilized units are ascribed to residue recovery (table 4). Example: Intermediate utilization under the shelterwood prescription results in a difference in cost per M bd. ft. of \$110-\$81 = \$29 (from table 3). This cost is assigned to residue recovery of 48 ft^3 per M bd. ft., resulting in a calculated residue recovery cost of \$29 ÷ 48 = \$0.60/ft^3 (table 4). The assumption is that costs of recovering merchantable material should not vary among the treatments; consequently, any change in cost must be attributable to recovering nonmerchantable material. Where residue recovery is required by contract, and in the absence of viable markets for residue material, this is likely to be the cost approximation method adopted.

Table 4.--Cost of residue recovery, allocating to residues all costs in excess of saw log harvesting costs experienced in conventionally logged units

Harvesting treatment	Residue volume recovered per M bd. ft. logged	Added cost of logging per M bd. ft.	Imputed cost of residue recovery		Cost per dry ton
			Per ft^3	Per m^3	
	Ft^3 (m^3)	*- - - - - - - Dollars (1974) - - - - - - - -*			
Shelterwood:					
(1) Intermediate	48 (1.4)	29	0.60	21	48
(2) Intensive	385 (10.9)	156	.41	14	33
Group Selection:					
(1) Intermediate	62 (1.8)	20	.32	11	26
(2) Intensive	152 (4.3)	65	.43	15	34
Clearcut:					
(1) Intermediate	29 (0.8)	12	.41	15	33
(2) Intensive	32 (0.9)	33	1.03	37	82

A second approach to estimating costs of recovering residue material, illustrated in table 5, allocates total harvesting costs to merchantable and nonmerchantable material. Felling, bucking, and bunching costs are identified separately for nonmerchantable material, and total yarding costs are prorated on the basis of cubic volume of each yarded. This would seem to be a preferred approach to calculating costs in situations where merchantable and residue material are being jointly harvested for identified end uses.

Table 5.--Cost of residue recovery, allocating costs to merchantable and nonmerchantable volumes recovered

Harvesting treatment	Residue volume recovered per production hour	Cost of felling, bunching[1]	Proportional cost of yarding[2]	Cost of residue recovery		Cost per dry ton
				Per ft^3	Per m^3	
	Ft^3 (m^3)	- - - - - - -	- - - - - - -	*Dollars (1974)*	- - - - - - -	- - - - - - -
Shelterwood:						
(1) Intermediate	114 (3.2)	17	43	0.53	19	42
(2) Intensive	488 (13.8)	91	132	.46	16	37
Group Selection:						
(1) Intermediate	189 (5.3)	28	53	.43	15	34
(2) Intensive	324 (9.2)	60	91	.47	16	38
Clearcut:						
(1) Intermediate	134 (3.8)	13	29	.31	11	25
(2) Intensive	100 (2.8)	15	31	.46	16	37

[1]Based on two-thirds of residue volume in trees requiring felling; one-third of residue volume in trees requiring felling and bunching.

[2]Yarding cost/hour prorated between merchantable and nonmerchantable material based on cubic volume of each yarded.

Tractor Skidding--The Lubrecht Site

The Lubrecht study site is located on Lubrecht Experimental Forest, a State-owned and administered area belonging to the University of Montana. The area is essentially dry site Douglas-fir, with a significant intermixture of ponderosa pine and western larch, on gentle terrain. The area has a cutting history of selective removal of older, larger timber in the late 1800's-early 1900's. The remaining mixed species and mixed age class stand is broadly representative of a major segment of the commercial forest land in the region. In addition, the stand occurs on one of the more productive Douglas-fir habitat types (*Pseudotsuga menziesii/Vaccinium caespitosum*), and represents an operating situation and management opportunity in which intensive utilization is likely to occur first. The mixed size and age classes provide an opportunity for a range of silvicultural and utilization options.

Harvesting treatments tested were developed to include combinations of silvicultural practices, utilization standards, and postharvest site treatments considered viable management options. Silvicultural prescriptions and utilization standards specified for the cutting units are described in table 6.

Table 6.--Harvesting treatment specifications for cutting, Lubrecht site

Silvicultural system	Cutting specifications	Utilization standards
CLEARCUT	Harvest all trees merchantable under the specified utilization standard.	Conventional utilization--removal of green and sound dead logs from sawtimber trees 9" (23 cm) and larger d.b.h.; utilization to 5" (13 cm) top, and one-third or more sound.
		Intensive utilization--removal of all green and dead saw log material if sound enough to skid; removal of all submerchantable trees 1" (2.5 cm) and larger in d.b.h., tree length (smaller stems hand bunched prior to skidding).
SELECTION	Harvest about half of the merchantable volume, leaving designated overstory of small sawtimber and pole stems. Dense sapling and pole stands selectively thinned.	Conventional utilization
UNDERSTORY REMOVAL	Harvest about half of merchantable volume (and up to two-thirds of total cubic volume), leaving designated overstory of better sawtimber and large poles.	Conventional utilization Intensive utilization
OVERSTORY REMOVAL	Harvest all sawtimber trees; thin pole stands, leaving seedling-sapling-small pole stems as residual stand.	Conventional utilization Intensive utilization

Four cutting units totaling approximately 60 acres (24 ha) were harvested, one under each of the described silvicultural prescriptions (fig. 2). The three units designated for clearcut, overstory removal, and understory removal were further subdivided into treatment areas for application of the two utilization standards. The remainder of this discussion will cover only the three harvesting treatments that included intensive utilization.

Figure 2.--Harvested units on the Lubrecht site included clearcut (left), and understory removal (right) treatments. Intensive utilization subunits are illustrated.

Gentle slopes and easy access to cutting units made possible the use of a ground skidding harvesting system. On all units logs were skidded with crawler tractors. On areas designed for intensive utilization, smaller trees (1" to 6" [2.5 to 15 cm] in diameter) were bunched by hand prior to skidding, and were skidded tree length.

Volumes of merchantable timber harvested from the units ranged from approximately 4 M bd. ft. (understory removal) to over 11 M bd. ft. (clearcut) (table 7). Volumes of nonmerchantable material recovered varied from 630 to 880 ft^3 per acre (44 to 62 m^3 per ha). Harvesting costs per acre and per unit of material recovered are shown in table 7.

The summary and analysis of harvesting productivity on this site is based upon documenting the volume and number of stems removed under each treatment specification, determining the crew and equipment time involved in each harvesting function, and relating time (and cost) to volume. Time and productivity data for the skidding operation were obtained by direct measurement of turn times and volumes or pieces moved. Sawyer time for felling and bucking was estimated from the contractor's records. Production rates for felling and bundling smaller stems under the intensive utilization option were derived from measured production per crew hour.

Typical industry costs (1977 dollars) for crew and equipment time were applied to derive cost per unit of volume produced. In the conventional utilization blocks, all costs were ascribed to the removal of merchantable logs. This base cost was also applied to the merchantable volume removed under intensive utilization, and the balance of harvesting costs incurred in these blocks was attributed to removing the nonmerchantable material.

Intensive utilization removes residue material that would otherwise typically require some residue reduction treatment (fig. 3). Slashing, or slashing followed by burning, are common treatments. Costs of residue recovery can be calculated either ignoring or recognizing the reduction in postharvest treatment costs, depending upon the rationale favored. Tables 8 and 9 demonstrate costs of residue recovery under both conditions. Gross costs of residue recovery, ignoring reductions in subsequent treatment costs, range from \$0.63 to \$0.80 per cubic foot (\$22-\$29/m^3) (table 8). Allowing credit for reduction in residue treatment costs (table 9) reduces the net costs of residue recovery to \$0.42 to \$0.75 per cubic foot (\$15-\$27/m^3).

Figure 3.--Residue reduction treatments following conventional saw log harvesting typically include slashing and burning.

Table 7.--Volume recovery and calculated costs of harvesting, Lubrecht site

Harvesting treatment	Volume recovery: Merchantable		Volume recovery: Nonmerch.		Cost/acre, stump to deck: Fell, buck	Bunch	Skid	Total cost per acre	Cost per M bd. ft. merch.[1]	Cost per m^3, all volume
	M bd. ft./a	*(m^3/ha)*	*Ft^3/a*	*(m^3/ha)*	- - - - - - - - - - -	- -	*Dollars (1977)*	- - - -	- - - -	- - - -
Understory removal:										
(1) Conventional	4.46	(51.9)	--		96	--	183	279	63	13
(2) Intensive	5.77	(67.2)	879	(61)	219	256	435	910	158	18
Overstory removal:										
(1) Conventional	8.80	(102.5)	--		196	--	367	563	64	14
(2) Intensive	8.85	(103.1)	632	(44)	253	200	513	966	109	16
Clearcut:										
(1) Conventional	11.59	(135.0)	--		195	--	380	575	50	11
(2) Intensive	10.66	(124.2)	732	(51)	310	176	633	1,119	105	16

[1]Total costs allocated to merchantable volume recovered.

Table 8.--Cost of residue recovery, assuming no credit for reduction in postharvest treatment costs, Lubrecht site

Harvesting treatment	Residue volume recovered per M bd. ft. logged	Added cost of logging per M bd. ft.	Imputed cost of residue recovery		Cost per dry ton
			Per ft^3	Per m^3	
	Ft^3 (m^3)	*Dollars (1977)*			
Understory removal:					
Intensive	152 (4.3)	95	0.63	22	50
Overstory removal:					
Intensive	71 (2.0)	45	.63	23	50
Clearcut:					
Intensive	69 (1.9)	55	.80	29	64

Table 9.--Cost of residue recovery, allowing credit for reduction in postharvest treatment costs, Lubrecht site

Harvesting treatment	Residue volume recovered per M bd. ft. logged	Added cost of logging per M bd. ft.	Less savings in slashing costs	Less savings in slashing and burning costs	Net cost per ft^3 (m^3) when treatment is		Net cost/ dry ton	
					Slash only	Slash/ burn	Slash only	Slash/ burn
	Ft^3 (m^3)	*Dollars (1977)*						
Understory removal:								
Intensive	152 (4.3)	95	77	64	0.51 (18)	0.42 (15)	41	34
Overstory removal:								
Intensive	71 (2.0)	45	40	34	.56 (20)	.48 (17)	45	38
Clearcut:								
Intensive	69 (1.9)	55	52	47	.75 (27)	.68 (25)	60	54

In-woods Chipping--The Teton Site

The Teton study site is located on the Gros Ventre District, Bridger-Teton National Forest, southwest of Dubois, Wyo. The site is typical of higher elevation old-growth lodgepole pine in the central and northern Rocky Mountains. The area is a gently rolling plateau at about 9,000 feet (2 743 m) elevation, in the *Abies lasiocarpa/Vaccinium scoparium* habitat type. The stands are essentially pure, overmature lodgepole pine, interspersed with natural, open meadows. Stand volumes are heavy for lodgepole pine, averaging in excess of 9,000 ft^3 per acre (254 m^3/ha) in stems 3 inches (7.6 cm) d.b.h. and larger. Standing and down dead material makes up approximately one-third of this volume.

Harvesting activity in old-growth lodgepole pine often results in large volumes of residue because of the decadent nature of the stands. Consequently, harvesting alternatives that can achieve more intensive recovery and utilization of the total fiber resource are particularly important to successful management of the site. Intensive utilization can solve a difficult residue disposal problem, reduce adverse public reaction to harvesting, and facilitate planting and other site-management activities.

Old-growth lodgepole pine is usually clearcut in some fashion because a manageable residual stand does not exist. Treatments applied to the study site specified clearcutting, and included two levels of utilization, described in table 10.

Table 10.--Harvesting treatment specifications for cutting units, Teton site

Silvicultural system	Cutting specifications	Utilization standards
CLEARCUT	All trees designated by utilization standard cut. On conventional utilization units, all green and recently dead merchantable sawtimber trees cut and bucked. On intensive utilization units, all trees (green and dead) 3" (7.6 cm) d.b.h. and larger cut with feller-buncher.	(1) Conventional: logs to 8'x6" (2.4 m x 15.2 cm) top, one-third or more sound, taken from all green and recently dead trees 9" (22.9 cm) d.b.h. and larger. (2) Intensive: in addition to saw log recovery, all non-merchantable trees 3"+ (7.6 cm) d.b.h., all sound down material 6'+ (1.8 m), and all residues from sawtimber trees chipped in field with whole-tree chipper.

Four cutting units, each approximately 20 acres (8.1 ha), were harvested. Two were logged to conventional utilization standards, using common chain saw felling and bucking, and log-length saw log skidding. Residue volumes following harvesting on these units amounted to over 4,300 ft^3 per acre (121 m^3/ha). The two remaining units were logged to a near-complete utilization standard using a feller-buncher (fig. 4), tree-length skidding with rubber-tired grapple skidders, and segregating merchantable logs at the deck. All material not meeting minimum specifications for saw logs was chipped using a portable whole-tree chipper at the site (fig. 5).

Figure 4.--A feller-buncher was employed on the Teton site to fell and bunch whole trees on the intensive utilization units.

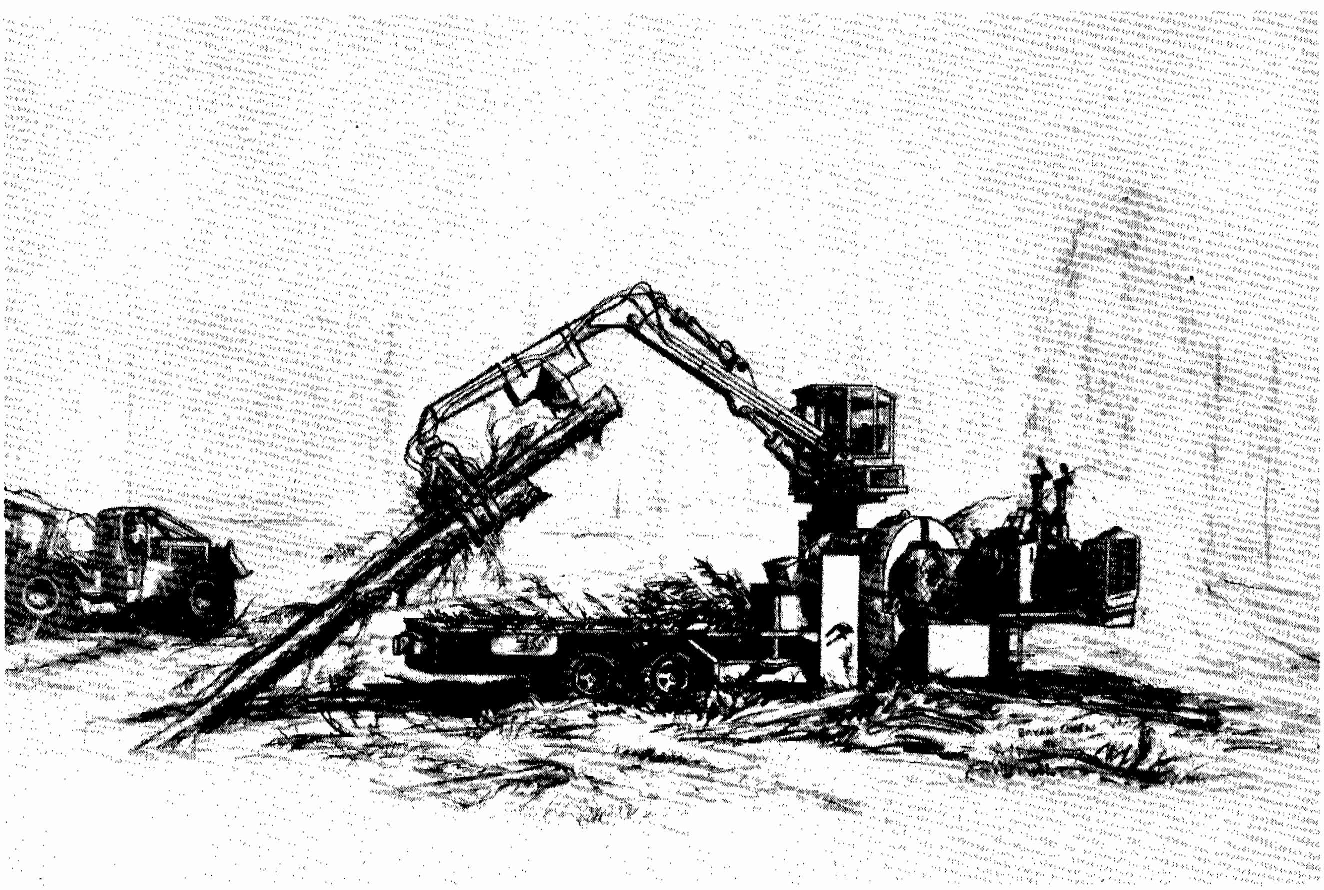

Figure 5.--All material not meeting minimum specifications for saw logs was chipped using a portable whole-tree chipper located on the logging site.

Gross volumes recovered from the cutting units included over 6,500 ft^3/acre (455 m^3/ha) of merchantable sawtimber, plus 4,580 ft^3/acre (320 m^3/ha) of nonmerchantable material from the intensive utilization units (table 11). Chip recovery was influenced by the utilization practices common at the time (1971). Only recently dead timber was considered merchantable for saw logs, and substantial volumes of standing sound dead timber were chipped. Under current utilization standards, much of this sound dead timber would be judged acceptable for sawn products.

Harvesting cost analyses for this site are based on documented crew and equipment time per unit of material harvested. Reported industry costs (1971) for crews and equipment were applied to derive costs per unit produced. Calculated costs, shown in table 11, indicate an average recovery cost of \$0.14/ft^3 for harvesting nonmerchantable and residue material.

Table 11.--Volume recovery and calculated costs of harvesting, Teton site

Harvesting treatment	Volume recovery		Cost/unit, stump to deck				Cost per dry ton
			Merchantable		Nonmerch.[1]		
	Merchantable	Nonmerch.	Per M bd. ft.	Per m^3	Per ft^3	Per m^3	
	Ft^3/a (m^3/ha)	*Ft^3/a (m^3/ha)*	*Dollars (1971)*				
Clearcut:							
(1) Conventional	7,698 (538)	--	16	2	--	--	--
(2) Intensive	6,522 (456)	4,580 (320)	17	2	0.14	5	11

[1]Cost through chipper.

SUMMARY

The case studies reported here were conducted over a span of several years, as indicated. Consequently, the costs experienced in each case reflect the price level prevailing at the time, and cannot be directly compared. Table 12 summarizes costs of residue recovery for the three study operations, and adjusts costs to a common 1980 price base.

Caution must be exercised in drawing any conclusion from differences in costs between the case studies. Each study operation is unique in many respects--timber character, operating mode, crew skill and aggressiveness, and other factors. Costs cannot be assumed to represent more than the specific set of circumstances under which the case study was conducted.

Costs of residue recovery were generally sensitive to the volume of material recovered, with higher volumes per acre resulting in lower unit costs of recovery. The relatively low cost of residue recovery on the Teton site probably resulted from an extremely high volume of recoverable material per acre and the use of a harvesting system specifically designed for efficient residue recovery.

Present research efforts continue to be directed toward developing harvesting systems that can more efficiently recover material currently considered unmerchantable. A principal deterrent to improved recovery of residue material during logging operations is the cost of harvesting large numbers of small pieces, and subsequent handling and transportation problems. Systems that facilitate prebunching, whole-tree processing, and in-woods conversion to a form more easily handled and transported can improve the potential for utilization. Systems that can more efficiently operate in small-stem stands also afford the opportunity to recover such material before it is left as logging or thinning residue.

Better systems are also needed to accommodate the wide mix of material size and quality that may come from older, mixed stands. Most harvesting systems are best adapted to handling one or a few types of material, and additional classes of material are difficult to accommodate. Yet, an essential element in more complete and efficient utilization is the allocation of material to optimum end uses. Efficient harvesting systems for mixed material may require close coordination with merchandising or concentration yard processing and allocation operations, intermediate between the woods and the final processing plant.

Table 12.--Summary of costs of harvesting nonmerchantable material, and cost adjustment to 1980 price level

Study site	Harvesting treatment		Cost/unit, stump to deck: Study year price level, per ft³	1980 price level[4]: Per ft³	Per m³	Per dry ton
			- - - - - - - - - - Dollars - - - - - - - - - -			
Coram	Shelterwood					
	Intermediate	1	0.60	0.92	32	74
		2	.53	.82	29	66
	Intensive	1	.41	.63	22	50
		2	.46	.71	25	57
	Group Selection					
	Intermediate	1	.32	.49	17	39
		2	.43	.66	23	53
	Intensive	1	.43	.66	23	53
		2	.47	.72	25	58
	Clearcut					
	Intermediate	1	.41	.63	22	50
		2	.31	.48	17	38
	Intensive	1	1.03	1.59	56	127
		2	.46	.71	25	57
Lubrecht	Understory removal					
	Intensive	1	.63	.79	28	62
		3	.42	.53	19	42
	Overstory removal					
	Intensive	1	.63	.79	28	63
		3	.48	.60	21	48
	Clearcut					
	Intensive	1	.80	1.01	36	81
		3	.68	.86	30	69
Teton	Clearcut					
	Intensive		.14	.26	9	22

[1]Allocating to residue recovery all costs in excess of saw log harvesting costs experienced in conventionally logged units.

[2]Allocating costs between residue and merchantable volumes recovered, proportional to volume of material handled.

[3]Net cost of residue recovery, allowing credit for reduction in postharvest slashing and burning costs.

[4]Based on Gross National Product implicit price deflator (1972=base 100). Source: Dept. of Commerce, Bureau of Economic Analysis.

LOW CAPITAL INVESTMENT LOGGING SYSTEMS

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ABSTRACT

The selling price of logging equipment directly affects ownership costs, and indirectly affects operating costs. This paper shows that equipment selling price is not an indicator of machine productivity. Translated into machine production costs, which do not include any wages, supervision, or overhead, it cost 12 to 48 cents to skid each piece, with higher costs associated with higher priced skidders. Ten skidders were studied which included horse, farm tractor, track and rubber tired skidders.

Fifteen yarders were studied. The selling price of these machines ranged from $72,000 to $240,000. Yarding costs varied directly with selling price and ranged from $1.10 to $4.30 per piece and $5.77 to $23.90 per cunit.

KEYWORDS: capital productivity, logging production, logging costs, yarding, skidding.

INTRODUCTION

This report, part of a larger study of factors affecting the utilization of small trees, deals with the impact of capital investment on logging productivity and costs.[1]

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[1]The use of trade names does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Generally, cost of capital refers to interest rates or capital stock marketing cost. But in the context of this report it refers to the production cost resulting from the cost of logging equipment. More specifically, this report discusses the machine cost of moving a tree, log, or piece of wood from the stump to a landing.

Two other terms have special meanings in the context of this report:

Skidding--refers to the process whereby a machine moves to a felled tree and drags the tree to a landing. Tractors can be used to skid logs or trees.

Yarding--refers to the process whereby a stationary machine, a yarder, sends out by cable a carriage or other device on which the felled trees or logs are attached. The trees or logs are then dragged or suspended to the landing by a process generally called line skidding. A jammer, line skidder, or yarder can all do the yarding function.

RESIDUE UTILIZATION LEVEL

Residue utilization involves a difficult set of conditions, including: 1) very low realization values, 2) cyclical or periodic markets, and 3) very high unit operating costs. The relationship between logging costs and residue utilization can be illustrated with a break-even approach to residue utilization levels.

Figure 1 shows the change in utilization level resulting from a change in logging cost. The solid curve represents normal logging cost with economic diameter limit at D and utilization level at M. A cost increase will shift to the lower dashed line, changing the economic diameter limit and utilization level to D_2 and M_2 respectively. The upper dashed curve shows the effect of a cost reduction; D shifts to D_3 and M shifts to M_3.

The significance of logging costs is clearly shown. Revenue represents the impact of realization values and markets.

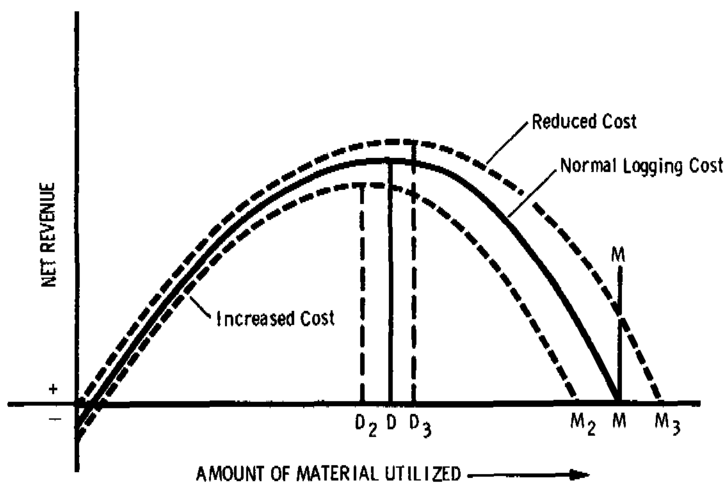

Figure 1.--Effect of logging cost on level of forest utilization.

Logging production costs are rising rapidly. It has been shown that sales realization changes directly affect stumpage rates (Host 1974); stumpage rates closely follow lumber prices. This suggests that revenues shown in figure 1 are relatively fixed or are beyond the control of the logger. Residue utilization levels, therefore, depend on logging costs, emphasizing the results illustrated in figure 1.

This paper will compare only the logging production costs of skidding and yarding. The choice between skidding and yarding is the most cost impacted decision in the logging system for it determines the feasibility of other parts of the total logging system.

SKIDDING PRODUCTION

Table 1 shows the observed production of 10 different skidding modes, including a horse. Machines 4 and 5 represent two different situations with the same farm tractor. Columns 8, 9, and 10 briefly describe the operating conditions; for example, column 10 shows the different travel speeds of loaded skidders on inhaul.

Because these observations were made over a period of years, all values have been adjusted to reflect summer 1979 price levels, shown in the adjusted price column. Where the original machine model has been discontinued (JD420, Garret 15 and AC180), a currently available comparable machine has been priced.[2] The last machine is a John Deere 540C with a grapple. This accounts for the drastic price difference from the other JD540's.

Horse skidding considers two horses, allowing one horse to rest while the other one skids small timber on steep ground.

Columns 4 and 6 show daily production in number of pieces (PCS) and cunits (CCF).[3] These are then divided by the adjusted purchase price (column 3) to produce the daily number of pieces and number of cunits per $100 of purchase price (columns 5 and 7). Cubic volume is used because the tree sizes are too small to measure in board feet. Also, the top volumes are included in these figures, which are gross scale volumes. There is not much defect in any of these volumes, except for the D2 machine study which had considerable material defect.

All the machines used chokers except the JD540-4 and AC180. Hence, number of pieces, trees, or logs is an important productive statistic. The table indicates the effect of grapples on number of pieces skidded per day, suggesting that added production rates compensate the added price of the grapple. This is shown in the upper set of curves in figure 2.

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[2]This paper's narrative and tables both abbreviate the names of specific equipment studied. Appendix A lists more detailed information about the machines.

[3]Gross cubic volumes are used to measure production rates. This was necessary because operating time on the landing did not allow for determining scaling defects and deductions. Cubic feet are used rather than board feet because most of these operations were in small timber which did not show board foot volumes. A cunit (CCF) equals 100 cubic feet.

Table 1.--Daily skidding production per $100 of purchase price.

	Machine model	Purchase price	Adjusted price	Pieces (PCS)	Daily Production PCS/$100	CCF[2]	CCF/$100	Vol/PC	Average Skid Distance		Average Skid Speed	
								ft^3	ft.	m	ft/min	m/min
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)		(10)	
1	Horse[2]	3,000	3,800	114	3.0	5.6	.15	4.91	164	50	91	28
2	JD420[2]	900	6,500	112	1.7	5.0	0.10	4.96	260	79	76	23
3	D2[3]	600	10,000	104	1.0	12.2	0.12	11.73	70	21	78	24
4	AC180[4]	11,000	20,000	346	1.7	28.5	0.14	8.28	994	303	523	159
5	AC180[4]	11,000	20,000	224	1.1	37.9	0.19	16.88	801	244	356	109
6	G15[2]	2,500	22,000	168	0.8	7.9	0.04	4.70	254	77	102	31
7	JD540-1[4]	26,000	43,700	259	0.6	11.0	0.03	4.23	1,092	333	364	111
8	JD540-2[4]	29,000	43,700	304	0.7	32.0	0.07	10.53	1,125	343	357	109
9	JD540-3[5]	29,000	43,700	197	0.5	16.2	0.04	8.24	150	46	185	56
10	JD540-4[5]	38,000	60,700	368	1.0	42.7	0.07	11.60	300	91	117	36

[1]CCF = Cunit (100 cubic feet)

Production data source:

[2]Host, and Schlieter 1978.
[3]Chase 1979
[4]Host 1978
[5]Unpublished in-woods chipping study data.

See appendix for machine description.

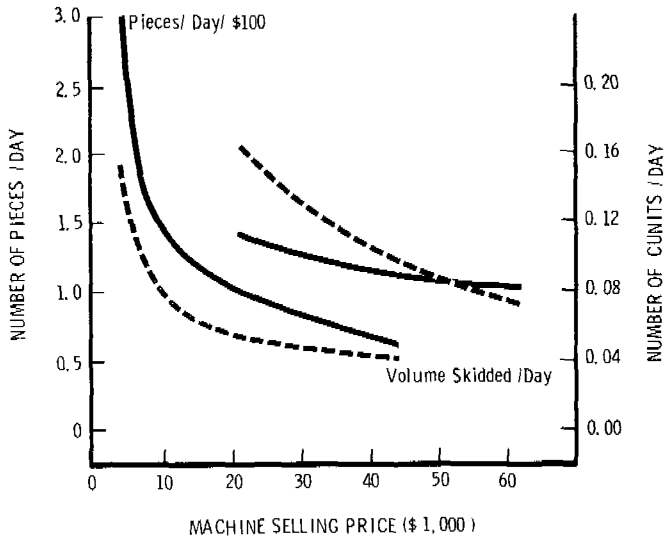

Figure 2.--Daily skidding production per $100 machine price--in cunits and number of pieces skidded.

Volume of material skidded per day is another important production statistic. Because this is greatly affected by individual average piece size, volume, in cubic feet, has been included in column 8. Relating these statistics to equipment selling price, it is obvious that skidding with horses is favorable in small timber. Figure 2 shows these statistics based on $100 selling price. Both statistics are included in the same figure in order to point out their similarity. This exclusion is made to point out that grapples represent a separate and unique skidding mode. Figure 2 shows that capital productivity decreases as more expensive skidding modes are used.

Skidding Production Costs

Table 2 shows the production costs for the units used in table 1 (pieces per day and volume per day in cunits). The table shows that total daily costs range from $22.98 to $109.82, with a mean of $56.32. There is a generally consistent increasing cost trend except for the Garrett 15. These costs might appear to be low, but these are machine costs and do not include any labor or overhead. (Figure 3 shows the daily machine costs for the skidders.) Columns 8, 9, and 10 are included to briefly describe the operating conditions. Figure 6 shows that the per cunit production cost increases only 7.1 cents per $1,000 selling price.

When looking at the cost to skid one piece, the trend is not as consistent as the total machine cost. Piece size has been included in table 2 because it might be thought to affect unit cost; but it does not appear to be a critical production variable. The larger sized timber does not have consistently higher costs per piece. Apparently, the same observation can be made when looking at cunit skidding costs. Figure 3 shows the daily machine cost as compared to machine selling price. The figure indicates that daily operating costs rise as the machines selling price rises.

Table 2.--Skidding production costs in dollars.[1]

Skidder	Daily Machine Cost			Unit Costs		Piece Size	
	Fixed	Variable	Total	Per Piece	Per CCF[2]	ft^3	M^3
Horse	3.12	19.86	22.98	0.20	4.10	4.91	.14
JD420	5.32	10.54	15.86	0.14	3.11	4.46	.13
D2	8.19	16.42	24.61	0.24	2.02	11.73	.33
AC180-1	16.38	25.08	41.46	0.12	1.45	8.28	.23
AC180-2	16.38	25.08	41.46	0.19	1.10	16.88	.48
G15	18.02	13.37	31.39	0.19	3.92	4.70	.13
JD540-1	35.80	55.70	91.50	0.35	8.32	4.23	.12
JD540-2	35.80	58.40	94.20	0.48	5.81	10.53	.30
JD540-3	35.80	61.20	97.80	0.32	3.03	8.26	.23
JD540-4	49.72	60.10	109.82	0.30	2.57	11.60	.33

[1]Costs do not include wages and overhead.
[2]CCF = Cunit (100 cubic feet).

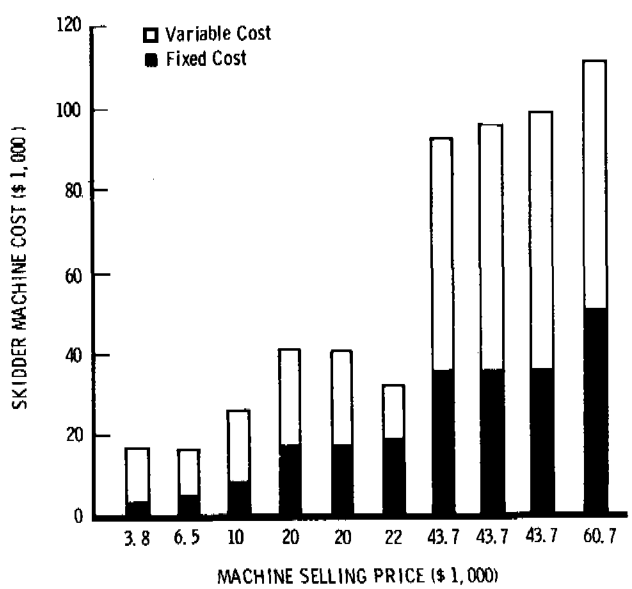

Figure 3.--Skidder machine cost versus selling price.

It is more difficult to compare yarding methods than skidding methods. Fixed costs become important in yarding, because the operation involves a relatively large portion of non-productive operating time during which the yarder is moved from one set to another. Production costs are greatly affected by piece size and volume cut per acre. Figure 1 showed that this affects economic diameter and volumes that can be utilized--a real dilemma.

Table 3 lists yarding production data for 15 different yarders one of which, the Ecologger I, was used in two different situations (nos. 6 and 7). It is important to point out that the production comparisons are based on $1,000 of machine price rather than $100, as in table 1. This transposition was necessary because of the high prices for yarders. As in table 1, columns 8, 9, and 10 have been included to briefly illustrate the conditions under which the machines were observed. Column 9 shows that the yarding distances did not vary as might be expected; that is, the difference between the average yarding distances for small and large machines was fairly small.

Neither were there differences as expected in line speeds (column 10). When determining line speeds, all inhaul delays were eliminated. A great deal of detail would be necessary to explain these. The impact of line speeds can be lessened considerably by other elements of the production cycle - chokersetting and lateral distances. Hence, they help to explain the production situation, but, often times, the significance of line speeds is over-emphasized.

Column 5 suggests there is no clear correlation between yarder price and number of pieces per day. However, there was an apparent drop after situation 10 (Link Belt 78-2). A trend in cunits per $1,000 (column 7) was even less apparent.

Figure 4 illustrates columns 5 and 7 of table 3. As with figure 2, the downward sloping line to the right indicates that the productivity of capital decreases as machine price increases.

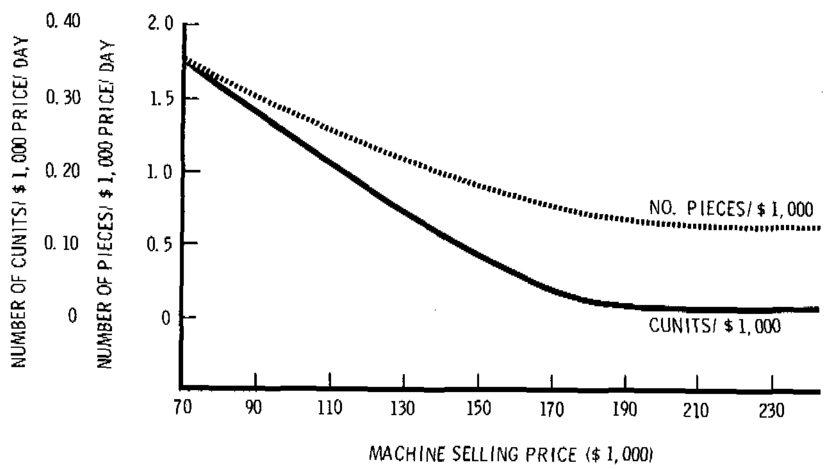

Figure 4.--Daily yarding production per $1000 machine price--in cunits and number of pieces yarded.

DISCUSSION

Many factors affect logging costs. This report considers only one of these factors in a sub-optimization context.

When evaluating capital productivity, one cannot be doctrinaire about purchase price impact on production cost. For instance, in some situations a $130,000 feller-buncher can be more economical than a $400 powersaw. It can be wrong to assume that smaller machines increase production efficiency in all cases. Efficiency is maximized when machines are properly matched to timber size and operating conditions within a total system. If it is valid to assume a decreasing capital productivity, why do some skidders and yarders sell for higher prices than others, and why would a smart logger buy a high-priced skidder or yarder? There are two different rationales explaining this phenomenon-- the "basic purchase function" and imposed logging constraints.

The "basic purchase function" has been described in detail elsewhere (Host 1978). Very briefly, it involves the assumption that higher priced machines have lower variable costs, so that the total cost is less for a high-priced than for a low-priced machine. The assumption is based on downtime and/or longer economic life.

Imposed logging constraints can be the overriding factor in machine purchase decisions. For instance, a long yarding distance requirement eliminates the possiblity of using many small yarders. This long line requirement has led to the demise of the "Idaho Jammer," the most efficient cable machine built. In addition, as has been shown, skidding is less costly than yarding; hence, when land management requirements exclude skidding, costlier yarders must be used.

This study documents that logging equipment prices directly affect logging costs. Followup analysis of downtime and delay causes would strengthen or weaken this documentation. At this time, it is apparent that machine size also affects logging costs.

The question of capital productivity also concerns the substitution of capital for labor. Labor shortages and an urgent need to keep production levels high can require large capital investments. In some cases, high production levels can reduce fixed cost impacts; for example, a small log operation would have low total costs, if it were transferring 3000 trees through the landing per 8 hour shift.

Figure 6 shows that the per cunit production cost increases only 7.1 cents per $1,000 of selling price. How does this slight cost increase, based on machinery price, translate to unit costs? The price ranges have a significant effect on residue utilization levels. Skidding unit costs range from 14 to 48 cents per piece and from $1.09 to $8.32 per cunit ($3.09 to $27.30 per cubic meter), with an average of 25 cents and $3.42, respectively. Yarding unit costs range from $1.10 to $4.30 per piece and from $7.19 to $23.90 per cunit ($23.59 to $78.41 per cubic meter), with a mean of $2.36 and $12.00, respectively.

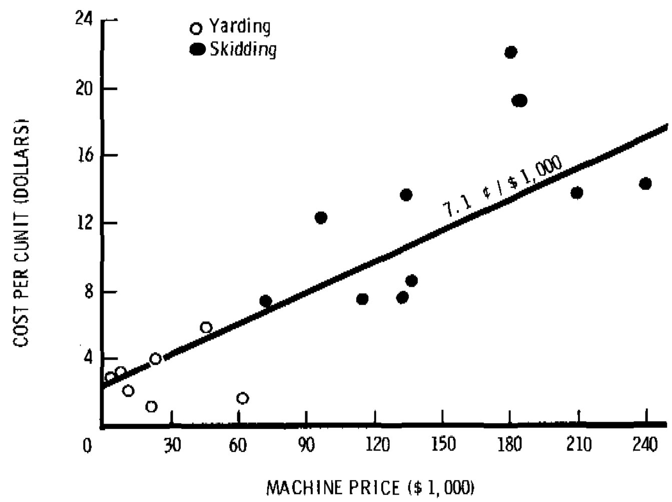

Figure 6.--Skidding and yarding production cost in dollars per cunit.

How does this affect utilization levels and resultant wood supplies? What would be the competitive advantage of substituting skidding for yarding in small timber and what is the net effect of capital equipment cost on residue utilization? These questions can be answered by a simple revision of figure 1.

In figure 1:

1. The solid line represents average logging machine price.
2. The upper dashed line represents skidders and the lower dashed line represents yarders.
3. Utilization levels will be improved by skidders where feasible. Or, instead of yarding utilized material, we should be skidding it. Or, utilization standards can be improved on skidding operations and slacked on yarding operations.

If we accept the conclusion that the costs of operating different machines vary in accordance with their different purchase prices, then any efficiency with size must come from labor productivity and supervision. That is, unit costs can be reduced by increasing daily production. This becomes increasingly critical when considering that skidders only need one person to operate them, whereas yarder crews consist of two to four persons. Some operating ratios show labor to total costs to be acceptable at 0.50 - 0.60. This means higher priced machines need much higher production rates.

Forest residues occur because they cannot be handled economically, so we need to reduce costs in order to utilize residues. But lighter cuts per acre and smaller timber increase costs and reduce values received. Where labor productivity is relatively constant, reduced logging costs will require consideration of other aspects. This suggests studying more productive ways to organize presently available technology. It also suggests studying and developing new logging technology.

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APPENDIX A

IDENTIFICATION OF LOGGING EQUIPMENT

Abbreviation	Machine
JD420	John Deere Model 420 tractor
D2	Caterpillar Model D2 (1958)
AC180	Allis Chalmers Model 180 farm tractor
G15	Garrett Tree Farmer Model 15
JD540-1, 2, 3	John Deere Skidder Model 540 C
JD540-4	John Deere Skidder Model 540 C Grapple
U	Urus 1000-3
B123	Koehring Bantam 3/8 yard converted shovel
22B	Bucyrus Eire 3/4 yard converted shovel
EI12	Ecologger I
LB7812	Link Belt Model 78 converted shovel
LB9812	Link Belt Model 98 converted shovel
C305	Koehring Model C305
LB10812	Link Belt Model 108 converted shovel
W78	Washington Yarder Model 78

APPENDIX B

Machine Cost Determination Assumptions

I. Fixed (Ownership) Cost

1. Straight line depreciation over 7 years at 1,500 hours per year.

$$\text{Depreciation per hour} = \frac{\text{Purchase price - Salvage value}}{\text{10,500 hours}}$$

Salvage value very often depends on the bargaining position at the time of disposal, willingness of seller, market conditions, etc. Consequently, to be consistent, we assume there is no salvage value.

For tax reasons one should use accelerated depreciation schedules. However, straight line depreciation is used on the assumption that the machines will wear out at a fairly constant rate over the 7 year life.

2. Average Annual Investment (AAI) is:

$$\text{AAI} = \frac{\text{Purchase Price - Salvage Value}}{\text{2 (Depreciation hours)}} - \frac{\text{Salvage Value}}{\text{Deprec. hours}}$$

$$= \frac{\text{Purchase Price}}{\text{2 (Depreciation hours)}} \quad \text{where salvage value is zero.}$$

3. Rate of interest is 15%. This is composed of the usual cost of money at 13% plus 2% for insurance and taxes.

4. Observations of these machines have been made over an extended period of time. In order to put these observations on a comparative basis, purchase prices have been updated to summer of 1979 price lists. Where some machine models have been discontinued, a comparable machine has been priced currently.

Because fuel prices are so variable, the diesel fuel prices have been set at a constant price of $1 per gallon. This might appear high but it is an estimated price. As long as it is consistent, it does not favrr any one machine.

II. Variable (Operating) Cost

1. No labor or supervision costs have been included. They are irrelevant as far as the machine price comparisons are concerned.

2. Daily repair and maintenance costs will increase throughout the operating life of the machine. These will also vary considerably by operators for the same machine and the same working conditions. Generally, it can be assumed that the total repair and maintenance costs will equal the purchase price at the end of the operable (depreciable) life of the machine.

The repair and maintenance costs used herein correspond to the stage of the machine life at the time the observations were made. That is, these costs pertain to the time of observation but have been updated to August, 1979.

3. Skidder number 1 is a horse. This causes a unique costing situation whereby operating costs are determined on annual basis and then divided by 213 for a daily operating cost determination. This procedure is necessary in order to include the non-work period costs of food and care.

The number of work days is determined as follows:

Logging -- 183 days (Consisting of 131 work days plus 52 days on weekends during logging season)

Ranch chores -- 30 days

Horse

Fuel = Feed--1 horse

7.40 months @ $110.00	=	$ 814.00
4.60 months @ $ 75.00	=	345.00
		$1159.00/horse/year

		$2318.00/year =	$10.88/day
Shoes--51¢/day/horse	=		1.02
Harness--$3.50/day/horse	=		7.00
Vet service--$350.00/year/2 horses	=		0.96
			$19.86/day/2 horses

Table 5.--Determination of yarder machine cost per day.

	Machine	Ownership Cost			Operating Cost				Total Cost	No. Pcs.	$/PC	Vol. CCF	$/CCF	$/m³
		Depn	AAI x 15%	Total	Maint. Repair	Fuel & Lube	Rigging	Total						
1	U	54.86	4.11	58.97	78.46	7.00	33.96	119.42	178.39	110	1.62	24.81	7.19	23.59
2	B-1	72.38	5.43	77.81	63.35	22.00	44.80	130.15	207.96	189	1.10	36.06	5.77	18.93
3	B-2	72.38	5.43	77.81	72.59	18.00	36.66	127.25	205.06	73	2.81	14.69	13.96	45.80
4	B-3	72.38	5.43	77.81	74.98	16.00	32.58	123.56	201.37	57	3.53	12.03	16.74	54.92
5	22B	85.33	6.40	91.73	88.40	19.00	52.82	160.22	251.95	163	1.55	34.63	7.28	23.88
6	EI-1	101.33	7.60	108.93	141.08	44.00	62.72	247.80	356.73	166	2.15	37.72	9.46	31.04
7	EI-2	101.33	7.60	108.93	96.23	49.00	69.85	215.08	324.01	207	1.57	18.53	17.49	57.38
8	LB78	104.00	7.80	111.80	56.64	31.00	64.38	152.02	263.82	222	1.19	33.30	7.92	25.98
9	LB78	104.00	7.80	111.80	94.26	30.00	62.30	186.56	298.62	207	1.44	34.63	8.62	28.28
10	LB98	137.14	10.29	147.43	107.92	34.00	84.89	226.81	374.24	87	4.30	15.66	23.90	78.41
11	LB98	137.14	10.29	147.43	137.14	37.00	92.38	266.52	413.95	117	3.54	21.06	19.66	64.50
12	C305	140.95	10.57	151.52	124.36	37.00	87.25	248.61	400.13	152	2.63	21.05	19.01	62.37
13	LB108	160.00	12.00	172.00	110.43	46.00	99.04	255.47	427.47	145	2.95	26.43	16.17	53.05
14	LB108	160.00	12.00	172.00	114.78	51.00	109.81	275.59	447.59	217	2.06	39.50	11.33	37.17
15	W78	182.86	13.70	196.57	137.62	59.00	113.19	309.81	506.38	141	3.59	36.10	14.03	46.03

OUTLOOK FOR NEW HARVESTING TECHNOLOGY

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ABSTRACT

Because of increased emphasis on utilization of residues and smaller timber, rising energy and labor costs, and more severe environmental constraints pertaining to logging and road construction, the criteria for harvesting systems in the future will require both technological and institutional innovation.

This paper analyzes harvesting *per se* as well as its role in the total forest management picture. Models are presented for testing the sensitivity of total management cost and the harvesting components of cost to alternative silvicultural, utilization, and other forest management objectives. These models are used to discern opportunities for new harvesting technology.

KEYWORDS: logging systems, timber harvesting, forest management, cost modeling, new technology

INTRODUCTION

This paper analyzes some of the major factors that influence logging and total on-site forest management costs, and assesses the opportunities for future harvesting technologies in light of assumed forest management objectives and constraints. Our principal focus will be on the problems associated with mountainous terrain.

While there may be alternatives to truck hauling as the final stage in timber harvesting, it seems unlikely that such alternatives will be used in the next few decades--at least on a widespread basis. Therefore, our analysis assumes a continued need for roads and trucks.

Similarly, while wood fiber in any form may eventually be usable for whatever products society needs, it seems likely that leaving wood in its largest natural states will still be preferable for the foreseeable future. Therefore, our analysis excludes consideration of chipping at the stump or similar breakdown of trees between stump and roadside.

Finally, while we acknowledge the economic advantages of ground skidding with tractors--even in relatively steep terrain, we will pay little attention to such methods here. This is not to deny the widespread importance of such methods; rather, we assume that environmental and safety considerations will preclude their general applicability in much of our mountainous terrain.

In short, we confine our analysis to the matter of stump-to-mill transport and handling of trees, logs, and sensibly large pieces or aggregations of wood in mountainous terrain, with full recognition of the potentials for roadside chipping of certain residues to facilitate disposal or subsequent transport by trucks.

ANALYSIS OF CURRENT TECHNOLOGY

Traditionally, timber harvesting has been treated as a distinct activity, separate from the remainder of forest management activities, in spite of its recognized influence on the remainder of management. With minor exceptions, management of virgin forests before entry for harvest has traditionally been limited to control of fire, insects, and disease. Then, based largely upon the capabilities and limitations of harvesting technology, roads are located and constructed to the stands. After harvesting is completed, slash disposal, planting, and subsequent cultural treatments are undertaken until the stand is again ready for harvest. The point is that until stands become ready for initial harvest entry, management is largely passive. Moreover, the nature of management after harvest is largely influenced by the roads that are built for harvesting; and the locations and types of roads are influenced largely by the types of harvesting technology used.

Through a combination of economic and political processes, road densities have been decreasing and yarding or skidding distances have been increasing. Both road and harvesting costs have been rising, but the rising prices of wood products have generally permitted a continuation of traditional ways of doing business.

As the harvesting industry has complied with pressures to increase yarding distances and avoid undesirable environmental impacts, so have the Forest Service and other forest management agencies continued to push for more restrictions and more demanding and costly road construction and harvesting requirements. Rightly or wrongly, in recent years there has been a shift toward using the harvesting process to accomplish a wider range of forest management objectives.

Thus, even though we are concerned here with harvesting technology, it is necessary to consider the totality of forest land management--with harvesting as but one component of the total management scheme--and to examine the effects of new harvesting requirements and technologies on total management costs. To do this, we will construct a generalized model to portray total management costs per acre, including harvesting costs.

General Cost Model

Consider a tract of forested land that is to be roaded, harvested, and placed under active management. The principal cost components include road design, construction and maintenance, inventory and planning, harvesting and subsequent post-harvest slash disposal, planting, and other cultural treatments. It is assumed here that costs of surveillance and control of fire, insects, and disease are unrelated to the characteristics of road systems. Similarly, our model ignores the costs incurred by recreationists, grazers, and other forest users.

ROAD COSTS

Appendix A shows how per acre road costs (RC) are derived. In general, these costs can be expressed

$$RC = K_R \frac{C_R}{S} \tag{1}$$

where RC is in dollars per acre; C_R is the cost for design, construction and maintenance of roads expressed in dollars per mile; S is the average maximum yarding distance or span expressed in feet; and K_R is a coefficient reflecting the acres served by the roads and over which road costs are distributed. K_R is expressed in units of ft.-mile per acre.

Figure 1 illustrates the general form of per acre road costs (RC) as a function of average maximum yarding distance or span (S).

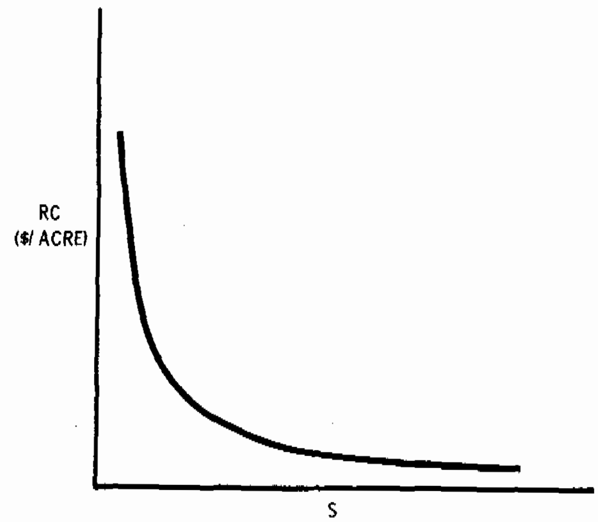

Figure 1.--General road cost (RC) versus span (S) relationship.

LABOR INTENSIVE COSTS

Appendix A contains a discussion of the types of pre- and post-harvest activities or treatments that are considered herein to be labor intensive, and for which the costs are affected by yarding distance or road spacing. The cumulative per acre costs (LIC) for such activities or treatments are derived in appendix A, and are shown to be

$$LIC = \sum_{i=1}^{m} \frac{C_i}{P_i T_i} \left(\frac{1}{1-K_i S}\right) \tag{2}$$

where C_i is the daily cost for the i^{th} system; P_i is the basic production rate for the i^{th} system in acres per hour; and T_i is the available number of hours in the workday for the i^{th} system, exclusive of vehicle travel to and from the woods. S is as defined previously, and K_i is a coefficient reflecting walking speed between the roadside and work site, length of workday, and type of yarding system.

Figure 2 illustrates the general form of per acre labor intensive costs (LIC) as a function of average maximum yarding distance or span (S).

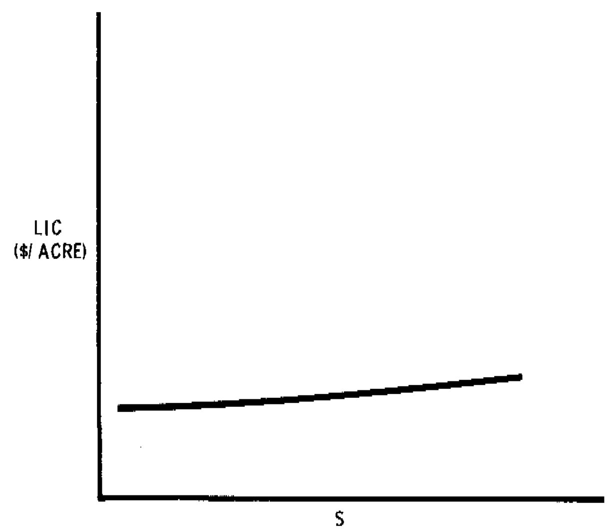

Figure 2.--Generalized relationship between labor intensive (LIC) and span (S).

LOGGING COSTS

It is convenient to consider logging as three separate operations: (1) falling (including in-woods processing); (2) yarding; and (3) hauling. Sometimes roadside processing, handling, and decking or loading accompany the yarding operation, in which case the definition of the yarding system would be broadened to include ancillary labor and machinery. At other times, roadside processing, sorting and loading might accompany the hauling operation, in which case the definition of the hauling system would be broadened accordingly.

Appendix A shows the derivation of expressions for per acre falling costs (FC), yarding costs (YC) and hauling costs (HC). Respectively, these expressions are

$$FC = \frac{C_f \overline{V}}{P_f T_f} \left(\frac{1}{1-K_f S} \right) \qquad (3)$$

$$YC = \frac{C_y}{60T_y} \left[\frac{43560}{b} \left(\frac{R_0}{S} + R_1 \right) + \frac{(\overline{V} + V_R)}{v} \left(Y_0 + Y_1 S + Y_2 b + Y_3 n \right) \right] \qquad (4)$$

and

$$HC = C_h \, (\overline{V} + V_R) \qquad (5)$$

where C_f and C_y are the daily costs for the falling and yarding systems, respectively; $\overline{V}$ and V_R are the per acre volumes to be extracted of merchantable timber and residues, respectively; T_f and T_y are the available hours in the work day for the falling and yarding systems, respectively; P_f is the falling system production rate, in units of volume per hour; K_f is a coefficient reflecting walking speed between roadside and work site, length of workday, and type of yarding system; b is the average spacing between yarding corridors, in feet; v is the average volume per yarding cycle, expressed in units compatible with $\overline{V}$ and V_R; C_h is the hauling system cost per unit volume (where volume is expressed in units compatible with $\overline{V}$ and V_R; R_0 and R_1 are coefficients reflecting yarding system rigging time; Y_0, Y_1, Y_2 and Y_3 are coefficients reflecting yarding cycle time; n is the average number of pieces (or piece equivalents) per yarding cycle; and S is as previously defined.

Figure 3 illustrates the general form of FC, YC and HC as well as total logging cost (LC) versus S, where

$$LC = FC + YC + HC. \qquad (6)$$

Note that there is an optimum span at which total logging cost is minimized, and beyond which per acre costs rise approximately at the rate at which per acre yarding costs increase.

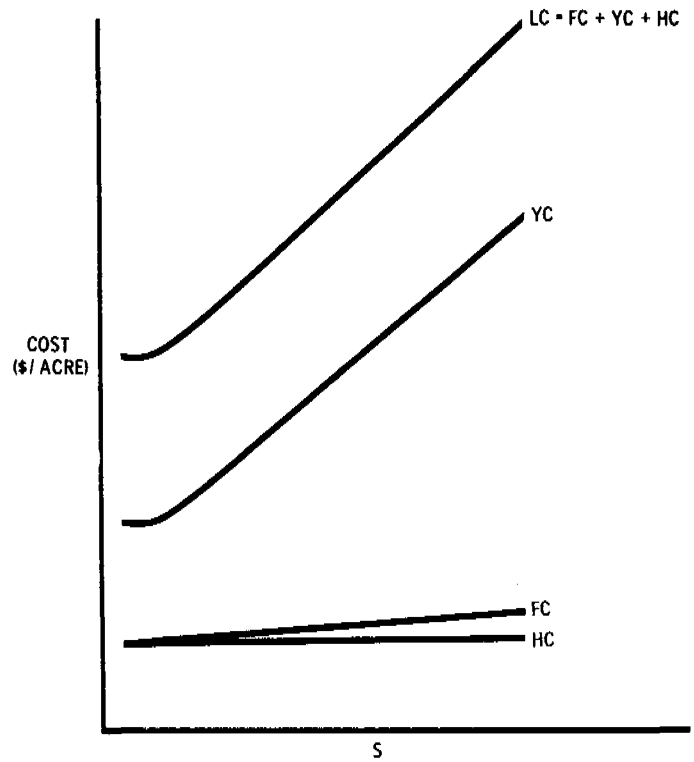

Figure 3.--General relationship between logging costs and span (S), where total logging cost (LC) is the sum of falling cost (FC), yarding cost (YC) and hauling cost (HC).

AGGREGATION OF COSTS

Assuming the period of consideration is sufficiently short that only one harvesting entry needs to be considered, and ignoring the time spread of investments during this period, then the total investment per acre (C) may be estimated as

$$C = RC + LIC + LC$$

or

$$C = K_R \frac{C_R}{S} + \sum_{i=1}^{m} \frac{C_i}{P_i T_i} \left(\frac{1}{1-K_i S}\right) + \frac{C_f \overline{V}}{P_f T_f} \left(\frac{1}{1-K_f S}\right)$$

$$+ \frac{C_y}{60 T_y} \left[\frac{43560}{b} \left(\frac{R_0}{S} + R_1\right) + \frac{(\overline{V} + V_R)}{v} \left(Y_0 + Y_1 S + Y_2 b + Y_3 n\right)\right]$$

$$+ C_h (\overline{V} + V_R) \ . \qquad (7)$$

Use of equation 7 requires numerous assumptions relative to the stand and terrain conditions, the harvesting system to be used, and the nature of pre-and post-harvest activities. Our purpose here is to show how such a model can be used and to analyze the general effects of selected changes in conditions on per acre management cost.

First, we assume that management constraints do not preclude operation of the yarding systems at other than optimal corridor spacing. To determine this optimum, we differentiate equation 7 with respect to b and equate the resulting expression to zero to find

$$b_{opt} = \sqrt{\frac{43560\ (v)\left(\frac{R_0}{S} + R_1\right)}{Y_2\ (\bar{V} + V_R)}} \qquad (8)$$

when we substitute equation 8 for b in equation 7, we obtain

$$C = K_R \frac{C_R}{S} + \sum_{i=1}^{m} \frac{C_i}{P_i T_i}\left(\frac{1}{1-K_i S}\right) + \frac{C_f \bar{V}}{P_f T_f}\left(\frac{1}{1-K_f S}\right)$$

$$+ \frac{C_y}{60T_y}\left[2\sqrt{\frac{43560\ Y_2\ (\bar{V} + V_R)\left(\frac{R_0}{S} + R_1\right)}{v}} + \frac{(\bar{V} + V_R)}{v}\left(Y_0 + Y_1 S + Y_3 n\right)\right]$$

$$+ C_h\ (\bar{V} + V_R) \qquad (9)$$

Note that yarding cost is now

$$YC = \frac{C_y}{60T_y}\left[2\sqrt{\frac{43560\ Y_2\ (\bar{V} + V_R)\left(\frac{R_0}{S} + R_1\right)}{v}} + \frac{\bar{V} + V_R}{v}\left(Y_0 + Y_1 S + Y_3 n\right)\right] \qquad (10)$$

Effects of Road Spacing or Span

Based on the example in appendix B, figure 4 illustrates the relationships of road costs, labor intensive costs, logging costs, and total managment costs versus span.

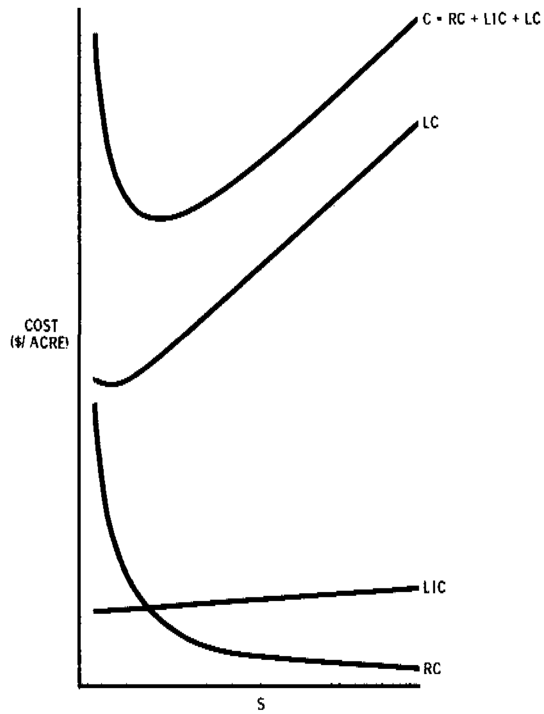

Figure 4.--General form of total management cost (C) versus span (S), where total management cost is the sum of road cost (RC), labor intensive cost (LIC) and logging cost (LC).

The major point to be made here is that the optimum span with respect to total management costs is significantly greater than the optimum span with respect to logging costs alone--nearly three-fold in this example, chiefly because of the influence of road costs.

A second point to be made from figure 4 is that, for spans greater than the optimum, the economic penalties increase at approximately the same rate as logging costs; as previously noted, logging cost increases are chiefly due to yarding cost increases.

The foregoing ignores any constraints on rigging, yarding, or road construction imposed by terrain or other factors. Indeed, as cable yarding distance is increased in mountainous terrain, multi-span capability often becomes necessary; and, correspondingly, rigging cost may rise dramatically. Obversely, as distances between roads increase, road costs per mile may decrease if road locations become less critical. Consequently, we believe that equations 7 and 9 above are generally both reasonable and useful with respect to a broad range of road spacings, even in difficult terrain.

Effects of Increasing Road Costs

Per acre road costs increase when per mile costs (C_R) increase or if the coefficient K_R increases. Figure 5 illustrates the effects of doubled per mile road costs on both per acre road costs and total management costs. The same effects would occur if per mile road costs remained unchanged and the acreage allocation coefficient K_A were to be halved. The implication of figure 5 is that as inflation or environmental constraints increase road costs, or as the proportions of accessed areas not managed or incapable of management increase, optimum yarding spans also increase. This implication alone makes increasing yarding distance capabilities a desirable goal for future logging technology.

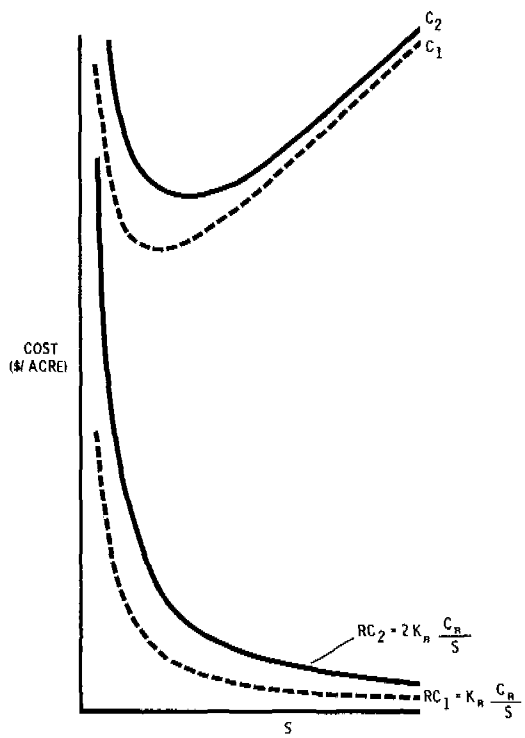

Figure 5.--Effect of doubled road cost on per acre road cost (RC) and total management cost (C) versus span (S). (RC_1 and C_1 represent the per acre road and total management cost of figure 4; and RC_2 and C_2 represent the per acre road and total management cost if per mile road costs are doubled.)

Effects of Reduced Cutting Intensity

If environmental considerations produce a preference for more selective logging and less clearcutting, the effect would be to reduce the extracted volumes per acre. With $\bar{V}_1$ representing the merchantable volume per acre to be removed on first entry into a stand, where

$$\bar{V}_1 = K\bar{V} \quad , \quad K < 1$$

(and $\bar{V}$, as before, is the total merchantable volume per acre in the stand), figure 6 shows the effect of selective logging on total per acre management cost and on cost per unit of merchantable volume removed versus span, S. (Figure 6 is based on calculations in appendix C, wherein K = 0.5.)

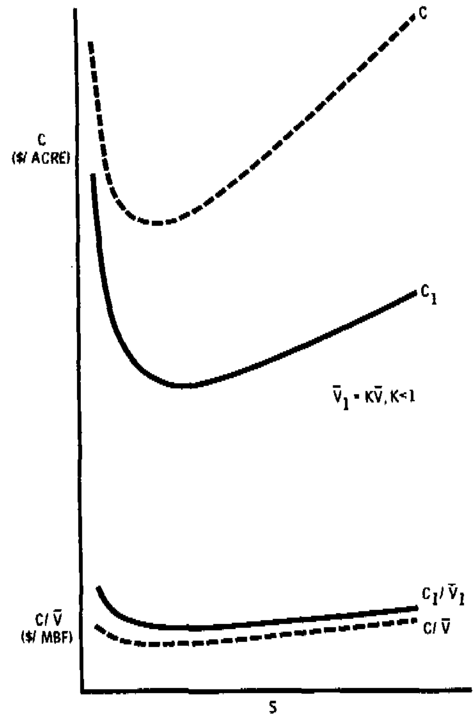

Figure 6.--Effect of partial cutting on total management costs per acre (C) and per unit volume (C/$\bar{V}$) versus span (S). (C and C/$\bar{V}$ correspond to figure 4; C and $C_1/\bar{V}_1$ correspond to the example of appendix C.)

Figure 6 shows that optimum spans are increased, based on total management costs incurred on first entry alone, and that economic penalties for increasing spans beyond the optimum are reduced in comparison with removal of the entire merchantable volume, $\bar{V}$. Of course, costs per unit volume also are increased, as shown in the bottom part of figure 6. Therefore, we conclude that selective logging increases the need for or the desirability of extended yarding spans and wider road spacings, at least on the basis of initial entry considerations alone.

If the economic planning horizon extends to later entries, however, then optimum spans would not be appreciably different from what they would be if all the merchantable volume were removed on first entry (fig. 7). That is, assuming the costs incurred on second entry are the same as those incurred on first entry (except for road costs), the sum of first and second entry per acre costs ($C_1 + C_2$) versus span, S, will be of about the same form as the C vs. S relationship shown in figure 4, although higher. Correspondingly, the total cost per unit volume will also be higher, or

$$\frac{C_1 + C_2}{\bar{V}} > \frac{C}{\bar{V}}$$

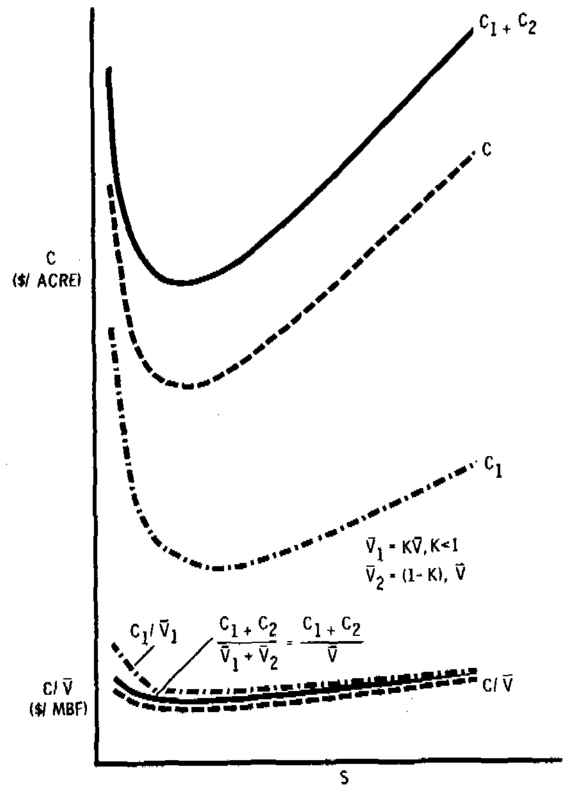

Figure 7.--Cumulative first and second entry management cost per acre ($(C_1 + C_2)$ and per unit volume $((C_1 + C_2)/\bar{V})$ versus span (S). (C, $C/\bar{V}$, C and $C/\bar{V}$ are from figure 5; C_2 and $\bar{V}_2$ are the additional costs incurred and volumes removed per acre, respectively, during second entry.)

Thus, based on considering all entries, from initial selective removal to final harvest cutting, there would appear to be no need for increasing yarding span capabilities; rather, the principal objective for new harvesting technology would appear to be a combination of lower costs and lower economic penalties for yarding beyond optimum spans.

Effects of Residues Removal

One may consider two basic classes of logging residues: (1) those that are similar in character to the merchantable logs (i.e., of comparable weight, length, and diameter), and (2) those that are small or irregular (e.g., limbs, tops, broken chunks, and small trees). The effect on cost of removing residues of the first type is not appreciably different from that of increasing per acre volumes to be removed. The upper part of figure 8 illustrates that total per acre management costs are increased, and that optimum spans are decreased, as per acre volumes of the first class of residues to be removed increase. (Figure 8 is based on data generated in appendix D.)

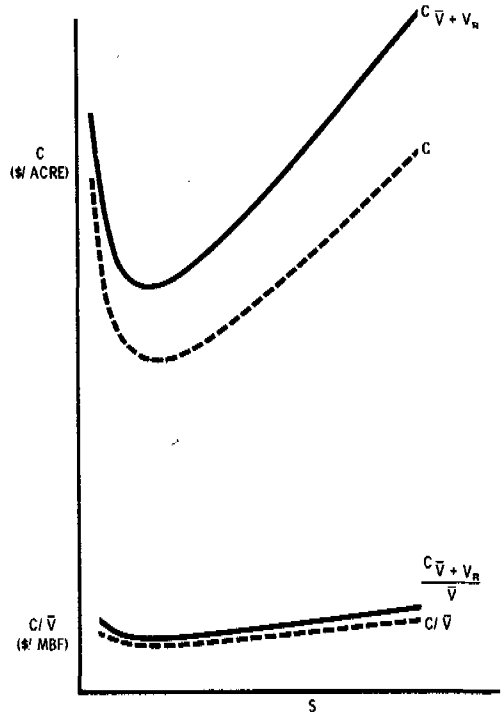

Figure 8.--Effect of residue removal on per acre management cost ($C_{\overline{V}+\overline{V}_R}$) and cost per unit of merchantable volume ($C_{\overline{V}+V_R}/\overline{V}$) versus span (S). (C and $C/\overline{V}$ are from figure 4.)

The lower part of figure 8 shows the effects of residue removal on cost per unit of merchantable volume; as would be expected, costs per unit volume in this situation are higher than for the case where $V_R = 0$.

If by removing the larger class of residues there would be no reduction in need for slash disposal or other labor intensive work (as was assumed in appendix D), then it would be of interest to determine what value these residues would need to possess in order to produce no economic penalty for their removal. If ρV_R were to represent the equivalent net merchantable volume in the residues, where $0 \leq \rho \leq 1$, then avoiding economic penalty would require that

$$\frac{C_{\overline{V}+V_R}}{\overline{V}+\rho V_R} \leq \frac{C}{\overline{V}}$$

or that

$$\rho \geq \frac{\overline{V}}{V_R}\left(\frac{C_{\overline{V}+V_R}}{C} - 1\right) \qquad (11)$$

where $C_{\overline{V}+V_R}$ is the total per acre management cost incurred when both merchantable timber and residues are removed. (C, as before, would represent the total per acre management cost incurred when only merchantable timber is removed.)

Figure 9 (again based on an example outlined in appendix D) illustrates the relationship between ρ and S, and shows that the net merchantable volume (or equivalent thereof) must increase as yarding distances or road spacings increase.

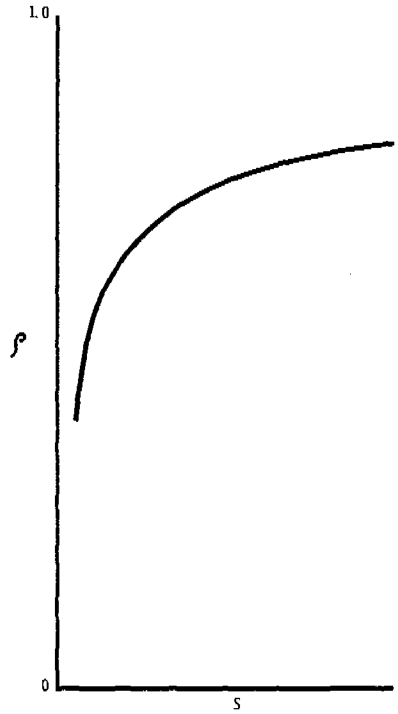

Figure 9.--Minimum net merchantability of residues (ρ) versus span (S) to avoid economic penalty for removal. (ρV_R is that function of gross residues volume, V_R, that is equivalent in value to the merchantable volume $\bar{\bar{V}}$.)

Obviously, for residues of the second class (i.e., those containing no merchantable volumes), there can be no economic justification for removal except insofar as other on-site treatment costs can be reduced.

INTERIM CONCLUSIONS

It seems clear from the foregoing that if road costs continue to increase and selective logging is prescribed with greater frequency, then road spacings and yarding distance capabilities will likewise be required to increase if economic penalties for operating below optimum spans are to be avoided. Correspondingly, the outlook for greater utilization of residues would be discouraging unless major reductions in yarding cost can be achieved.

As major goals for future harvesting technology, we see the following:

(1) Reduce total per acre management cost by providing the capability to yard at or beyond optimum spans.

(2) Reduce economic penalties associated with yarding distances or road spacings greater than the optimum.

We conclude that improved logging systems would offer the greatest opportunities for meeting these goals. In particular, yarding or stump-to-roadside operations would require the most improvement.

ANALYSIS OF PROSPECTS

We will now examine some possibilities for improving the stump-to-roadside transport situation. Our analysis assumes that little can be done to alter or reduce the cost of timber falling in steep terrain, at least in the near future, and that current labor intensive falling methods will continue indefinitely. The major opportunities for reducing the difficulties and costs of falling appear to be in reducing or eliminating the need for limbing and bucking in the woods through whole tree extraction and roadside processing.

We will consider opportunities for technological innovation in three areas:

(1) Aerial systems

(2) Cable yarding systems

(3) Combination yarding and forwarding systems

Aerial Systems

Three classes of aerial systems are analyzed in appendix E: (1) "small" helicopters, (2) "large" helicopters, and (3) "giant" airships. Based on these analyses, figure 10 shows an apparent potential for larger capacity helicopters or airships to achieve the desired goals of lower costs and reduced economic penalties for operating beyond optimum road spacings. However, as shown in the bottom portion of the figure, this potential can only be realized when production rates are in the order of 25 to 50 times those of "conventional" technology. Unless we can solve the logistical problems associated with falling and concentrating loads of logs or stems at rates sufficient to match the yarding production capacity of large aerial systems, it seems unlikely that the potential cost savings shown in figure 10 will be realized.

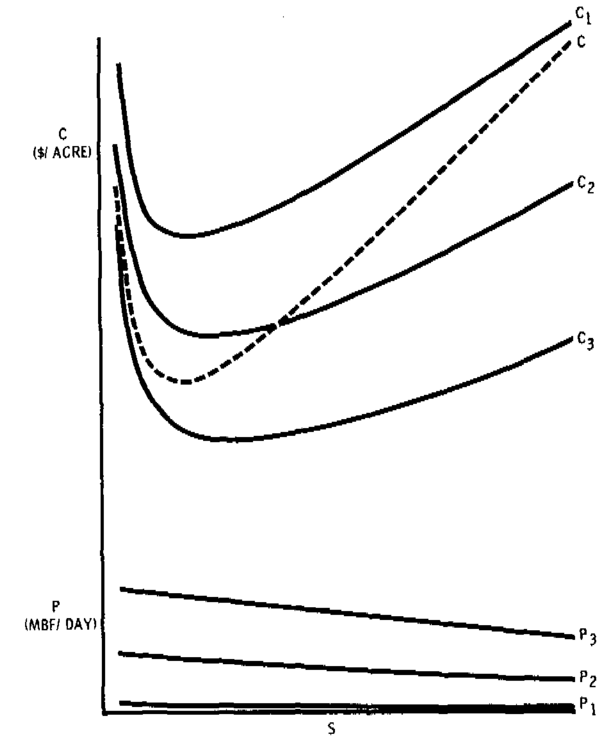

Figure 10.--Total per acre management costs (C) and daily production rates (P) versus span (S) with three classes of aerial systems. (C and P represent small helicopters, C_2 and P_2 represent large helicopters, C_3 and P_3 represent giant airships, and C is from figure 4.)

Cable Yarding Systems

With cable yarding systems, it would seem that opportunities for meeting our improvement objectives would be as follows:

(1) Increase load capacity

(2) Increase speed

(3) Reduce system cost

Increasing load capacity implies increasing either cable tensions or deflections. Given the prospects for harvesting smaller timber in the future, the difficulties associated with anchoring to resist higher cable tensions must be carefully considered. Increasing cable deflections--either through use of intermediate supports or by extending spans to take advantage of mountainous topography would be more likely to be acceptable.

Increasing the load capacity of yarding systems is likely to require some type of pre-bunching or load concentration in advance of or in conjunction with yarding, especially if selective logging of smaller timber is to be a common practice in the future. Simultaneously, pre-bunching should permit a reduction in yarding system labor requirements, assuming that pre-bunching is done in such fashion as to eliminate or reduce the need for pre-setting chokers.

Finally, it may be reasonable to assume that carriage speeds could be increased without appreciable increases in yarding equipment costs.

Appendix F contains an analysis based on a set of assumptions regarding all three of the above improvement objectives, and figure 11 illustrates the results of this analysis. As emphasized in appendix F, the assumptions used in developing figure 11 are exceedingly optimistic. Nevertheless, there appear to be significant opportunities for improving both conventional cable yarding systems and the procedures by which they are used, to reduce both total management costs and economic penalties for operation beyond optimum spans.

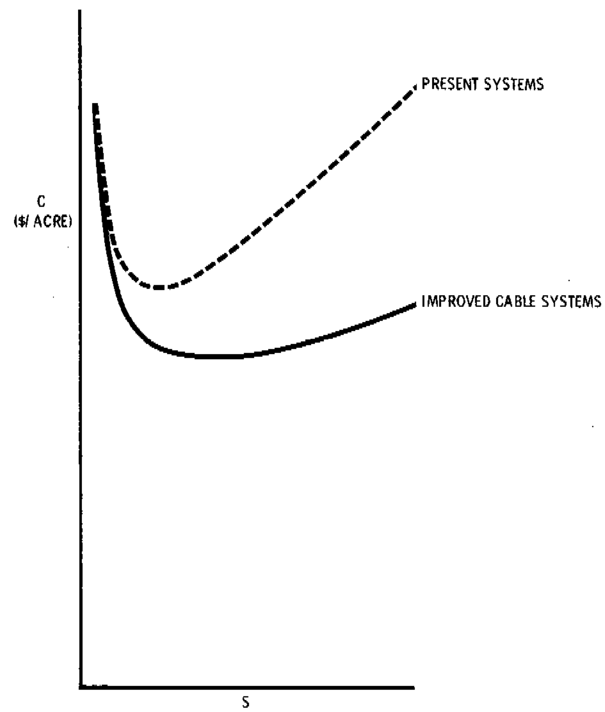

Figure 11.--Potential effect of cable systems improvements on total management cost (C) versus span (S). (Curve labeled "present systems" is from figure 4.)

Combination Yarding and Forwarding Systems

From the foregoing analyses, we realize that when using relatively high road densities (or relatively short yarding distances), road costs have a dominant influence on total management costs per acre. In contrast, at relatively low road densities (or relatively long yarding distances), road costs per acre become relatively minor, while yarding production costs exert the dominating influence on total management cost.

This suggests that, if we could (1) provide relatively inexpensive access for on-site-work--including timber falling and yarding of stems and logs, and (2) transport inexpensively large loads of stems and logs over relatively long distances, we might realize significant improvements both economically and environmentally.

Recently, attention has focused on giant airships to fulfill the latter objective, but little attention has been given to the former objective. Moreover, the sizes of airships being proposed are such that their economic feasibility depends on large quantities of available timber--so large that coordination among numerous logging operations or between logging operations and other transportation tasks may be necessary to justify operation. There are both institutional and natural limits on the scale of technology, and some proposed airships may exceed these limits.

What, then, might we envision as an alternative to airships that would fulfill our objective of low cost, relatively long distance "roadless" transport without commensurate institutional problems and large energy requirements?

The situation represented in figure 12, where a system of "trails" spaced nominally at 10 percent of the road spacing, presents a potential solution. Appendix G analyzes the possibilities of this situation, in which some yet undeveloped yarding, forwarding and personnel transport technologies are assumed. Figure 13 illustrates the potential effects of such technologies on total management cost in comparison with present circumstances and with the optimistic cable yarding possibilities discussed previously.

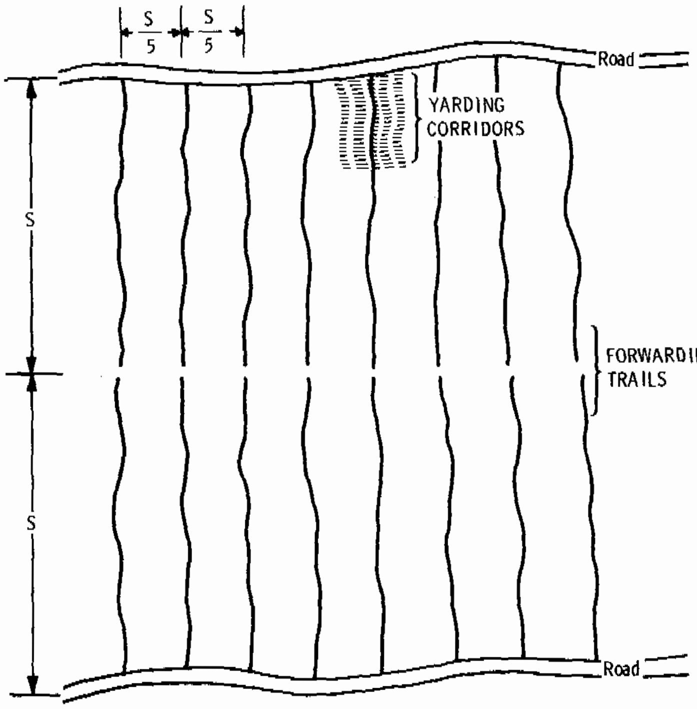

Figure 12.--Layout of roads, forwarding trails, and yarding corridors for hypothetical new yarding-forwarding systems.

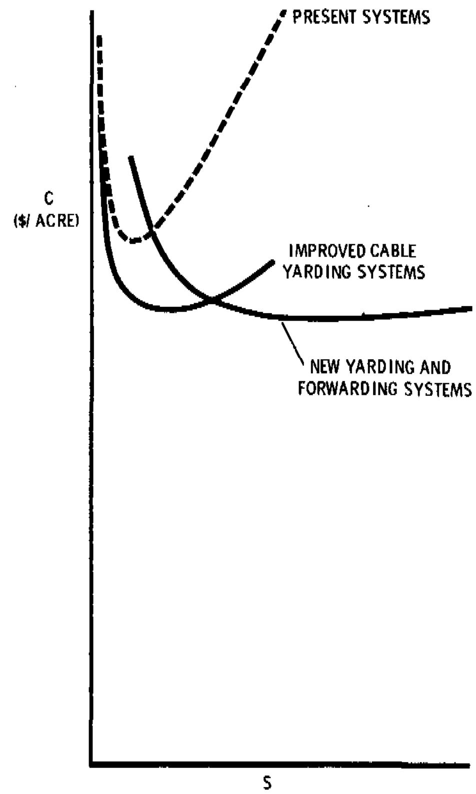

Figure 13.--Potential effects of technological improvements on total management cost (C) versus span (S). (Curves labeled "present systems" and "improved cable yarding systems" are from figure 11.)

SUMMARY AND CONCLUSIONS

As economic and environmental constraints become more severe, as timber sizes decline, and as more of the timber supply is derived from steep, difficult terrain, the prospects grow bleaker for new harvesting technology that will significantly reduce the costs of logging and total forest management. We can envision concepts that would appear to reduce the economic penalties of forest management in adverse circumstances, but it is unlikely that significant cost reductions will occur in the future.

Given the greater opportunities for logging mechanization in gentle terrain, it is virtually certain that management of steep terrain will always be economically disadvantageous. Nevertheless, timber in mountainous terrain is a resource that presumably will be needed. Therefore, there is strong justification for seeking less costly alternatives for extracting and replacing this resource.

Recognizing the risks, obstacles, and costs inherent in the development of radically new technology, it seems prudent first to seek improvements through "small" changes in existing technology and procedures. Given the likelihood of increasing labor, energy, and road construction costs, greater restrictions on road location in difficult terrain, and the likelihood of more intense utilization and more partial or selective logging, the following approaches seem to offer moderate changes for cost reductions or improved operability:

(1) Extension of cable yarding distance capabilities

(2) Increasing the transport speeds of cable yarding systems

(3) Pre-bunching on site in combination with falling operations

Of course, increasing the load carrying capabilities of yarding systems also would theoretically lower costs; but it must be recognized that increasing load capabilities creates greater anchoring problems and/or the need for intermediate skyline supports. Moreover, greater difficulties are encountered in assembling larger loads as timber sizes decline.

The prospects for aerial yarding systems, such as helicopters and airships, are theoretically good, but the difficulties in providing sufficient timber to utilize their capabilities must be recognized and dealt with.

The prospects of a radically new, "trail-based" yarding and forwarding technology are appealing from both economic and environmental standpoints, and such a technology would seem almost as universally applicable as aerial systems. However, a gigantic effort would be required for development of such technology in a short period of time.

Although we have not dealt with the issue of in-woods processing, we suspect there are numerous opportunities for adoption or development of new handling, sorting, processing, and truck loading technologies. Indeed, there may be promising alternatives to conventional trucks for transporting wood products from forest landings to manufacturing facilities.

Finally, and perhaps most important, it must be recognized that minimizing logging costs may not--and probably will not--minimize total on-site forest management costs. In addition, depending on the transportation and harvesting technologies applied, the economic penalties for extending yarding distances beyond economic optima may be acceptable. Thus, while the economic justifications for modifying or developing harvesting technologies may be weak, there may be strong environmental and political reasons for doing so.

APPENDIX A

General Cost Model Derivations

ROAD COSTS

If the average distance between roads (road spacing) is $K_S S$ (where S is the average maximum yarding distance or span, in feet, and K_S is a coefficient reflecting whether the yarding system can yard in one or both directions to the road system), then the average total acreage accessed by each mile of road will be

$$\frac{5280\ (K_S S)}{43560} \approx 0.121\ (K_S S)$$

If only a fraction (say, K_A) of the acreage accessed by the road system will be harvested or otherwise considered appropriate for road cost allocation, then the average acreage over which costs for each mile of road will be distributed is

$$0.121 K_A K_S S$$

Therefore, if road costs are C_R dollars per mile, road costs per acre served (RC) will be

$$RC = \frac{C_R}{0.121 K_A K_S S} = K_R \frac{C_R}{S} \quad ,$$

where $K_R = \dfrac{1}{0.121 K_A K_S}$

For example, if the yarding system can yard both uphill and downhill over average spans of S (feet), then $K_S = 2$ and average road spacing would be $K_S S = 2S$ (feet); and if road costs were to be allocated over the entirety of the acreage accessed, then $K_A = 1$. Accordingly,

$$K_R = \frac{1}{0.121(1)(2)} = 4.125 \text{ ft-mi/acre}$$

and

$$RC = 4.125 \frac{C_R}{S}$$

Alternatively, if the yarding system could yard only in an uphill direction to the road, then $K_S = 1$; and, if $K_A = 1$, then $K_R = 8.25$. But if only half the total acreage accessed by a road system contains resources that would justify the roads, then $K_A = 0.5$; and if $K_S = 1$, then $K_R = 16.5$ ft-mi/acre.

LABOR INTENSIVE COSTS

There are many reconnaissance, inventory, and planning activities that occur before roads are constructed, involving both aerial and on-site methods. These will be ignored in this derivation and considered to be a part of general forest management cost, similar to cost of fire surveillance. However, once roads are in place, the costs for on-the-ground cruising, timber marking, boundary surveying, slash disposal, planting and other activities before and after harvesting are affected by road spacing. We recognize that the cost per acre for some of these activities, such as unit boundary surveying and marking or fire line construction, are dependent upon the sizes and shapes of the harvest units. Nevertheless, we will ignore relationships between unit perimeters and unit areas in this development. Basically, we need consider only the production rate for on-site activities and the distance from site to road.

In any workday, the hours spent by a worker in walking to and from the work site may be expressed as

$$2\left(\frac{1}{2}\right)\left(\frac{K_S S}{2}\right)\left(\frac{1}{V_w}\right) = \frac{K_S S}{2V_w}$$

where $K_S S/2$ is the average maximum distance, in feet, from roadside to the work site; and V_w is the average walking speed, in feet per hour. If the total available time in a workday is T hours (exclusive of time spent in vehicle travel at the beginning and end of the workday) then the average net time available for work on site is

$$T - \frac{K_S S}{2V_w} = T\left(1 - \frac{K_S S}{2TV_w}\right) .$$

If the hourly production rate for the i^{th} labor intensive activity is P_i, in acres/hour, then the acres treated per workday will be, on the average,

$$P_i T_i \left(1 - \frac{K_S S}{2T_i V_w}\right) ,$$

and the cost per acre treated will be

$$\frac{C_i}{P_i T_i}\left(\frac{1}{1 - \frac{K_S S}{2T_i V_w}}\right)$$

where C_i is the daily cost for labor, equipment, travel, and administration corresponding to the hourly production rate of P_i, and T_i is the available working hours in the workday for the i^{th} system.

Therefore, letting

$$K_i = \frac{K_S}{2T_i V_w} ,$$

the total of all labor intensive costs will be

$$LIC = \sum_{i=1}^{m} \frac{C_i}{P_i T_i} \left(\frac{1}{1 - K_i S} \right)$$

where m is the total number of discrete pre-and post-harvest labor intensive activities or treatments to be conducted, and LIC is expressed in dollars per acre so treated.

As an example, suppose the i^{th} activity is lopping and scattering of slash after logging, and the i^{th} system is a worker and chainsaw. Suppose C_i is \$100 per day, P_i is 0.1 acre per hour, and T_i is 6 hours per workday. If $K_S = 2$ and $V_w = 2500$ ft/hr, then $K_i = 6.67 \times 10^{-5}$ ft.$^{-1}$ and, if S = 1000 ft., then $K_i S = 0.067$. Accordingly,

$$\frac{C_i}{P_i T_i} \left(\frac{1}{1 - K_i S} \right) = \$178.57/\text{acre} \quad .$$

Note that $C_i/P_i T_i$ = \$166.67/acre is the basic cost for lopping and scattering in this example, where no time is used walking from the roadside to the work site.

LOGGING COSTS

Logging comprises three major elements: (1) falling, limbing and bucking, (2) yarding or skidding, and (3) loading and hauling.

In most circumstances, the falling system is a sawyer and chainsaw and, as such, can be treated in a manner analogous to that used for other labor intensive work. That is, the sawyer must spend time walking to and from his work site each day--just as does a timber cruiser or tree planter--and the amount of such time depends on the average distance between roads. During the remaining available time, the sawyer will have an hourly production rate, say P_f, that is most conveniently expressed in volume or number of stems or logs processed per hour. The cost for a sawyer, say C_f, can be expressed in dollars per day.

If $\overline{V}$ represents the total volume (or number of stems or logs) per acre to be processed by the sawyer, then the cost per acre for falling, limbing and bucking (FC) during any particular entry can be expressed as

$$FC = \frac{C_f \overline{V}}{P_f T_f} \left(\frac{1}{1 - \frac{K_S S}{2 T_f V_w}} \right)$$

where P_f and $\overline{V}$ are expressed in compatible units. T_f is the available working hours in the workday and S, K_S, and V_w are as previously defined. Letting

$$K_f = \frac{K_S}{2 T_f V_w} \quad .$$

we can express falling, limbing and bucking costs as

$$FC = \frac{C_f \overline{V}}{P_f T_f} \left(\frac{1}{1 - K_f S} \right) .$$

It should be noted that P_f will depend on a large number of variables, including stand characteristics, silvicultural prescription, utilization standards, and terrain.

Skidding or yarding fallen timber is conducted by systems of workers and machines (or animals). Most of these systems require some time to set up or prepare to move wood, the amount of which depends on the average transport distance (or length of span, in the case of cable yarding systems). For example, ground skidding systems (e.g., horses or tractors) require skid trail clearing and landing preparations, and cable yarding systems must be moved from corridor to corridor. Perhaps only helicopters can be considered unique in this respect; whatever their necessary preparatory expenditures, they are generally unrelated to the yarding transport distance.

If the time, in minutes, spent in preparatory or rigging activities can be estimated as

$$R_0 + R_1 S$$

and the area served by a single set up (i.e., skid trail or corridor) is

$$b\ S$$

(where b is the average distance between skid trails or corridors, in feet), then the set-up or rigging time, in hours/acre, for skidding or yarding is

$$\frac{43560}{(60)b} \left(\frac{R_0}{S} + R_1 \right) .$$

Now, if the average skidding or yarding cycle time, in minutes, can be expressed as

$$Y_0 + Y_1 S + Y_2 b + Y_3 n$$

(where n is the average number of stems or logs extracted per cycle and Y_0, Y_1, Y_2 and Y_3 are time coefficients), then the operating time, in hours per acre, for skidding or yarding will be

$$\frac{(\overline{V} + V_R)}{60(v)} \quad (Y_0 + Y_1 S + Y_2 b + Y_3 n) \quad ,$$

where v is the average volume per cycle and V_R represents the residues quantity to be extracted per acre in excess of the quantity processed by the sawyers ($\overline{V}$), all expressed in equivalent units. Therefore, the total yarding or skidding cost, in dollars per acre, will be

$$YC = \frac{C_y}{60 T_y} \left[\frac{43560}{b} \left(\frac{R_0}{S} + R_1 \right) + \frac{(\overline{V} + V_R)}{v} \quad (Y_0 + Y_1 S + Y_2 b + Y_3 n) \right]$$

where C_y is the daily cost, in dollars, for the yarding or skidding system, and T_y is the available on-site hours per workday.

Finally, we may assume that loading and hauling costs relate only to volume, so the cost per acre for these operations may be expressed simply as

$$HC = C_h\,(\overline{V} + V_R)$$

where C_h is the loading and hauling cost per unit volume, with the unit volume being consistent with the units of $\overline{V}$ and V_R.

APPENDIX B

Effects of Road Spacing or Span

To examine this matter, we make the assumptions listed in table B-I. Note that $K_S = 2$ (i.e., the yarding system can yard both uphill and downhill to the road system).

If S = 1000 feet, equation 8 yields

$$b_{opt} = \sqrt{\frac{43560\ \text{ft}^2/\text{acre}\ \left(0.3\ \frac{\text{MBF}}{\text{cycle}}\right)\left(\frac{30\ \text{min.}}{1000\ \text{ft.}} + 0.03\ \frac{\text{min.}}{\text{ft}}\right)}{(0.0125\ \text{min/cycle - ft})\ (10\ \text{MBF/acre})}}$$

or $b_{opt} = 79.2$ ft.;

and equation 9 yields

$$C = 4.125\left(\frac{50{,}000}{1000}\right) + 210\ \left[\frac{1}{1 - 0.05}\right] + 20\ (10)\ \left[\frac{1}{1 - 0.05}\right] + \frac{1000}{60(8)}\ \left\{2\sqrt{\frac{43560\ (0.0125)\ (10)\ \left(\frac{30}{1000} \bullet 0.03\right)}{0.3}}\right.$$

$$\left. + \frac{10}{0.3}\ [3 + 0.0025\ (1000) + 0.1\ (3)]\right\} + 20\ (10)$$

or C ≈ \$1378/acre.

Table B-II shows the total management cost (C) and components thereof, the daily production rate (P), and the optimum spacing between corridors versus yarding distance or span (S) under the assumptions in table B-I. Note that the daily production rate is determined from

$$P = \frac{C_y\overline{V}}{YC}$$

Table B-I.--Basic assumptions.

$$\frac{C_f}{P_f T_f} = \$20/\text{M bd. ft.}$$

$$C_h = \$20/\text{M bd. ft.}$$

$$C_R = \$50{,}000/\text{mi}$$

$$C_y = \$1{,}000/\text{day}$$

$$K_A = 1$$

$$K_S = 2$$

$$\sum_{i=1}^{m} \frac{C_i}{P_i T_i} = \$210/\text{acre}$$

$$n = 3 \text{ pieces/cycle}$$

$$R_0 = 30 \text{ min}$$

$$R_1 = 0.03 \text{ min/ft}$$

$$T_i = 8 \text{ hours/day; } i = 1, 2, \ldots m$$

$$T_y = 8 \text{ hours/day}$$

$$\overline{V} = 10 \text{ M bd. ft./acre}$$

$$V_R = 0$$

$$V_w = 2{,}500 \text{ ft/hr}$$

$$Y_0 = 3 \text{ min/cycle}$$

$$Y_1 = 0.0025 \text{ min/cycle-ft.}$$

$$Y_2 = 0.0125 \text{ min/cycle-ft.}$$

$$Y_3 = 0.1 \text{ min/cycle-piece}$$

$$v = 0.3 \text{ M bd. ft./cycle}$$

$$K_R = \frac{43560}{5280 K_A K_S} = 4.125 \text{ ft-mi/acre}$$

$$K_f = K_i = \frac{K_S}{2 T_i V_w} = 5\text{x}10^{-5} \text{ ft}^{-1}\text{; } i=1, 2, \ldots m$$

Table B-II.--Costs and production rates vs. span, under the assumptions in table B-1.

S (ft)	b_{opt} (ft)	RC ($/acre)	LIC ($/acre)	FC ($/acre)	YC ($/acre)	HC ($/acre)	C ($/acre)	P (M bd. ft./day)
250	125.2	825	212.7	202.5	490.0	200	1,930.2	20
400	104.8	515.6	214.3	204.1	480.5[1]	200	1,614.5	21
500	97.0	412.5	215.4	205.1	484.4	200	1,517.4	21
1,000	79.2	206.2	221.1	210.5	540.3	200	1,378.1	19
1,100	77.4	187.5	222.2	211.7	554.5	200	1,375.9[1]	18
2,000	68.6	103.1	233.4	222.2	695.5	200	1,454.2	14
3,000	64.7	68.8	247.1	235.3	862.3	200	1,613.5	12
4,000	62.6	51.6	262.5	250.0	1,032.3	200	1,796.4	10
5,000	61.3	41.2	280.0	266.7	1,203.7	200	1,991.6	8

[1] Designates minimum costs.

APPENDIX C

Effects of Reducing Cutting Intensity

Continued controversy relative to timber harvesting, and a tendency to increase the use of selective or partial cutting, tend to reduce the volumes per acre. Thus, consider the effect of reducing $\bar{V}$ from 10 M bd. ft./acre to 5 M bd. ft./acre, while retaining all remaining assumptions in table B-I. The resulting costs are shown in table C-I, and they show that the optimum yarding distances with respect to both yarding cost alone and total management cost are increased in comparison with table B-II. Moreover, the economic penalties incurred in total management cost by extending yarding distances beyond optimum are less severe as volume removed per acre is decreased.

Table C-I.--Costs and production rates vs. span for selective logging example. (C_1 = total first entry management cost)

S (ft)	b_{opt} (ft)	RC ($/acre)	LIC ($/acre)	FC ($/acre)	YC ($/acre)	HC ($/acre)	C_1 ($/acre)	P (M bd. ft./day
250	177.1	825	212.7	101.3	290.0	100	1,529.0	17
500	137.2	412.5	215.4	102.6	277.1[1]	100	1,107.6	18
1,000	112.0	206.2	221.1	105.2	298.6	100	931.1	17
1,500	102.2	137.5	227.0	108.1	333.5	100	906.1[1]	15
2,000	97.0	103.1	233.4	111.1	372.4	100	920.0	13
3,000	91.5	68.8	247.1	117.6	454.4	100	987.9	11
4,000	88.5	51.6	262.5	125.0	538.7	100	1,077.8	9
5,000	86.8	41.2	280.0	133.4	623.9	100	1,178.5	8

[1] Designates minimum costs.

Of course, when costs are expressed in terms of the merchantable volume removed, they become higher as volume decreases, as shown in Table C-II.

Table C-II.--Comparison of costs per unit of merchantable volume for complete ($C/\overline{V}$) and partial ($C_1/\overline{V}_1$) removal on first entry.

S (ft)	$C/\overline{V}$ [1] $\overline{V}$ = 10 M bd. ft./acre ($/M bd. ft.)	$C_1/\overline{V}_1$ $\overline{V}_1$ = 5 M bd. ft./acre ($/M bd. ft.)
250	193.0	305.8
500	151.7	221.5
1,000	137.8	186.2
2,000	145.4	184.0
3,000	161.4	197.6
4,000	179.6	215.5
5,000	199.2	235.7

[1]Based on appendix B.

If, on second entry, the remaining volume ($\overline{V}_2$) is removed, where

$$\overline{V}_2 = \overline{V} - \overline{V}_1 = 10 - 5 = 5 \text{ M bd. ft./acre},$$

then we may assume no road costs but that all remaining costs are the same as in table C-I. Table C-III shows the total of the second entry management costs, C_2, as well as the combined total of first and second entry costs ($C_1 + C_2$) and the corresponding combined cost per unit volume, or

$$\frac{C_1 + C_2}{\overline{V}_1 + \overline{V}_2} = \frac{C_1 + C_2}{\overline{V}} .$$

Table C-III.--Second entry costs and combined first and second entry costs vs. span for selective logging example.

S (ft)	C_2 ($/acre)	$C_1 + C_2$ ($/acre)	$(C_1 + C_2)/\overline{V}$ ($/M bd. ft.)
250	704.2	2,233.4	223.3
500	695.1	1,802.7	180.3
1,000	724.9	1,656.0	165.6
2,000	816.9	1,736.9	173.7
3,000	919.1	1,907.0	190.7
4,000	1,026.2	2,104.0	210.4
5,000	1,137.3	2,315.8	231.6

APPENDIX D

Effects of Residues Removal

Suppose (1) that residues with characteristics similar to merchantable timber (e.g., standing or down dead trees) are to be removed, (2) that their volume, V_R, is equivalent to 2.5 M bd. ft./acre, (3) that the sawyer's rates must be increased (to compensate for falling or processing the residues) from $20 per M bd. ft. to $25 per M bd. ft., and (4) that all else in table B-I remains unchanged. Accordingly, the total management cost per acre, $C_{\overline{V} + V_R}$, and the corresponding cost per merchantable volume would be as shown in table D-I.

Table D-1.--Total management cost per acre and per unit of merchantable volume vs. span for V_R = 2.5 M bd. ft./acre and C_f/P_fT_f = $25/M bd. ft.

S (ft)	$C_{\overline{V} + V_R}$ ($/acre)	$C_{\overline{V} + V_R}/\overline{V}$ ($/M bd. ft.)
250	2,124.6	212.5
500	1,717.5	171.8
1,000	1,597.6	159.8
2,000	1,717.8	171.8
3,000	1,923.0	197.3
4,000	2,152.6	215.3
5,000	2,395.2	239.5

If removal of residues causes no reduction in other site treatment costs (e.g., slash disposal) then, to avoid economic penalty, it is necessary that the residues contain an equivalent net merchantable volume of ρV_R, where

$$\rho \geq \frac{\overline{V}}{V_R}\left(\frac{C_{\overline{V} + V_R}}{C} - 1\right) .$$

Table D-II shows the minimum values of ρ needed to enable removal of the residues in this example.

Table D-II.--Minimum values of ρ vs. span for residues removal example ($\overline{V}$ = 10 M bd. ft./acre, V_R = 2.5 M bd. ft./acre)

S (ft)	$C_{\overline{V}+V_R}$[1] ($/acre)	C[2] ($/acre)	ρ
250	2,124.6	1,930.2	0.40
500	1,717.5	1,517.4	0.53
1,000	1,597.6	1,378.1	0.64
2,000	1,717.8	1,454.2	0.73
3,000	1,923.0	1,613.5	0.77
4,000	2,152.6	1,796.4	0.79
5,000	2,395.2	1,991.6	0.81

[1]From table D-I.
[2]From Table B-II.

APPENDIX E

Analysis of Aerial Yarding Systems Prospects

We may assume that "rigging time" for aerial systems is negligible, and that there is no lateral yarding component in the yarding cycle. Accordingly, we may rewrite the expression for total per acre management cost as

$$C = K_R \frac{C_R}{S} + \sum_{i=1}^{m} \frac{C_i}{P_i T_i} \left(\frac{1}{1 - K_i S}\right) + \frac{C_f \overline{V}}{P_f T_f} \left(\frac{1}{1 - K_f S}\right) + \frac{C_y}{60 T_y} \frac{(\overline{V} + V_R)}{v} (Y_0 + Y_1 S + Y_3 n) + C_h (\overline{V} + V_R) \quad . \qquad \text{(E-1)}$$

Consider first a "small" helicopter system. Assume its cost, C_y, is $2,000 per day; its speed is such that Y_1 = 0.00025 min/cycle-ft.; its load carrying capability is such that v = 0.1 M bd. ft./cycle and n = 1 piece/cycle; that Y_0 = 2 min/cycle; and that all else is as assumed in table B-I. Table E-I shows the resulting costs based on equation E-1, as well as the corresponding daily production rates. (Note that the production rates in table E-I are comparable to those for the yarding system in table B-II.)

Table E-I.--Costs and yarding production rates for small helicopter system.

S (ft)	RC ($/acre)	LIC ($/acre)	FC ($/acre)	YC ($/acre)	HC ($/acre)	C ($/acre)	P (M bd. ft./day)
250	825.0	212.7	202.5	901.0	200	2,341.2	22.2
500	412.5	215.4	205.1	927.1	200	1,960.1	21.6
1,000	206.2	221.1	210.5	979.2	200	1,817.0	20.4
2,000	103.1	233.4	222.2	1,083.3	200	1,842.0	18.5
3,000	68.8	247.1	235.3	1,187.5	200	1,938.7	16.8
4,000	51.6	262.5	250.0	1,291.7	200	2,055.8	15.5
5,000	41.2	280.0	266.7	1,395.8	200	2,183.7	14.3

Next, consider a relatively "large" helicopter system, costing $20,000 per day, and having a load carrying capability equivalent to v = 2 M bd. ft./cycle. As for the small helicopter, we assume Y_1 = 0.00025 min/cycle-ft. and Y_0 = 2 min/cycle. However, we assume also that falling costs are doubled, owing to the need to gather or bunch stems or logs such that n = 1 "piece"/cycle. (We are assuming here the existence of some unspecified technology that would permit a sawyer or team of sawyers to maneuver logs or stems over short distances on steep slopes such that small piles or bunches equivalent to the helicopter's load capability would result.) Table E-II shows the costs and production rates for this system.

Table E-II.--Costs and yarding production rates for large helicopter system.

S (ft)	RC ($/acre)	LIC ($/acre)	FC ($/acre)	YC ($/acre)	HC ($/acre)	C ($/acre)	P (M bd. ft./day)
250	825.0	212.7	405.0	450.5	200	2,093.2	444
500	412.5	215.4	410.2	463.5	200	1,701.6	432
1,000	206.2	221.1	421.0	489.6	200	1,537.9	408
2,000	103.1	233.4	444.4	541.7	200	1,522.6	369
3,000	68.8	247.1	470.6	593.8	200	1,580.3	337
4,000	51.6	267.5	500.0	645.8	200	1,659.9	310
5,000	41.2	280.0	533.4	697.9	200	1,752.5	287

Finally, we assume the possibility of using some new, large capacity airship costing $20,000 per day and having a load capacity of v = 10 M bd. ft./cycle and a cruising speed equivalent to Y_1 = 0.0005 min./cycle-ft. We will further assume that its acceleration and deceleration rates, and its load retrieval rates, are such that Y_0 = 4 min/cycle and Y_3 = 1 min/cycle-piece; and again that n = 1 "piece"/cycle and that falling costs are doubled to account for load concentration in the woods. Table E-III shows the estimated costs and production rates for this system.

Table E-III.--Costs and production rates for hypothetical airship.

S (ft)	RC ($/acre)	LIC ($/acre)	FC ($/acre)	YC ($/acre)	HC ($/acre)	C ($/acre)	P (M bd. ft./day)
250	825.0	212.7	405.0	213.5	200	1,856.2	937
500	412.5	215.4	410.2	218.8	200	1,456.9	914
1,000	206.2	221.1	421.0	229.2	200	1,277.5	873
2,000	103.1	233.4	444.4	250.0	200	1,230.9	800
3,000	68.8	247.1	470.6	270.8	200	1,257.3	739
4,000	51.6	262.5	500.0	291.7	200	1,305.8	686
5,000	41.2	280.0	533.4	312.5	200	1,367.1	640
10,000	20.6	420.0	800.0	416.7	200	1,857.3	480
15,000	13.8	840.0	1,600.0	520.8	200	3,174.6	384

APPENDIX F

Analysis of Cable Yarding System Prospects

Consider the optimistic prospect that, by pre-bunching in advance of yarding, the average load capacity could be doubled. Consider further that carriage speed could be doubled and that, because of pre-bunching, the system cost could be reduced by 25 percent as a result of labor savings. Finally, assume that pre-bunching could be accomplished by sawyers through some unspecified technology that would merely double their production costs.

In accordance with our optimism, let v = 0.6 M bd. ft./cycle; Y_1 = 0.00125 min/cycle-ft; C_y = $750/day; C_f/P_fT_f = $40/M bd. ft.; n = 2 "pieces"/cycle; and assume that all remaining values are as in table B-I. The results are shown in table F-I, based on equations 8 and 9 in the text.

Table F-I.--Costs and production rates vs. span for optimistic improvements in cable yarding technology.

S (ft)	b_{opt} (ft)	RC ($/acre)	LIC ($/acre)	FC ($/acre)	YC ($/acre)	HC ($/acre)	C ($/acre)	P (M bd. ft./day)
250	177.1	825.0	212.7	405.0	206.8	200	1,849.5	36
500	137.2	412.5	215.4	410.2	188.9	200	1,427.0	40
1,000	112.0	206.2	221.1	421.0	188.8	200	1,237.1	40
2,000	97.0	103.1	233.4	444.4	211.6	200	1,192.5	35
3,000	91.5	68.8	247.1	470.6	240.5	200	1,227.0	31
4,000	88.5	51.6	262.5	500.0	271.2	200	1,285.3	28
5,000	86.8	41.2	280.0	533.4	302.6	200	1,357.2	25

APPENDIX G

Combination Yarding and Forwarding Systems

Consider the possibility that trail-based harvesting technologies could be devised such that yarding systems capable of spanning 1,000 feet could be maneuvered on trails, and that forwarding systems could move logs on these trails to truck roads. Obviously, personnel could also be readily transported on the trails.

Let the average distance between truck roads be represented by 2S, and assume that the average distance between trails would be 0.2S. If C_T represented the total cost per mile for trails, and if $K_A = 1$, then the average cost per acre served by the trails would be

$$TC = \frac{43560C_T}{5280(0.2S)} = 41.25 \; \frac{C_T}{S} \quad .$$

Obviously, the cost per acre served by the truck roads would still be

$$RC = 4.125 \; \frac{C_R}{S} \quad .$$

Now, based on our prior analysis, the cost per acre for labor intensive work, including falling, would be multiplied by a factor of

$$\left(\frac{1}{1 - \frac{0.1S}{T_i V_w}}\right) ,$$

because the walking distance would have been reduced by a factor of 10. Similarly, the model for yarding cost would be modified; thus,

$$YC = \frac{C_y}{60T_y} \left[\frac{43560}{b}\left(\frac{R_0}{0.1S} + R_1\right) + \frac{\left(\overline{V} + V_R\right)}{v} \left(Y_0 + 0.1Y_1S + Y_2b + Y_3n\right)\right] \quad .$$

Our forwarding system would cost C_F dollars per day, and its average travel distance would be S/2. Accordingly, the hours spent per acre for forwarding would be

$$\frac{\left(\overline{V} + V_R\right)}{60v_f} \left(Y_{f0} + Y_{f1}S + Y_{f3}n_f\right)$$

where v_f is the volume carried per forwarding cycle; Y_{f0} is the average fixed amount of time, in minutes, spent in each cycle (such as for maintenance, decking of logs at the truck roads, etc.); Y_{f1} is the travel time coefficient in min/cycle-ft.; Y_{f3} is the minutes per piece for loading and unloading the forwarder; and n_f is the number of pieces transported per cycle.

Accordingly, if loading of trucks and truck hauling costs remained the same as at present,

$$\text{or } C_h\left(\overline{V} + V_R\right) \quad ,$$

then our total cost per acre would become

$$C = 4.125\,\frac{C_R}{S} + 41.25\,\frac{C_T}{S} + \sum_{i=1}^{m} \frac{C_i}{P_i T_i}\left(\frac{1}{1 - \frac{0.1S}{T_f V_w}}\right) + \frac{C_f \bar{V}}{P_f T_f}\left(\frac{1}{1 - \frac{0.1S}{T_f V_w}}\right) + \frac{C_y}{60T_y}\left[\frac{43560}{b}\left(\frac{R_0}{0.1S} + R_1\right) + \frac{(\bar{V} + V_R)}{v}\,(Y_0 + 0.1Y_1 S + Y_2 b + Y_3 n)\right] + \frac{C_F}{60T_F}\,\frac{(\bar{V} + V_R)}{v_f}\,(Y_{f0} + Y_{f1}S + Y_{f3}n_f) + C_h\,(\bar{V} + V_R) \quad . \tag{G-1}$$

The optimum spacing between yarding corridors would now be

$$b_{opt} = \sqrt{\frac{43560(v)\left(\frac{R_0}{0.1S} + R_1\right)}{Y_2\,(\bar{V} + V_R)}} \quad , \tag{G-2}$$

so that when equation G-2 is substituted for b in equation G-1, the total per acre management cost becomes

$$C = 4.125\,\frac{C_R}{S} + 41.25\,\frac{C_T}{S} + \sum_{i=1}^{m} \frac{C_i}{P_i T_i}\left(\frac{1}{1 - \frac{0.1S}{T_f V_w}}\right) + \frac{C_f \bar{V}}{P_f T_f}\left(\frac{1}{1 - \frac{0.1S}{T_f V_w}}\right) + \frac{C_y}{60T_y}\left[2\sqrt{\frac{43560\ Y_2\ (\bar{V} + V_R)\ (R_0/0.1S + R_1)}{v}} + \frac{(\bar{V} + V_R)}{v}\,(Y_0 + 0.1Y_1 S + Y_3 n)\right] + \frac{C_F}{60T_F}\,\frac{(\bar{V} + V_R)}{v_f}\,(Y_{f0} + Y_{f1}S + Y_{f3}n_f) + C_h\,(\bar{V} + V_R) \quad . \tag{G-3}$$

Now, because we would be operating from trails, it is likely that forwarding rates would have to be compatible with yarding rates. Accordingly, before proceeding further, we should examine whether operation in this fashion would be technically feasible.

Compatibility of Forwarding and Yarding Systems

Compatibility of the forwarding and yarding systems means essentially that the time spent per acre by each of the systems should be approximately equal, or that

$$2\sqrt{\frac{43560\ Y_2\ (\bar{V} + V_R)\ \left(\frac{R_0}{0.1S} + R_1\right)}{v}} + \left(\frac{\bar{V} + V_R}{v}\right)(Y_0 + 0.1Y_1 S + Y_3 n) = \frac{(\bar{V} + V_R)}{v_f}\ (Y_0 + Y_{f1}S + Y_{f3}n_f) \quad .$$

From this we can obtain

$$Y_{f1} = \frac{v_f}{(\bar{V} + V_R)S}\left[2\sqrt{\frac{43560\ Y_2\ (\bar{V} + V_R)\left(\frac{R_0}{0.1S} + R_1\right)}{v}} + \frac{(\bar{V} + V_R)}{v}\,(Y_0 + 0.1Y_1 S + Y_3 n) - \frac{(\bar{V} + V_R)Y_{f0}}{v_f} - (\bar{V} + V_R)Y_{f3}\,\frac{n_f}{v_f}\right] \quad .$$

Because our yarding system is likely to be of lower power and lower load carrying capability than conventional systems, n and v will probably be less, and Y_1 will probably be greater than for conventional systems. Nevertheless, to be conservative, we will assume these factors to be unchanged--that is, that n = 3 pieces/cycle, v = 0.3 M bd. ft./cycle, and Y_1 = 0.0025 min/cycle-ft.

We will assume further that $Y_{f0} = Y_0$ = 3 min/cycle, but that $Y_{f3} = 10\ Y_3$ = 1 min/piece (recall from table B-I that Y_3 = 0.1 min/cycle-piece). Retaining Y_2 = 0.0125 min/cycle-ft, $(\bar{V} + V_R)$ = 10 M bd. ft./acre, R_0 = 30 min, R_1 = 0.03 min/ft, and assuming $n_f/v_f = n/v$ = 10 pieces/M bd. ft., we obtain the following relationship:

$$Y_{f1} = 0.1\,\frac{v_f}{S}\left[269.4\,\sqrt{\frac{300}{S} + 0.03} + 33.3\,(3.3 + 0.00025S) - \frac{30}{v_f} - 100\right]$$

Our worst condition would occur when S is large and v_f is small. Suppose, for example, that S = 10,000 feet and $v_f = 2v$ = 0.6 M bd. ft./cycle. Then Y_{f1} would have to be less than or equal to 0.00065 min/cycle-ft, which is equivalent to an average forwarder speed of 1 ÷ 0.00065 = 1538 ft/min, or about 17 miles per hour. If $v_f = 4v$ = 1.2 M bd. ft./cycle, and S = 10,000 feet, the average forwarder speed would only need to be about 7 miles per hour.

In short, it would appear technically feasible to maintain forwarder production equivalent to yarder production over relatively long distances. Of course, the forwarder would probably be under-utilized at shorter distances, but for simplicity and conservatism, we will assume the forwarding costs would be lumped with yarding costs. Accordingly, we may rewrite equation G-3 as follows:

$$C = 4.125\,\frac{C_R}{S} + 41.25\,\frac{C_T}{S} + \sum_{i=1}^{m} \frac{C_i}{P_i T_i}\left(\frac{1}{1 - \frac{0.1S}{T_i V_w}}\right) + \frac{C_f \bar{V}}{P_f T_f}\left(\frac{1}{1 - \frac{0.1S}{T_f V_w}}\right) + \frac{(C_y + C_F)}{60T_y}\left[2\sqrt{\frac{43560\,Y_2\,(\bar{V} + V_R)\left(\frac{R_0}{0.1S} + R_1\right)}{v}} + \frac{(\bar{V} + V_R)}{v}\,(Y_0 + 0.1Y_1 S + Y_3 n)\right] + C_h\,(\bar{V} + V_R) \quad . \qquad \text{(G-4)}$$

Assuming $C_y + C_F$ = \$1,000/day, that $C_T = 0.1\ C_R$ = \$5,000/mi, and that all other values remain the same as in table B-I, we obtain the results listed in table G-I.

Table G-I.--Costs and production rates vs. S for combined yarding and forwarding system.

Road Spacing (ft)	S (ft)	b_{opt} (ft)	RC ($/acre)	TC ($/acre)	LIC ($/acre)	FC ($/acre)	Yard & forward ($/acre)	HC ($/acre)	C ($/acre)	P (M bd. ft./day)
2,000	1,000	185.7	206.3	206.3	211.1	201.0	569.0	200	1,593.7	18
4,000	2,000	137.2	103.1	103.1	212.1	202.0	502.0	200	1,322.3	20
8,000	4,000	104.8	51.6	51.6	214.3	204.1	480.5	200	1,202.1	21
12,000	6,000	91.5	34.4	34.4	216.5	206.2	492.1	200	1,183.6[1]	20
16,000	8,000	84.0	25.8	25.8	218.8	208.3	513.9	200	1,192.6	19
20,000	10,000	79.2	20.6	20.6	221.1	210.5	540.3	200	1,213.1	18

[1]Designates optimum.

OUTLOOK AND OPPORTUNITY FOR WHOLE-TREE CHIP QUALITY IMPROVEMENT

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ABSTRACT

Three processes have been developed in the United States, one in Canada, and one in Finland for improving the quality of whole-tree and forest residue chips. They have potential application individually or in combination. Two of them have been applied commercially by the pulp and paper industry. Application of these processes coupled with integrated utilization of the various output wood, bark, and foliage fractions for fiber and energy products should promote the recovery of more forest residues.

KEYWORDS: bark removal, residues, biomass, utilization, foliage removal

INTRODUCTION

The demand for wood and fiber products is projected to increase due to high energy costs and a decreasing forest land base. The forest industry can help meet the projected increase by improving the recovery and utilization of forest residues.

Enormous quantities of forest residues are generated annually throughout the country. In the Eastern United States, there is an estimated potential annual supply of slightly over 200 million dry tons (USDA Forest Service 1978). National forests in the Pacific Northwest, California, and Northern Rocky Mountains annually generate 24 million, 15 million, and 5.5 million tons respectively of residue (Lowery and Host 1978). The cost of extracting and processing these residues for wood fiber products or other uses exceeds that of using available standing round wood or sawmill residues.

Whole-tree harvesting could recover a large portion of these unutilized materials economically. By this method entire trees are skidded to the landing, the more valuable saw logs are bucked out, then the tops and limbs are chipped. Non-saw-log trees, including culls, are chipped on the spot. Whole-tree harvesting should result in lower residue recovery costs for the following reasons:

- The available fiber is more completely utilized by chipping of tops, limbs, small trees, and other material currently abandoned as residues. Yield increases in tons per acre over conventional harvesting can reach 150 percent.
- Slash treatment, site preparation, and regeneration costs are reduced by removal of all the material from the stand.
- Chips can be handled easier than round wood. Chips are small and can be transported continuously as a bulk commodity over long or short distances using belts, conveyors, or pneumatic pipelines.
- Since several trees can be chipped at a time if the stems are small, chipping productivity is unaffected by tree size.
- Delimbing and bucking are reduced considerably. Only the saw log portion of trees requires delimbing and bucking.

Four factors that have promoted the great activity in research, development, and utilization of whole-tree chips are the steady growth of pulp markets, the abrupt increases in the cost of energy, the increasing public and environmental pressure to more fully utilize the forest biomass, and the development of mechanized harvesting.

The amount of whole-tree or unbarked chips acceptable in a specific mill depends upon its pulping process, cleaning facilities, and end product specifications. A number of pulp mills are using whole-tree or forest residual chips by blending small percentages of them with other "clean" chips. Although some mills have used over 30 percent barky chips, most mills have limited their use to less than 20 percent. The number of mills using whole-tree chips has decreased in recent years due to an adequate supply of clean chips and/or problems that were encountered in their initial trials with whole-tree chips. Widespread use of forest residues for pulp and paper will depend on methods for improving the quality of forest residual chips.

To increase utilization, field chipping of residues--including whole trees--must be coupled with an effective system for removing the bark from the chip mass. This paper reviews significant progress made in bark segregation in the United States, Canada, and Finland. The segregation processes developed have the potential of not only upgrading residue chips but also producing a valuable fuel. The processes could be the key to an integrated fiber and fuel raw material supply system for the future.

RESEARCH BY THE USDA FOREST SERVICE

Research in improving whole-tree chip quality has been conducted by the North Central Forest Experiment Station's Forestry Sciences Laboratory at Houghton, Michigan. The research has resulted in three promising processes--steaming-compression debarking, vacuum-airlift segregation, and photosorting (Arola and Erickson 1973; Mattson 1975; Sturos 1978; Sturos and Brumm 1978). Combinations of the above processes are also possible.

The patented steaming-compression debarking process (Erickson and Hillstrom 1974) basically consists of three steps: (1) presteaming the unbarked chip mass, (2) passing the chips through a compression debarker, and (3) screening the compression debarker output to remove fines (fig. 1). Additional (optional) steps include mechanical attrition of the smaller chip output fractions followed by screening to remove additional fines.

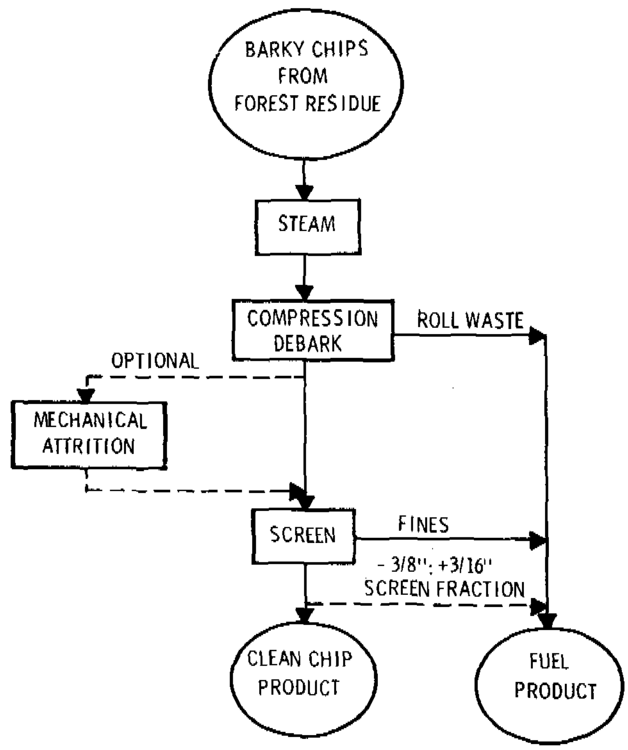

Figure 1.--Flow chart of the steaming-compression system for upgrading forest residue chips.

Bark removal tests have been conducted with western forest residues using the steaming-compression debarking process (Arola and Host 1976). Bark removal ranged from 60 to 85 percent and wood recovery from 87 to 92 percent with the lodgepole pine, ponderosa pine, Douglas-fir, and western larch residue chips. The output bark content ranged from 1 percent for lodgepole pine to 7 percent for western larch. However, by rejecting the 3/16-inch screen fraction from the output, bark content in the output was reduced to less than 4 percent for all four species. This, however, decreased the wood recovery to a range of 72 to 84 percent.

Successful chip debarking trials have also been conducted with three additional western species, namely, western hemlock, red alder, and bigleaf maple (Hillstrom 1974). Best results were obtained with red alder; more than 92 percent of the input bark was removed and 92 percent of the input wood fiber was recovered (table 1). The clean output chips had a bark content of 1.7 percent compared to 20.4 percent in the input.

The Forest Service steaming-compression debarking process has been put into practice commercially by Parsons & Whittemore, Inc. who designed and built a debarking plant at their St. Anne Nackawic pulp mill in New Brunswick, Canada. The plant has been operating since April 1975 processing all of their hardwood whole-tree chips. The plant capacity is rated at 10 oven-dry tons per hour. The bark content of their whole-tree chips has been reduced from 12 to 3.6 percent with a wood loss of 9 percent (Wawer and Misra 1977). One major advantage of the compressed chips is that the cooking time in the digester decreased by 9 percent.

Table 1.--Compression debarking of whole-tree chips of four western species (Hillstrom 1974)

(In percent)

Species	Treatment[1]	Input bark	Output bark	Bark removed	Wood recovered
Western hemlock	SCD	16.0	4.1	74	92
Douglas-fir	CD	15.5	7.9	49	91
Red alder	SCD	20.4	1.7	92	92
Bigleaf maple[2]	CD	15.8	5.8	64	92

[1]SCD - Presteaming, compression debarking, and mechanical attrition
CD - Compression debarking and mechanical attrition.
[2]Chips produced from stem only.

A second steaming-compression debarking pilot plant has been erected and operated at Saint-Gaudens, France, by Groupement Européen de la Cellulose (GEC) (Tyrode et al. 1977). The process consists of four stages as follows: prescreening, steaming, compression debarking, and postscreening. After 1 year of operation the bark level of a mixture of French hardwoods has been reduced from 18.8 percent to 7.8 percent with 5 percent or less wood loss. The compressed hardwood chips have not modified the physical properties of the pulp made with their kraft process. A better liquor penetration has been obtained, thereby requiring less alkali and a reduction in pulp screenings. Promising results have also been obtained with softwoods.

A 60 green ton per hour debarking plant using presteaming, compression debarking, and screening should process whole-tree chips for an estimated $7.58 per dry output ton, exclusive of raw materials costs (Biltonen et al. 1979). The total physical plant cost is estimated to be about $4 million, including about $1.6 million for the process equipment.

A vacuum-airlift segregator has also received laboratory scale testing both by the USDA Forest Service and by industry (Sturos and Marvin 1978). This consists of a wire mesh conveyor belt with vacuum hoods placed above the belt at various stations (fig. 2). Whole-tree chips are spread over a continuously moving conveyor belt passing through fields of air currents that subject the chips to vacuum forces from above the belt. The material is then segregated on the basis of differences in terminal settling velocities caused by density and geometric differences. Typically in a multiple-stage system, foliage, clean wood chips, and middlings are removed at different locations along the belt. Bark, knots, and twigs remain on the belt to discharge to a hog fuel product area. Fines, including bark, foliage, dirt, and grit, fall through the mesh belting and discharge to the hog fuel pile.

The "middlings" fraction contains from 30 to 50 percent of the total input material, depending on species, and has a bark content equal to or greater than the as-received whole-tree chips. This fraction can be used for pulp, particleboard, fuel, or chemicals. If the middlings are to be used for pulp, further beneficiation by the compression debarking process is recommended.

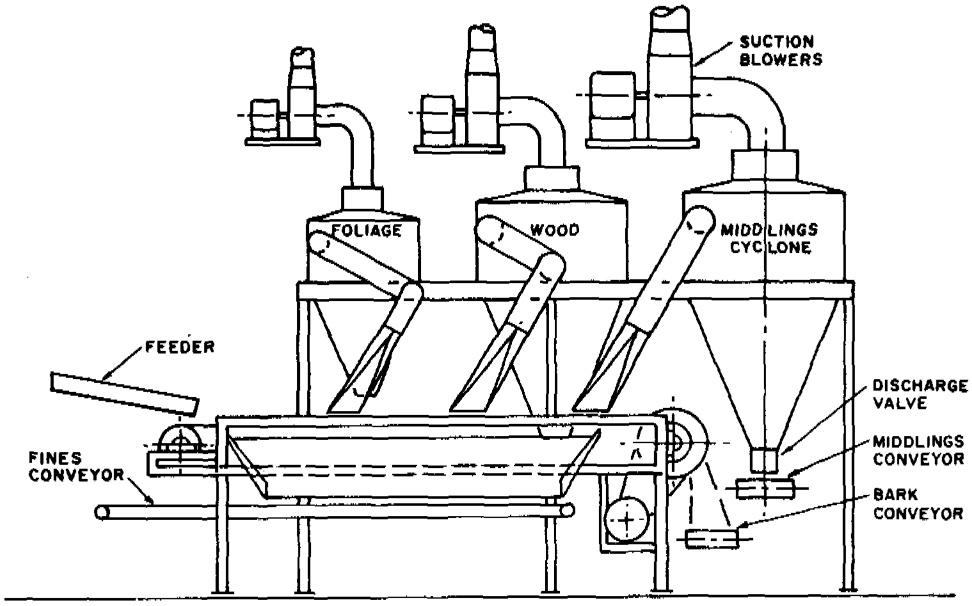

Figure 2.--Multiple-stage vacuum-airlift segregator. Fines fall through the wire mesh conveyor.

For maximum recovery of "clean" fiber, a combined system is recommended (fig. 3). It consists of vacuum-airlift segregation followed by steaming-compression debarking of the middlings. Typical results for Lake States aspen is as follows: By means of the vacuum-airlift stage, 4 percent of the input is removed as commercial foliage, 4 percent falls through the wire mesh conveyor as fines, 42 percent is recovered as clean wood chips acceptable for pulping, 36 percent is recovered as middlings, and 14 percent is left on the conveyor primarily as bark (fuel). Passing the middlings through the compression debarker results in an additional 29 percent clean wood chips and 7 percent bark. The combined product recovery results are 71 percent fiber, 25 percent fuel, and 4 percent foliage.

A limited amount of testing was conducted on western forest residues with vacuum-airlift segregation alone and in combination with compression debarking (Lowery et al. 1977). The vacuum-airlift stage recovered 38 to 85 percent of the input wood with bark levels of 1.5 to 3.6 percent (table 2). Processing the middlings from the vacuum-airlift segregator through the steaming-compression debarking process increased the wood recovery to 95 to 99 percent with bark levels of 1.9 to 5.1 percent in the combined output.

Several cost analyses of the steaming-compression debarking system, the vacuum-airlift system, and combinations of these two systems have revealed that the combined system is the most cost efficient. One of the primary advantages of coupling the vacuum-airlift segregator and the compression debarker is to decrease the amount of material the compression debarker has to process, which in turn reduced steam requirements and the size of the press. Therefore both capital equipment and beneficiation costs are reduced. The beneficiation costs (excluding raw material costs) are estimated to range from $7.85 per dry ton of debarked chips for a steaming-compression debarking system, to $5.60 for a combined system in which only 34 percent of the material is compression debarked. Total capital investment for a 60 ton per hour debarking plant ranges from about $4 million for a steaming-compression debarking plant to $2 million for a combined vacuum-airlift and steaming-compression system.

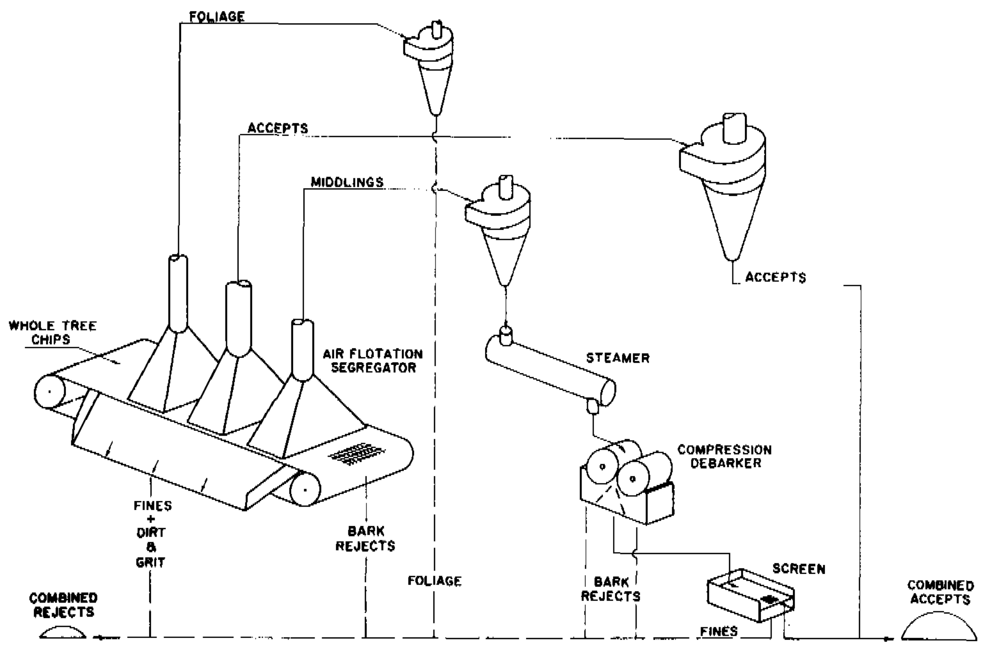

Figure 3.--Combined vacuum-airlift and steaming-compression debarking process for upgrading whole-tree and forest residual chips.

Table 2.--Bark removal results obtained with the vacuum-airlift system alone and in combination with the compression debarking system (Lowery et al. 1977)

(In percent, dry weight)

			Vacuum-airlift segregation		Vacuum-airlift and compression debarking		
Species	Condition	Input bark	Output bark	Wood recovered	Output bark	Bark removed	Wood recovered
Engelmann spruce	Green	13.4	3.0	79	4.1	73	99
Engelmann spruce	Dead standing	12.3	1.5	38	1.9	87	96
Western larch	Dead down	8.6	3.6	85	5.1	45	95

As mentioned earlier, the combined system is recommended for pulp mills needing a fiber supply where maximum "clean" wood recovery is the prime objective. In the near future many powerplants, both at forest industrial sites and others, will likely be fueled with whole-tree and/or forest residue chips. To help cover the potentially higher costs of recovering forest residues, an effort should be made to "scalp off" some clean pulp chips from the incoming wood because of the high value of pulp chips compared to fuel chips. As indicated in table 2, 38 to 85 percent of the input wood can be recovered with acceptable bark levels from western residue chips through the use of the vacuum-airlift segregator alone. Cost to install a 20 ton per hour vacuum-airlift system into an already existing plant has been estimated to be $175,000. The processing cost would be about $1 per input ton with a total connected horsepower of 205.

Photosorting has also been investigated at the laboratory scale by the USDA Forest Service. Wood and bark chips differ sufficiently in their optical transmittance to be sortable (Sturos and Brumm 1978). During photosorting, the chips are fed by a conveyor over a linear array of optical detectors (fig. 4). Light from an incandescent source is incident on the chips from above. The light intensity is adjusted so that most wood chips transmit sufficient light to be sensed by the detector array. When a bark chip passes over the detectors, the transmitted light falls below a preset detection threshold and the detector photo current decreases. The resulting signal is amplified to energize an air valve, which deflects the bark chips with a blast of air (fig. 5). Promising results have been obtained with three Lake States species, namely, balsam fir, white spruce, and aspen (table 3): 84 to 92 percent of the bark has been removed while recovering 58 to 65 percent of the wood. Photosorting should be considered as only a part of a total chip debarking system. It could be used ahead of the steaming-compression debarking process similar to the vacuum-airlift segregator, to "scalp off" a clean chip fraction. A modular 8 green ton per hour capacity photosorter is estimated to cost less than $40,000.

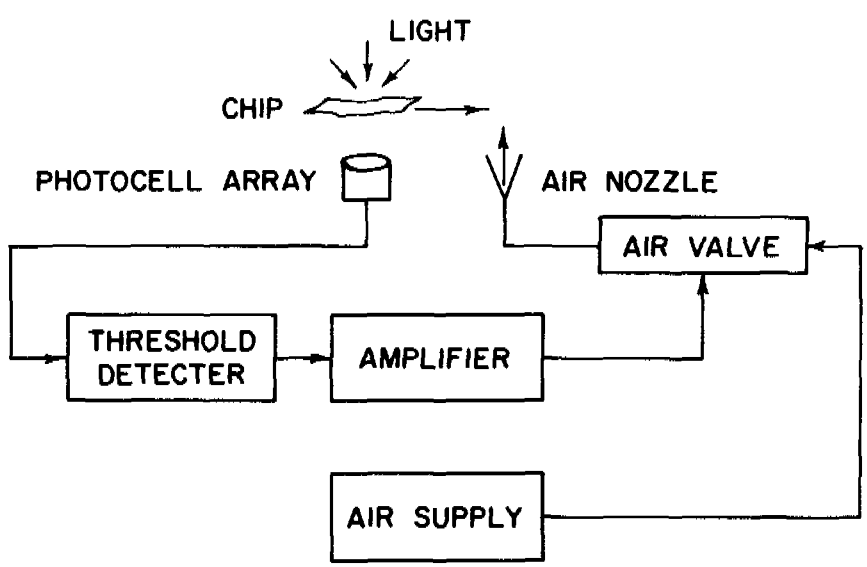

Figure 4.--Photosorting system diagram.

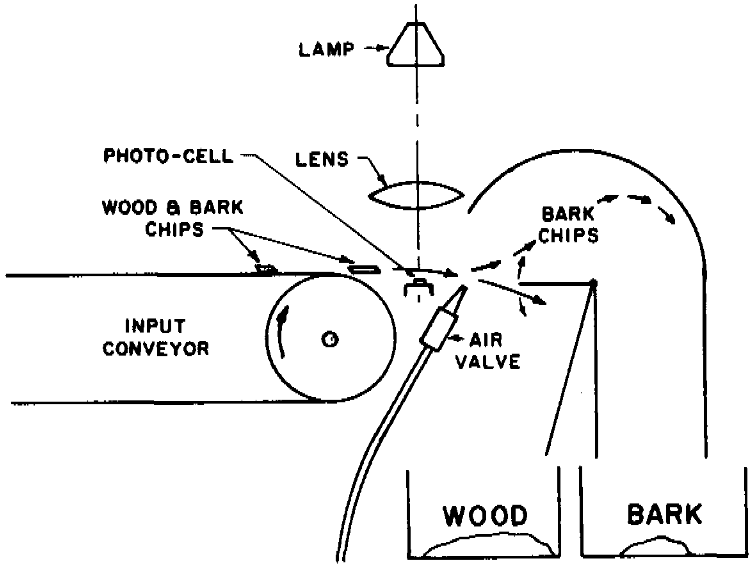

Figure 5.--Mechanical configuration of the photosorting system.

Table 3.--Typical photosorting results with the 5/8-inch size chips of three Lake States species

(In percent)

Species	Input bark	Output bark	Wood recovered	Bark removed
Balsam fir	10.2	1.3	64	92
White spruce	5.9	1.4	58	87
Aspen	10.3	2.7	65	84

RESEARCH BY PPRIC AND FERIC[1]

The Pulp and Paper Research Institute and the Forest Engineering Research Institute of Canada have developed a patented process for upgrading whole-tree chips (Berlyn et al. 1979). The method consists of three stages:

[1]PPRIC - Pulp and Paper Research Institute of Canada

FERIC - Forest Engineering Research Institute of Canada

- Conditioning by storing the chips in a pile or by steaming to increase the difference in strength between wood, bark, and foliage.
- Agitating in water to separate the bark and foliage from the wood and then breaking the bark and foliage down into small fragments.
- Segregating the fragmented bark and foliage from the wood chips by washing them over a screen plate.

Six weeks of storage in a chip pile or six to ten minutes of steaming at atmospheric pressure is generally required as a conditioning pretreatment. The process is designed to be set up as either a batch or continuous process. The Canadian researchers have experienced some problem with the thick outer bark on some species. However they do report good bark removal even from bark/wood chips (tight bark) and twigs, so as to reduce the bark/foliage content of whole-tree softwood chips from 20 percent to 2 percent with 91 to 96 percent wood recovery. They estimate the capital cost of a 220 O.D. ton per day batch process to be about $1 million with operating costs ranging between $3.70 and $7.40 per ton of whole-tree chips. The batch process would consist of a 15-minute processing cycle in a 12-foot diameter pulper (agitation chamber). Advantages noted are that the process has application to both softwood and hardwood and that the process uses no specialized or new equipment. Two disadvantages are the recycling and treatment of the waste water required and the low solid content of the bark/foliage fraction removed, thereby lowering the fuel value.

METHOD DEVELOPED IN FINLAND

A ballmilling process for beneficiating whole-tree and forest residual chips has been developed cooperatively in Finland by Kone Osakeyhtio and Enso-Gutzeit Oy (Hakkila et al. 1979). The process begins by removing oversized material, including stones, with a disc screen (fig. 6). This is followed by removal of iron tramp metal with a magnet. From this point the whole-tree chips are fed into a revolving ballmilling drum where the bark and foliage are fragmented and subsequently segregated from the wood by two stages of screening. The first screening stage is a thickness sort on a disc screen. Overthick chips are rechipped and fed back through the disc screen. The material which passes through the disc screen is then conveyed to a flat screen where long slivers (over-long particles) are removed. They are rechipped and screened again. The fines removed are collected as hog fuel.

Experimental results with pine, birch, and alder whole-tree chips indicate that 15.9 to 21.3 percent input bark can be reduced to 3.4 to 5.4 percent bark in the output material with a range of wood recovery of 87.6 to 92.5 percent. The hog fuel rejects represent 23-25 percent of the input. The experimental trials were conducted with a pilot scale chip debarking plant built at the Enso-Gutzeit Oy site in Imatra, Finland. The capacity of the plant is 8 to 12 solid cubic meters (20 to 30 loose cubic meters) per hour. The manufacturer, Kone Osakeyhtio, estimates that the capacity of the plant can be increased to the 40-120 solid cubic meters per hour level. The power requirements of the process range from 12 to 25 kilowatt-hours per solid cubic meter.

The developers of the process consider the debarked chips acceptable for sulphate pulping. In addition they claim the following advantages:

- Neither water nor chemicals are used.
- The fuel value of the reject material is high and waste water problems are avoided.
- The labor requirement is small.

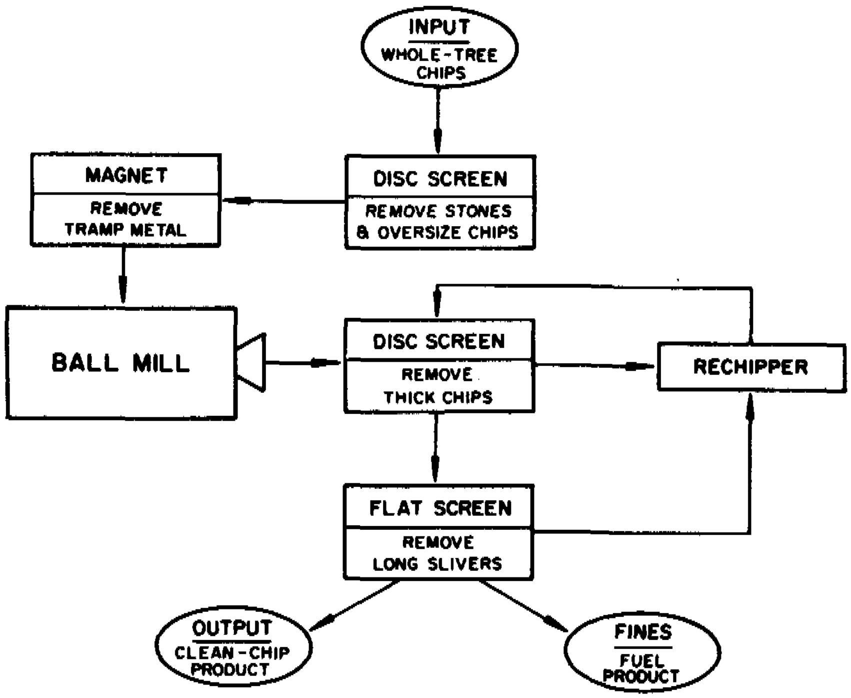

Figure 6.--Schematic of the Finnish ballmilling process for upgrading whole-tree chips.

SUMMARY

Significant progress has been made in developing the technology to improve the quality of whole-tree and forest residue chips. The USDA Forest Service has developed three methods: steaming-compression debarking followed by an optional ballmilling process, vacuum-airlift segregation, and photosorting. They have potential both individually and in combination. The steaming-compression debarking process has been scaled up to commercial pilot plants by St. Anne Nackawic Pulp and Paper Company, New Brunswick, Canada, and by Groupement Européen de la Cellulose (GEC), Saint-Gaudens, France. The Pulp and Paper Research Institute and the Forest Engineering Research Institute of Canada, Point Claire, Quebec, have developed a method for separating and breaking off bark. Whole-tree chips are exposed to microbial action during 6 weeks of storage and then subjected to heavy attrition motion in water in a device resembling a pulper. In Finland, Kone Osakeyhtio in cooperation with Enso-Gutzeil Oy has developed a whole-tree chip upgrading process based on ballmilling.

Certainly more and more residuals are going to be used in the future. Even though the major obstacle preventing widescale use of forest residues is the high harvesting and transporting costs, a considerable amount of tops and cull trees and logs can be recovered from ongoing logging operations by employing integrated harvesting techniques. The use of whole-tree chippers at the landing simultaneously with the saw log recovery system is usually the most economical way to recover residues for fiber and fuel.

To help pay for the high residue recovery costs, attention should be given to processing the residue chips so that they are allocated to the highest end value. The new chip upgrading processes presented in this paper can fractionate forest residue chips into clean wood chips for the pulp mill and bark, twigs, and poor quality wood chips for the boiler as hog fuel. The fuel value of the bark more than covers the operating cost of the chip debarking process.

Processes to improve whole-tree and residue chips will become a part of the total residue recovery system because they can provide both fiber and energy for the future. Fuller utilization of the forest biomass is rapidly becoming a necessity for the pulp and paper industry. Companies that do not provide close utilization for a sizable portion of their fiber and energy will find it more and more difficult to compete.

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EVALUATING IN-WOODS CHIPPING FEASIBILITY

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ABSTRACT

Economic analysis of data from a demonstration test showed that in-woods debarking-chipping was only marginally competitive with conventional methods of harvesting roundwood for pulp chips. The future for in-woods chipping appears to be whole tree chipping. Cost of delivered chips may not be much different from conventional roundwood systems unless credits are taken for increased utilization and slash disposal.

KEYWORDS: chipping machines, logging economics

In-woods chipping has received attention as an inexpensive means of producing pulp chips. Today, there is interest in using in-woods chipping in producing wood for energy. Whatever the intended use of the product, the technical and economic feasibility of in-woods chipping should be carefully evaluated before a commitment is made.

In 1973 the Rocky Mountain Forest and Range Experiment Station and National Forest and Range Experiment Station and National Forest System Regions 2 and 3 (Rocky Mountain and Southwestern), Four Corners Regional Commission, and Southwest Forest Industries, Inc. cooperated in a demonstration test of in-woods chipping. This paper presents an evaluation of the test results and uses the results to predict the future of in-woods chipping. The details of the demonstration test were reported in three published papers (Markstrom, Worth, and Garbutt, 1977; Sampson and Worth, 1976; Sampson, Worth and Donnelly, 1974).

IN-WOODS CHIPPING DEMONSTRATION TEST

The demonstration of in-woods chipping was a summer-long test in Arizona and Colorado. The chips produced were to be used for pulp. The receiving mill required that the chips be essentially bark-free.

System Used

The portable debarking-chipping machine used in the demonstration test was the Nicholson Logger Model Utilizer.1/ Trees were felled, limbed, and bucked with chainsaws by contract cutters, then bunched and skidded with rubber-tired and tracked skidders. Logs were stacked at the landing, partially by the skidders, and partially by a front-end loader. The self-loading debarker-chipper usually worked from a cold deck, although occasionally logs were skidded directly to it. Chips were blown directly into chip vans which hauled the chips either to the pulp mill or to a rail transfer point.

Study Area

The Arizona study area was part of an ongoing multiproduct sale in uneven-aged ponderosa pine timber marked for partial cutting. Sawtimber tops and trees smaller than sawtimber size (12 inches dbh) were being taken for pulpwood. Sawlogs and pulpwood were bucked at the stump and were skidded and decked together. Sawlogs were loaded and hauled from the decks leaving the pulpwood to be debarked and chipped at the landings. Some reskidding and consolidation of the pulpwood was necessary to obtain sufficient volumes in individual log decks. Chip haul distance from the woods to the pulp mill was about 75 miles.

The Colorado study area was an Engelmann spruce-subalpine fir tract marked for silvicultural thinning. It had been logged for sawtimber more than a year earlier. This area had a large volume of down and standing dead timber. All dead timber that was judged to be at least 50 percent sound was brought in along with the spruce-fir thinnings. Chips produced at the Colorado study area were truck hauled 146 miles to Gallup, New Mexico and reloaded on railroad cars for shipment the last 116 miles to the pulp mill.

Initial Concerns

Early questions about the feasibility of in-woods debarking-chipping were segregated into environmental concerns and economic concerns. While preliminary analyses had indicated in-woods debarking-chipping should be economically feasible, some problems were expected in the environmental realm.

ENVIRONMENTAL CONCERNS

It was expected that in-woods debarking-chipping would result in increased utilization and hence more wood removed per acre, but it was anticipated there would be little difference between the proposed system and conventional multi-product harvesting systems up to the point of debarking-chipping. Adverse environmental impacts from this part of the operation were not a major concern. However, there was concern about the size of forest openings necessary to accommodate the log deck, the debarker-chipper, chip vans, and turn around areas.

1/ The use of trade, firm, or corporation names does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Another major environmental concern was possible soil sterilization (nitrogen starvation) caused by disposing of bark on site. We developed data showing the bark depths that would likely occur if the bark were uniformly spread around the landing. However, there was no previous research which could be used to accurately predict the biological effects of spreading the bark and leaving it.

ECONOMIC CONCERNS

While it was anticipated that actual debarking-chipping cost would be slightly higher in the woods than at a permanent installation, it was believed that lower costs in the other functions would more than offset this. Under the in-woods operation, measuring and bucking to bolt lengths could be eliminated, allowing some efficiency in limbing and bucking, and utilization could be improved slightly. Skidding is affected only slightly because volume per turn is increased by about 1 percent. With in-woods debarking-chipping, loading of roundwood is eliminated. Also, hauling of bark (10 to 12 percent of the volume) is eliminated. Offsetting these advantages in part, chip vans are slightly less maneuverable on forest roads than log trucks, which increases haul time.

Considering all functions except debarking-chipping, it was estimated that the in-woods system should provide a cost advantage of $0-$5.00 per bone dry unit. (A bone dry unit is 2,400 pounds of chips at zero moisture content.) At that time, the assumed mill chipping cost was $3.20 per unit. Thus, an in-woods debarking-chipping cost of $8.20 or less per unit should result in an overall cost that could be competitive with the conventional system. Preliminary analyses had indicated an in-woods cost of $5-$6.00 per unit.

Methods

During the demonstration test, most effort was devoted to monitoring the operation of the debarker-chipper. The nature of the environmental concerns was such that numerical data could not be taken for analysis. Instead, general observations were made about environmental problems identified earlier.

Detailed data were taken on the debarking-chipping operation throughout the demonstration test period. Planned starting and stopping times were recorded each day. Delays of one minute duration or longer were noted along with the cause. Estimated dimensions of each piece chipped (end diameters to the nearest inch and length to the nearest foot) were recorded. Taking such detailed data was important for a fair analysis to be made.

To determine probable costs under improved conditions, estimates of production when the machine as actually operating were developed and then realistic delays representing optimum conditions were applied. The debarker-chipper's production was significantly affected by the lineal feed rate and the rate at which the operator loaded individual pieces onto the machine. The mechanics of the debarking operation required that only one piece could be processed at a time, and design of the machine resulted in a 6-foot space between pieces as they fed into the debarker. A computer simulation model incorporationg these characteristics was developed to predict chipping rate for various loading rates using data from the logs actually chipped as input.

Results

ENVIRONMENTAL IMPACTS

In the ponderosa pine type the landing sizes that resulted were acceptable to forest managers. Ten landings were used for chipping in the ponderosa pine type with an average of 48 units of chips produced at each landing. Landing sizes were, at the largest, 215 feet by 55 feet and were about what had been predicted. The open nature of the ponderosa pine type made the landings unobtrusive. In the spruce-fir type in Colorado, only one landing was used for producing the 421 units of chips. This landing was on a hill top which was not forested. Landings as large as those in the ponderosa pine type might have an adverse esthetic impact in some areas of dense spruce-fir.

Bark disposal was probably the environmental factor of greatest concern to forest managers prior to the field test. In the ponderosa pine type, bark was spread on the landing and in the adjacent residual timber stand by a front-end loader. After the debarking-chipping operation, it was not apparent that any bark had been spread, however, and further study of the long range effects of spreading the bark was not considered necessary. In the spruce-fir type, the bark was piled adjacent to the landing where it remained until after the field test, when it was spread on the landing with no apparent detrimental effect.

ECONOMIC ANALYSIS

Actual chip production averaged only 15 bone dry units per day over the 63 working day period for the debarker-chipper. At this rate, the cost of chipping alone would be about $38 per unit. However, the 63 day period included much time lost to various kinds of mechanical and logistic delays, some of which should be eliminated or reduced in an ongoing operation.

Excluding all delays, production rates were 7.9 bone dry units per net operating hour in Arizona and 7.6 units in Colorado (points A and B, respectively fig. 1). Maximum production was only about two-thirds of what had been predicted in the analysis done before the demonstation test. The debarking-chipping costs per bone dry unit for net production rates are shown in figure 2.

The abscissa scale of figure 2 is in terms of R and the different curves represent four combinations of the remaining variables as shown below:

Curve	T	U	M
Arizona (actual)	0.54	48	1.08
Colorado (actual)	0.54	-	None
Arizona (potential)	0.80	48	0.40
Colorado (potential)	0.80	-	None

For each curve it was assumed H (time per day available for chipping or moving) = 7.5.

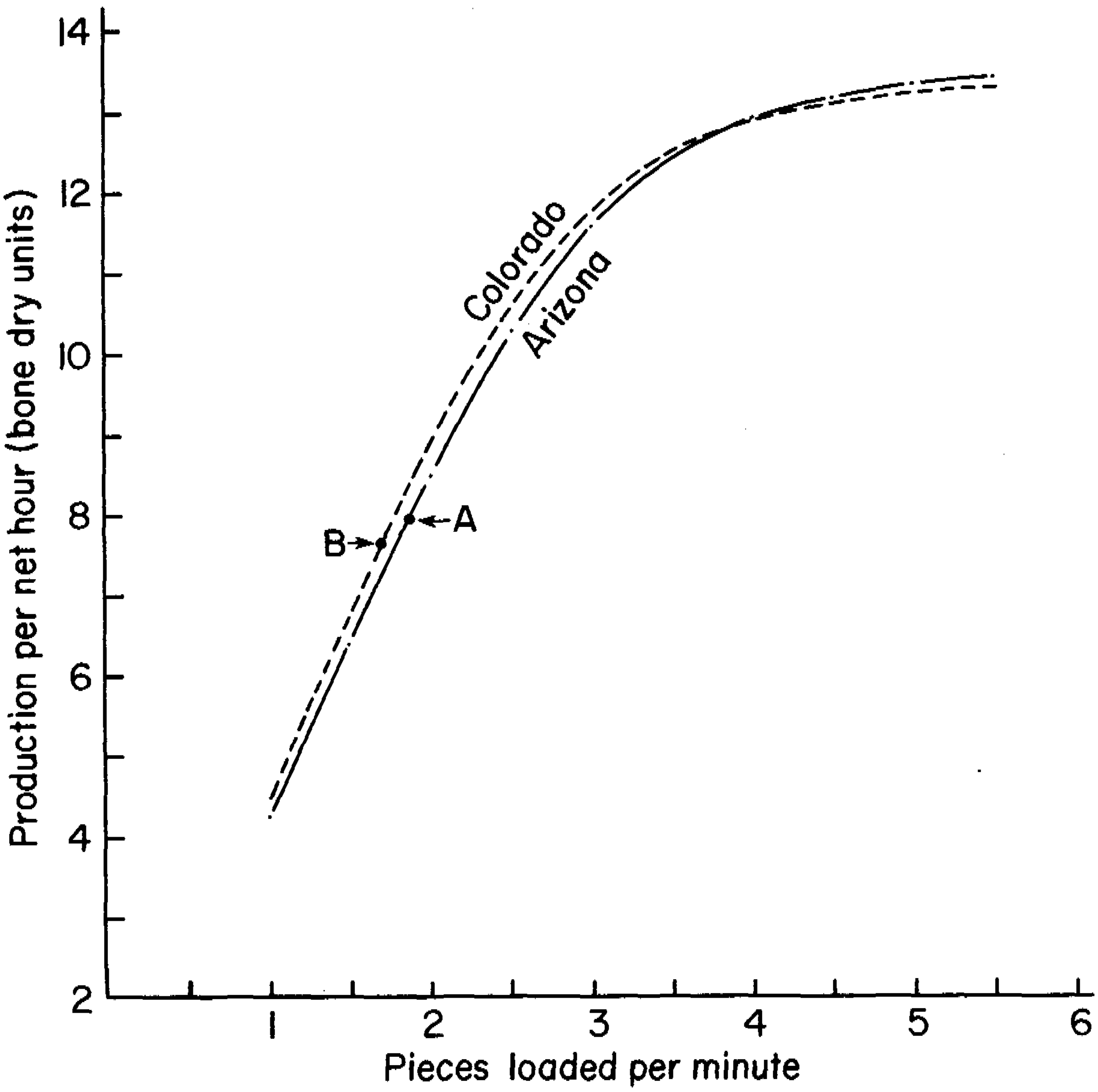

Figure 1.--Theoretical chipping rate in bone dry units per net hour at a feed rate of 85 feet per minute for actual pieces chipped.

The Arizona (actual) curve represents conditions similar to those that would have been encountered on the Arizona test area if startup problems and weather delays were eliminated. Point A on this curve represents the 7.9 bone dry units per net production hour experienced in actual operation. The Colorado (actual) curve represents conditions that would have been encountered in the Colorado test without startup and weather delays. Point B on this curve represents the 7.6 bone dry units per net production hour experienced during the field test. Moving time was not deducted since all production was at a single landing.

Curves Arizona (potential) and Colorado (potential) portray production and cost levels that would be achievable by increasing the porportion of net operating time from 54 to 80 percent and for curve Arizona (potential) decreasing the average time for moving the chipper from 65 to 24 minutes (Colorado (potential) assumes no moving). Points C and D, on these curves represent production when production per net hour is 11 bone dry units, which is probably near the maximum possible production for the size of pieces being chipped.

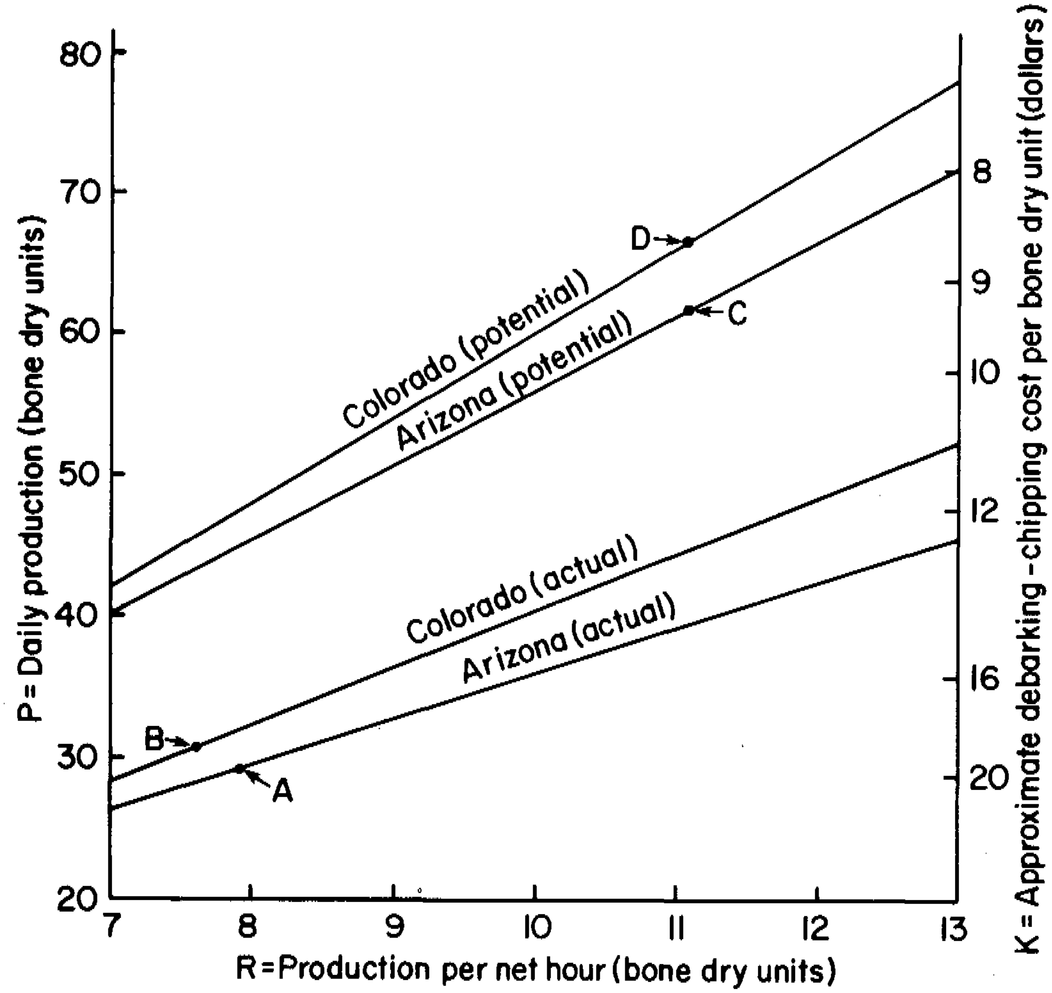

Figure 2.--Daily chip production and approximate cost by net production rate, size of log deck, proportion of available time in production, and moving time between log decks.

Daily productivity and cost are based on the following:

Time per log deck = $\frac{U}{R\,T} + M$

and

Log decks per day = $\frac{H \div}{\frac{U}{R\,T} + M}$

Thus the equations for the two ordinate (vertical) scales of the curves in figure 2 are given by:

$$P = \left[\frac{H}{\frac{U}{R\,T} + M}\right] U \text{ or } P = \frac{HRT}{1 + \frac{MRT}{U}} \text{ and } K = \frac{572.16}{P}$$

Where: P = daily production in units of chips.

H = hours per day available for chipping and moving the machine.

R = units of chips produced per net production hour.

T = percent of time available for chipping that the machine is actually in production, expressed as a decimal.

M = moving time (in hours) between decks.

U = number of bone dry units per deck.

K = cost per bone dry unit.

572.16 = average daily cost of operating the debarker-chipper system, in dollars.

Conclusions

The conclusion we reached after this study was that in-woods debarking-chipping, at best, was only marginally competitive with producing chips from stem wood transported to the mill. We also recognized that a promising way to lower chip costs was to eliminate the requirement for debarking. There is no doubt that whole-tree chipping can deliver chips to the mill at a lower cost than in-woods debarking-chipping. Disadvantages of whole-tree chipping are: possible greater damage to the residual stand during harvesting, possible long term growth potential reduction due to nutrient depletion, and cost of bark separation if bark cannot be tolerated in processing and use of the chips for pulp or fuel.

ECONOMIC COMPARISON OF CHIPPING SYSTEMS

Cost comparisons among chipping systems are difficult because of the scarcity of data and the variation among situations encountered. The subjective comparison we developed was based on our experience of in-woods debarking-chipping of stem wood, conventional debarking-chipping of stem wood at the mill, and whole tree chipping in the woods. The cost for each function within the conventional system was assigned the index value of 1.0. A comparative index number was developed for each function in the other two chipping systems (table 1). Cost comparisons of the three systems were then developed.

The productivity of the in-woods debarking-chipping system was assumed to be equivalent to point C on figure 2. The ratio of at-plant chipping costs to in-woods debarking-chipping costs was assumed to be the same as that determined during the 1973 study. Current average costs for felling, limbing, and bucking, skidding, and loading pulpwood applied to timber sales by Forest Service Region 2 were used (United States Department of Agriculture, Forest Service, 1979). Chipping costs at a mill were estimated after consulting several sources (Bonneville Power Administration, U.S. Forest Service, Pacific Northwest Region and Pacific Northwest Region and Pacific Northwest Forest and Range Experiment Station, 1979 2/, Folkema, 1977: U.S Forest Service, North Central Forest Experiment Station, 1978). Hauling costs were assumed to be 8.8 cents per ton mile for logs. Extra handling costs were included for log handling when chipping was done at the mill. For whole tree chipping, extra costs were included for bark and wood separation (which might not be necessary depending on the use to be made of the chips). The results are graphed in figure 3.

Conclusions

For the costs used, whole tree chipping was comparable with conventional roundwood harvesting with chipping at the plant. If barky chips can be used, the bark and chip separation cost can be eliminated, making whole tree chipping even more attractive. The cost of whole tree chipping can be reduced even further if credits can be taken for removing material that would otherwise have to be piled and burned or removed in some other manner.

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Table 1. Cost comparison index for harvesting/chipping systems

FUNCTION	SYSTEM		
	At-plant	In-woods	
	Debark and chip stem wood	Debark and chip stem wood	Chip whole tree
	------ -cost index- ------		
Fell, limb and buck	1.00	.65	0.40
Skid	1.00	1.05	1.20
Load	1.00	0.00	0.00
Chip	1.00	2.70	1.50
Haul	1.00	0.90	1.05
Extra handling	1.00	0.00	2.00

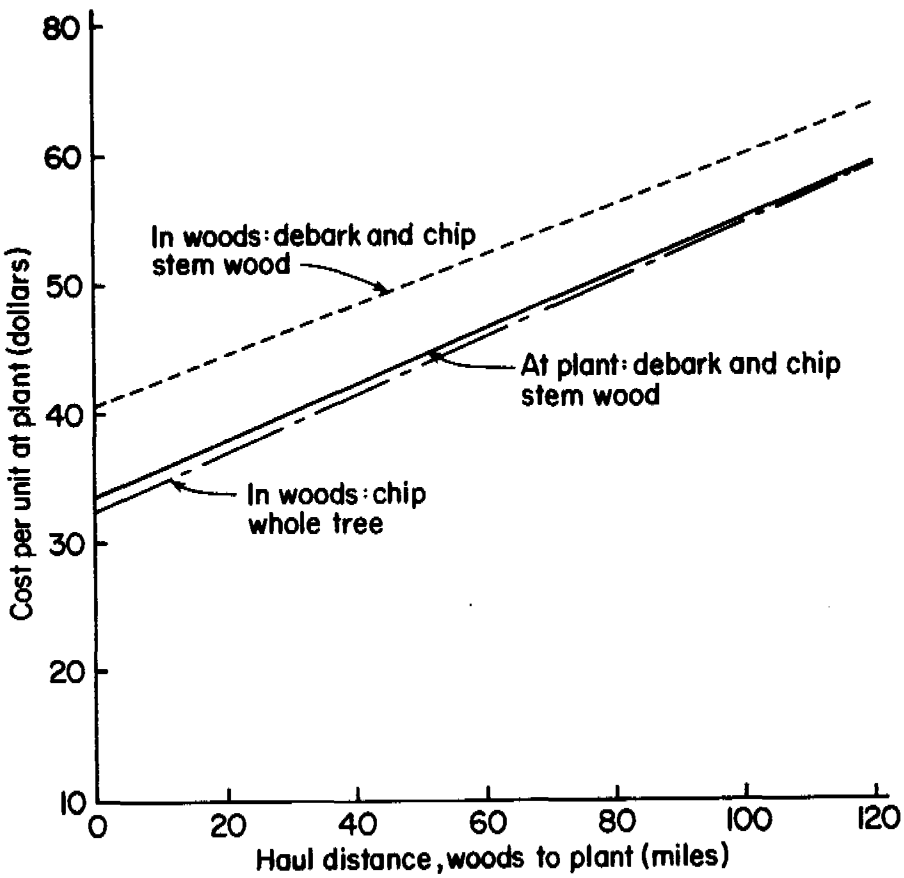

Figure 3.--Cost comparisons for harvesting/chipping systems for short haul distances.

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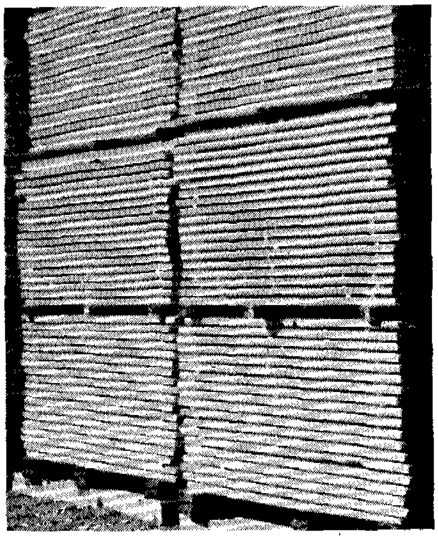
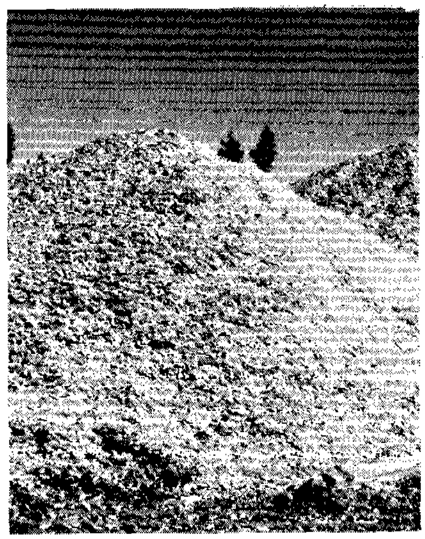

UTILIZATION OPPORTUNITIES

The wood processing industry has faced numerous challenges in the past, and with a combination of ingenuity, perseverance, and a little research, has surmounted difficult obstacles. A major challenge facing the industry today is the need to achieve more complete and efficient use of our available wood resource. Product, process, and market experience and research being reported in this Symposium are directed specifically toward improving the feasibility of utilizing forest residues. In the Rocky Mountain west, this places emphasis upon dead timber, and upon small stems, since these comprise the major proportion of the residue resource.

Forest residues include material that can be used for virtually every product manufactured from the so-called "merchantable" timber resource. Given favorable economic conditions, material historically considered residue is being used for lumber, house logs, treated wood products, and for chip and fiber-based products. Recent concerns about high energy costs and fuel shortages have renewed interest in wood as a fuel. Processing characteristics and methods frequently differ from those used for commercial timber, however, leading to a need for new information and new technology.

Research and industrial experience being reported here deals with the recovery and use of residues in general, but emphasizes utilization of dead timber. In that regard, the Symposium serves to assemble information that can enhance utilization opportunities for dead timber, and help avoid some of the potential pitfalls in processing.

PARTICLE AND FIBER BUILDING PRODUCTS FROM RESIDUE RAW MATERIAL

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ABSTRACT

Considerable research has been conducted on the use of dead standing trees of western white pine (Pinus monticola) and lodgepole pine (Pinus contorta) for use in various composition board materials. Much of this raw material is normally unacceptable for solid wood products such as lumber and plywood. It can, however, constitute an important resource for wood construction materials in the form of composition materials. Composition panel materials include underlayment grade particleboard, furniture grade particleboard, structural flakeboard, hardboard, and medium density fiberboard. The material would also be acceptable as core material for composites made of particleboard cores and veneer faces. Experimental boards have been made which meet the commercial standards for the above named composition panel materials. Economic analyses have shown that there are no particular penalties in cost associated with the use of the dead material in comparison with standard green material once the raw material has been delivered to the plant site. The residue raw material could also be used in molded products and lumber products of composition materials or composites.

KEYWORDS: residue utilization, building materials

INTRODUCTION

Forest residues are considered garbage by much of the forest products industry. It is difficult to use much of this raw material in lumber and plywood manufacture; however, compared to the raw material used for much of the composition materials industry, forest residues can be a quality raw material.

Using forest residues only for composition materials probably is not an appropriate path to follow in developing this resource. Lumber, veneer, house log, and other high value products should be made with whatever raw material can be "creamed" from the harvest for these products. Then, producing composition material for use in building or furniture becomes a distinct possibility as part of an integrated forest products complex.

This paper will cover definitions of the composition and composite materials, provide a brief history of this segment of the forest products industry, describe types of building materials now being produced or possible to produce, discuss recent developments, and--finally--present the role of forest residue raw material.

DEFINITIONS

Definitions of the various wood composition materials can be quite confusing. The definition I've developed for composition materials covers all types of fiberboard, particleboard, flakeboard, mineral bonded products, and molded materials. The term covers all products made with various types of wood particles including fiber. A full discussion on these definitions can be found in the first book cited at the conclusion of this paper.

In the wood industry, composites have come to mean a material made of particleboard and wood veneer. The common product at present is a panel with veneer faces and a particleboard core. What I call a "true" composite is made of dissimilar materials, e.g., metal-faced plywood.

BRIEF HISTORY

Wood composition materials are a development of the twentieth century. Wet process insulation board and mineral bonded products were developed in 1914. The first American particleboard plant was in operation in the 1930's. The major development of this industry has taken place since World War II, as has the development of extruded particleboard. Dry process hardboard arrived in the late 1940's. The manufacture of molded products started about this time as well. Medium density fiberboard production started in the mid 1960's. Oriented flakeboard arrived in the 1970's, as did the first wood panel composites.

Figure 1 is a graph of the production of insulation board, particleboard, and hardboard since 1960. Notable increases in production are apparent. An interesting relationship is the weight of wood going into these products and medium density fiberboard as compared to softwood plywood. Taking into account the various thicknesses and board densities, approximately 90 percent as much wood ends up in composition materials as in softwood plywood.

The major point is that the composition materials industry is well developed, having a solid scientific, technical, and experienced manufacturing base which can provide the background data for any new plant or development. It is not a new industry as some not in close contact with the industry might surmise. It is a viable, well established segment of the forest products industry.

An interesting observation is that the Inland Empire and Northern Rocky Mountain area has more types of composition and composite plants than any other part of the country. The first waferboard plant (now obsolete and closed) was located at Dover, Idaho. Other plants are wet process hardboard and insulation board at

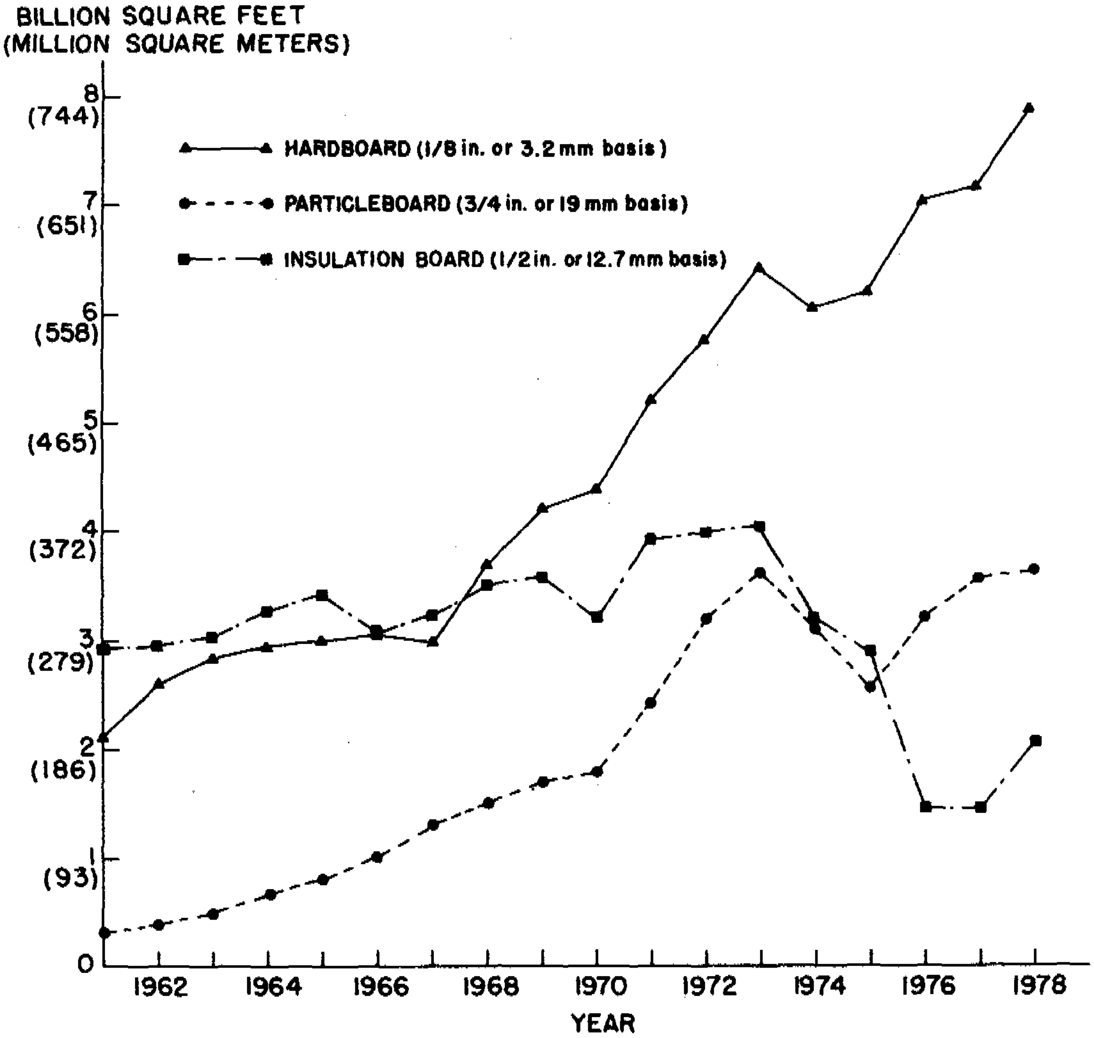

Figure 1.--Production of three different composition board products from 1960-1978.

Pilot Rock, Oregon; medium density fiberboard at Kalispell, Montana; underlayment particleboard at Post Falls, Idaho; industrial particleboard at LaGrande, Oregon, and Missoula, Montana; composite panel with oriented flake core at Lewiston, Idaho; and composite panel with randomly layed up core at Baker, Oregon. Thus intensive in-region experience has already taken place in the area of composition and composite panel manufacture.

TYPES OF BUILDING MATERIALS

The composition panel materials already mentioned are being used extensively for sheathing, siding, wall paneling, floor underlayment, furniture, cabinets, and mobile home decks. These panels include hardboard, insulation board, mineral bonded board, underlayment and industrial particleboard, medium density fiberboard, thin particleboard and fiberboard used for wall paneling, flakeboards made with relatively thin flakes for industrial and construction uses, and flakeboards with specially cut thicker flakes (waferboard) for sheathing and other construction uses.

Wood panel composites, as mentioned previously, are being made with veneer faces and two different types of particleboard core. However, veneer or lowgrade particleboard core could be used as the core with flake, fiber, or other particles for the faces of such composites. All composite products have the advantage of lower weight and less adhesive use as compared to an all composition panel material.

True panel composites are not new. They include plywood and composition panels overlayed with resin-impregnated paper sheets, plastics, fiberglass and metal. A recent and interesting new possibility is the use of basalt fiber as part of the composite. Developments at Washington State University have made possible the production of strong fiber from the vast amounts of raw material available.

Lumber products have been produced and used in demonstration projects. These include flakeboards, composites with veneer on the lumber faces and particleboard in the core, and composites with veneer strips on the edges of a particleboard core.

For a number of years, shaped and engineered composition materials have been manufactured, including molded products for doorskins, window sills, door jambs, and other building parts. Molded particleboard pallets are being manufactured in Europe and the United States. Corrugated panels have already been invented. Such engineered panels provide high strength materials while conserving raw material because of the panel design. Flakeboard is a distinct possibility for use in engineering products such as wood I-beams. Flakeboard can serve as an excellent web material in these products. Composition materials may well be developed for use in trusses and laminated beams.

Many engineered products are made possible by engineering materials with various shapes. Superior strengths and other properties can be developed by use of the right combinations of wood particles, appropriate arrangement of the particles within the material, the use of the right adhesive and adhesive additive type, the selection of the appropriate material density, incorporation of additives for preservative treatment and fire retardancy, and using other materials in combination with the wood.

RECENT DEVELOPMENTS

Some of the more recent developments such as composites, paneling core, and pallets have already been covered. It is important to recognize, however, that the production of these products already is being expanded. Waferboard, while an old product, is enjoying a tremendous new expansion.

Particleboard overlayed with resin-impregnated paper is being used for concrete form board. Sizes much larger than conventional plyform are available, thus reducing the flashing marks in the concrete made at the joints between panels. On large jobs, the use of the large panels has the possibility of reducing the costs as fewer panels have to be handled.

Particleboard shelving has become a major item over the last several years. Particleboard stepping is another product now available at a much lower cost than conventional clear lumber stepping. Treatments are being developed for use as surface and edge coatings for particleboard used in building construction. The coatings prevent or reduce the pickup of water during the construction period. Thus excessive swelling of the panel is alleviated along with concomittant reduction in properties.

The industry is striving constantly for new and improved products. All such work provides a greater data base for new industry to draw upon in developing plants and products.

ROLE OF RESIDUE RAW MATERIAL

Predictions are for a strong demand for housing through the 1980's. Problems with harvesting sufficient timber for conventional lumber and plywood production are well known. However, very high levels of forest residues are available for use. To meet the demand for construction and other wood materials, it will be absolutely necessary to utilize more of the forest residue material. In order to do this, composition and composite materials will have to be a major part of the product mix simply because of the irregular or small shapes of the raw material available.

The role of residue raw material, therefore, will be extremely significant because of its availability and relative suitability as a raw material for composition materials. Furthermore, good or superior panel, lumber-type, and shaped materials can be manufactured.

Cooperative research on the use of the dead tree resource for composition board has been conducted by Washington State University and the following USDA Forest Service Stations: Pacific Northwest Forest and Range Experiment Station, Rocky Mountain Forest and Range Experiment Station, and the Intermountain Forest and Range Experiment Station. The research has shown that good underlayment and industrial particleboards, hardboards, medium density fiberboard, and flakeboard can be made from the dead standing resource of western white pine (*Pinus monticola*) and lodgepole pine (*Pinus contorta*). Complete information on this research and development has been reported in the second and third publications cited.

The major conclusion of the research was that the dead classes of white pine and lodgepole pine could be used effectively for various types of composition boards. Some refinements of the board-producing parameters are needed to optimize commercial board formulations, but these would be minor and reasonable changes according to today's board technology. Of the particles studied, hammermilled, ring-cut flakes, atmospheric-and pressure-refined fiber appeared to be best. Structural flakeboards of drum-cut flakes had low internal bond, indicating gluing problems with flakes cut from dry dead material. Further research on this type of board is underway, and is directed towards handling this problem.

Several conclusions were reached on boards evaluated for internal bond, modulus of rupture and modulus of elasticity, 24-hour water-soak responses, and linear expansion. Differences in internal bond occurred between live and dead classes in some cases, whereas no great differences were observed otherwise. Phenolic bonded particleboards of hammermilled particles made from dead lodgepole pine were better than those from live lodgepole. Fiberboards (pressure-refined fiber) of live material bonded with urea were better than those of dead material. Flakeboards of drum-cut flakes from live and dead material were quite low in internal bond. Milling the wide flakes from live material into narrow widths resulted in an approximate doubling of the internal bond.

With a few exceptions, modulus of elasticity was about the same for each species when comparable particles were used. Particleboards of hammermilled particles made of live material of both species were better than those of dead material because of the better particle geometry. Fiberboards of live white pine exhibited moduli of elasticities that were slightly greater than those of dead classes. Flakeboards had the highest modulus of elasticity values, with live class material higher in stiffness than the dead classes.

Boards from live and dead classes for all these board types were about the same in 24-hour water soak responses.

In linear expansion, more moisture was absorbed than expected, which seems to be a species effect. Some unidentified mold formed on the urea-bonded fiberboards. Particleboards of hammermilled particles from live material were lower in linear expansion, and therefore, were better than those from dead material. This was due to the better particle geometry of the live material. Fiberboards of dead white pine were higher in linear expansions than those from live, while the reverse was true with lodgepole. Flakeboards were very low in linear expansion and were best in this property.

Standing dead white pine and lodgepole pine as sampled for this study retained to a remarkable degree their original properties important for use in composition board products--even after many years of standing dead. The types of deterioration which prevent its use in lumber and plywood--such as deep checking, widespread sapstain, and pockets of decay--did not have appreciable adverse effects on those aspects of suitability for composition board considered in this phase of the study.

Sapstain, which was widespread, apparently has little effect on milling properties or resin compatibility.

Actual decay, in the form of saprot or heartrot, was present in such small amounts (overall much less than one percent) that it has negligible effect when uniformly dispersed through the furnish, as occurs automatically in board manufacture.

Deep checking caused some additional surface to be exposed to weathering and oxidation, but the depth of the surface effects is so slight that nearly all of the new surface formed in any of the particle-generating processes is new, unweathered surface.

The measurable chemical properties (pH and buffering capacity) of the dead wood important to resin compatibility, particularly with urea resin, are essentially unchanged from the live wood and are in a range easily accommodated by present practices in the industry.

The amounts of usable particle furnish that can be made by the five particle-making methods studied are high and not appreciably different from the amounts made from live trees of the same species.

A wide spectrum of particles, capable of meeting the needs of many different types of board plants, ranging from crude hammermilled particles through sophisticated pressure-refined fiber, can be generated from the dead material. Optimum particle-generating techniques were not established, and better results could be expected with such optimization. Excellent fiber of very low bulk density was produced by simple atmospheric attrition milling, and it is assumed that quality fiber could also be made at higher bulk densities.

Two aspects in which the dead material differed markedly from the live were in the amounts of bark and moisture present, both decreasing with elapsed time from death of the trees. In present composition board practice, the loss of bark would be considered an advantage. The reduced moisture content (mostly below fiber saturation) would have important advantages in reducing transportation and drying costs and should reduce the rate of deterioration in stored logs or chips.

Moisture content had marked effect on power requirement in hammermilling of chips--the less moisture, the less power required. Power requirement was little affected by moisture in the other milling methods for which measurements were made. Because of the very short runs involved, the measured power requirements should be considered only as approximations, but the relatively low power requirement for drum-flaking could be of considerable economic significance. Also, because of the short runs, no estimate could be made of the effect of the drier dead material on knife life and required sharpening frequency.

Moisture content of the raw material also affects the geometry of particles generated by hammermilling and by drum flaking and thus can affect the mechanical properties of the boards. In drum-cut flakes, the particle geometry of flakes cut from live material can be modified after the flaking and drying operations by light attrition milling of the flakes to split them to narrower width, thus approximating the geometry of flakes made at lower moisture content, if desired. Moisture content of chips could be adjusted to optimum levels before ring-flaking or hammermilling operations if needed, but logs from drum-flaking would presumably be flaked at the moisture content as received.

Typical commercial boards of dead class material showed excellent properties in general. Underlayment boards had good properties except for excessive linear expansion in lodgepole pine. This high linear expansion over white pine, observed throughout this part of the research, was attributed to a species effect.

Furniture-core particleboards had superior properties. Door core had excellent internal bond, and 1C1 particleboard requirements were met for modulus of rupture and modulus of elasticity. However, 1C2 board requirements for bending and stiffness were not met. Linear expansion minimums were exceeded for both 1C1 and 1C2 boards, with white pine barely exceeding the minimums. (1C1 and 1C2 refer to the designations in the particleboard standard found in the last reference cited.)

Good modulus of rupture and modulus of elasticity values were observed in structural flakeboards. It was difficult to achieve internal bond values meeting the commercial standard requirements. Poorer quality flakes, due to flaking dead, dry material, apparently were responsible for the low internal bond. Because of the favorable flake geometry, linear expansion was the lowest for any type of board made.

Excellent dry process hardboards were made from both atmospheric- and pressure-refined fiber. A reduction in the 3 percent resin level used should be possible while still meeting appropriate standards.

Medium density fiberboards had good internal bond, modulus of rupture, and modulus of elasticity properties. Some problems occurred in measuring linear expansion, making it difficult to assess this property.

The important point is that appropriate standards and specifications were met for most of the various types of panels made. It was demonstrated also that bonding problems expected in working with a dead wood resource were non-existent. Thus, the dead standing tree resource--and by extrapolation, the dead and down resource--is a valuable raw material for composition materials. Some work was performed with dead and down material for lodgepole pine which provided about the same results as with the dead standing resource, thus indicating such extrapolation of the research results was reasonable.

More recent research has investigated the economics of producing the composition materials mentioned above with both standard green and dead raw material. The analyses were made based on the costs of production once the logs were received at the plant. (See the fourth source cited).

The following table provides production costs comparing boards made from the two types of raw material. The analyses called for debarking the logs and using all wood waste for fuel (table 1).

The important observation is that the production costs are about the same when using either type of raw material for any of the board products. Tradeoffs are found in particle preparation, drying, and amount of fuel available, but the various tradeoffs balance out throughout the production process.

Table 1.--Comparison of Production Costs for Various Types of Composition Boards Made from Conventional Live and Dead Tree Raw Material.

Particleboard	Plant Size (Tons)	Costs/MSF (3/4 in. basis) Conventional	Dead Tree
Underlayment	150	$120	$123
Industrial	150	159	164
Industrial	300	120	122
	Plant Size (Tons)	Costs/MSF (3/8 in. basis Conventional	Dead Tree
Flakeboard	200	$ 79	$ 78
Flakeboard	300	71	69
Fiberboard	Plant Size (Tons)	Costs/MSF Conventional	Dead Tree
		(3/4 in. basis)	
Medium-density fiberboard	150	$162	$162
Medium-density fiberboard	300	126	125
		(1/8 in. basis)	
Hardboard	224	$ 35	$ 35

CONCLUSION

More wood composition and composite materials will be needed in the immediate future. Present wood products manufacturers can stay in business or expand their business by producing some type of composition or composite material. The field is open also to new manufacturers.

Manufacturers will need some type of guarantee of the amount of raw material available as these types of plants are expensive. No one can make the investment without a supply of assured raw material. Collection or harvesting the raw materials has to be performed economically. Great efforts are underway in this area. Success will provide even greater incentive to produce composition and composite materials from forest residues.

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EXTENDED USE OF RESIDUE FOR CONVENTIONAL SOLID WOOD PRODUCTS

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ABSTRACT

There is no inherent difference between the wood from dead trees and green trees. Solid wood product studies have indicated that dead trees can be used for lumber, houselogs, and posts and poles although the amount of usable lumber is usually lower for dead trees than for green trees. Dead trees may be preferred for houselogs, posts, and poles; however, extra care is required in selecting and processing these products.

KEYWORDS: dead tree utilization, dead tree lumber, posts and poles, lodgepole pine, western white pine

INTRODUCTION

The management of timber stands, including the harvesting of trees, creates large quantities of forest residue. This residue, of all sizes and shapes, remains on the area after removal of the merchantable logs and includes branches, tops, cull and unmerchantable small trees, broken pieces, long butts, and standing and down dead trees. In the northern Rocky Mountain area, dead timber often constitutes most of the post-harvest residue. The slow rate of wood deterioration in this region allows trees killed by insects and disease to accumulate in the forest, adding to harvest waste. During the past few years, we have investigated the qualities of wood in dead trees and possibilities for utilizing it.

Our initial investigations concerned the inherent wood characteristics, chemical and mechanical, that might inhibit the use of dead trees. One study (Lieu and others 1979) indicated that for lodgepole pine (*Pinus contorta Dougl.*) and western white pine (*Pinus monticola Dougl.*) there was no difference in the quantities of cellulose, lignin, or other chemical constituents between dead and green tree wood. The ash content of the dead trees tended to be slightly greater than for green wood, but this difference was probably due to the wind-blown dust and dirt that had collected in the wood surface of the barkless trees.

Another study (Gernert and others 1979) evaluated physical characteristics, percentages of shrinkage values, and specific gravity of long-term dead, recently killed, and green western white pine. No differences were found in these variables for the three wood types studied.

A third study (Lowery and Pellerin[1]) determined the mechanical, or strength, properties of lodgepole and western white pine. Results indicated that the modulus of rupture and of elasticity for the dead and green dimension lumber were very similar; therefore, the lumber could be used interchangeably without any ill effects.

These studies showed that nothing should limit the use of dead tree wood, however, the appearance and defects of dead trees and logs may inhibit their utilization for solid wood products such as lumber, house logs, posts and poles. Available information on these products is discussed separately.

LUMBER

One of the highest-valued products from green trees is lumber, so dead trees were also evaluated for this end use. Studies have determined the quantity and quality of lumber from dead trees, and compared these values with those of green logs. Summaries of these studies follow.

Lodgepole Pine

Carr (1978)[2] and Dobie and Wright (1978) have reported the results of lumber grade-yield studies for lodgepole pine. Carr summarized investigations made on three National Forests--the Bitterroot, Gallatin, and Beaverhead, in Montana. The Bitterroot study used green and dead trees obtained from a decadent, old-growth stand. The dead trees were from a wide variety of natural mortality quality classes, from the recently dead to downed trees. Both dimension and boards were cut from the study logs.

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[1]Lowery, D. P. and R. Pellerin 1979. Evaluation of dimension lumber made from dead trees. Review draft.

[2]Carr, W. R. 1978. Comparison of lodgepole pine lumber recovery from live and dead timber. USDA For. Serv. Office Report, 19 p. Region 1, Missoula, MT.

In addition to the green control logs, the Gallatin study included green-needled trees that showed signs of medium to heavy bark beetle infestation; red-needled trees, dead less than 3 years; and trees dead longer than 3 years. Only 1-inch (2.5 cm) thick lumber was produced in this study.

The Beaverhead dead trees included a few that were red-needled and a few taken from the ground. The other trees in this category had been beetle-killed for various intervals of time.

All the study logs had a minimum small end diameter of 5.6 inches (14.2 cm) a minimum length of 8 feet (2.4 m) and were at least one-third sound. A summary of the results is shown in table 1.

The table shows that dead trees have considerable value when used in lumber production. The quality of lumber is reflected in the lumber value per thousand board feet (M bd. ft.), which ranged from $178 to $222 for the green trees and from $150 to $200 for the dead trees. Obviously, a lower quality of lumber is produced from dead tree logs. The differences between dead and green tree lumber values ranged from $16.71 in the Beaverhead study to $71.58 in the Bitterroot study.

Table 1.--Summary of the results of mill scale studies made on three national forests in Montana.

Study	Timber type	Percent dimension lumber	Value per M bd. ft. lumber tally[1]	Percent lumber recovery	Value per M bd. ft. net log Scale
Bitterroot	Live	40	$221.99	150	$332.98
	Dead	60	150.41	134	201.55
Gallatin	Live	0	261.53	121	316.45
	Dead	0	199.81	141	227.78
Beaverhead	Live	89	177.53	172	305.35
	Dead	91	161.82	150	242.73

[1]The lumber values are based on Western Wood Products Association year-end Report No. 12, 1977.

The highest values for dead wood were obtained when 1-inch thick (2.5 cm) lumber was produced (Gallatin study). The percentage of lumber recovery indicates a smaller amount of lumber was made from the dead tree logs than from the green tree logs, except for the Gallatin study. Just as the increased number of kerfs required to produce 1-inch boards reduced the percent lumber recovery in the Gallatin study, so also the increased number of defects in the dead logs reduced the percent lumber recovery in all the studies. The value per thousand net log scale indicates both the quality and quantity of lumber produced for the two log types.

Four categories of lodgepole pine trees--(1) green, (2) red-needled, with some dead more than 2 years, (3) gray with tight bark, probably dead more than 4 years, and (4) gray with loose bark, dead longer than the preceding groups--were used in a Canadian study (Dobie and Wright 1978). The results of this investigation were essentially the same as for Carr's studies (1978). A smaller quantity and lower quality of material was recovered from the dead trees than from the green trees. The study also indicated that beetle-attacked trees should be harvested prior to foliage loss, if possible. The lowest values and quantities were obtained from those trees dead the longest time.

Western White Pine

Two studies have determined the value of dead western white pine in northern Idaho (Snellgrove and Fahey 1977; Carr 1979).[3] In the first study, the trees were classified as either live, dead 1 or 2 years, dead 3 to 6 years, or dead more than 7 years. The average d.b.h. of the classes ranged from 19 to 21 inches (18.3 to 53.3 cm). All logs were processed into 4/4- and 5/4-inch (2.5 and 3.2 cm) lumber.

The study's results showed that the trees dead the longest time had the greatest loss in usable wood. The loss in volume for the different classes due to felling, handling, and transporting to and around the mill was as follows:

Quality class	Percent loss
Live	4.5
Dead 0 to 2 years	6.7
Dead 3 to 6 years	9.5
Dead 7+ years	10.8

The tops of older trees can absorb less shock, and tend to shatter when the trees are felled. In addition, smaller amounts and lower grades of lumber were obtained from dead trees (table 2).

The second white pine study (Carr 1979) had three classes of trees: (1) live; (2) probably dead less than 5 years, with 90 percent or more of the bark retained on the tree; and (3) probably dead more than 5 years, with less than 90 percent of the bark retained on the tree. All logs were at least one-third sound and were cut into 1- and 2-inch thick (2.5 and 5.1 cm) lumber.

The results, summarized in table 3, showed that older dead trees had a greater percentage of defective material (gross vs. net log scale) but that a greater percentage of lumber, based on net log scale, was recovered from these logs. However, both the value per M bd. ft. and the associated lumber quality were lower for the older wood.

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[3]Carr, W. R. 1979. Comparison of white pine lumber recovery from live and dead timber. USDA For. Serv. Office Report, 14 p. Region 1, Missoula, MT.

Table 2.--Summary of western white pine mill scale data.[1]

Mortality class	Log scale defect	Average value[2] per M bd. ft.	Average value per C ft.[3]	LUMBER GRADE RECOVERY: D Select & better	#1,2,3 Shop	#1,2 Common	#3 Common	#4,5 Common
	Percent	Dollars	Dollars	Percent				
Live	14	214	109	5	9	27	47	12
Dead 0-2 yrs	50	167	81	2	3	16	26	53
Dead 3-6 yrs	85	122	49	0	4	4	33	59
Dead 7+ yrs	94	95	34	0	1	1	13	85

[1]Snellgrove and Fahey 1977.
[2]Calendar year 1977 average prices.

Table 3.--Summary of western white pine mill scale data.[1]

Mortality class	Log scale: Gross	Log scale: Net	Lumber: Quantity	Lumber: Percent of	Value per M bd. ft.[2]	LUMBER GRADE RECOVERY: #3 Clear & better	Shop	#5 Common & better	Standard & better	Utility & economy
	Bd. ft.	Bd. ft.	Bd. ft.	Pct.	Dollars	Percent				
Live	51,450	41,900	54,350	130	284	13.7	9.8	61.4	12.9	2.2
Dead <5 yrs.	40,330	18,420	37,469	204	214	3.0	5.0	67.8	17.9	6.2
Dead >5 yrs.	42,910	4,980	41,682	237	152	0.4	0.4	14.7	36.3	42.2

[1]Carr 1979 (see footnote 3 in text).
[2]Calendar year 1977 average prices.

Summary

The grade yield studies indicated that dead trees can be used for lumber production. However, the lumber made from such trees is usually lower in quantity, quality and value than lumber made from comparable green trees. Differences in volume result from breakage during felling and handling operations, decay and borer damage in the sapwood, and foreign objects imbedded in the outer wood of barkless trees.

If lumber quality is to be maintained, dead trees must be salvaged before complete foliage loss. Usually the best and highest-valued boards can be cut from the clear wood immediately under the bark. This same wood is most readily attacked by decay and stain fungi and wood-boring insects. Lumber made from the inner part of the log often contains knots or other degrading features. As long as bark remains intact on dead trees, lumber quality decreases slowly; but after about 5 years bark sloughs, deep checks develop, and the rate at which quality declines will accelerate.

Quality and quantity directly affect the value of lumber cut from dead tree logs. As the time since death lengthens, the value of the lumber that could be produced decreases.

SPECIALTY PRODUCTS

One way of increasing the value of relatively low quality lumber obtained from dead tree logs is to promote its use for specialty products, such as interior paneling, picture framing, furniture and decorative moldings. These uses accentuate the differences between dead and green tree wood and emphasize the uniqueness of dead tree lumber. This approach has been used in previous years to develop markets for white pocket veneer and boards, pecky cypress, knotty pine, wormy chestnut and, most recently, gray weathered barn wood.

Recent research at the University of Idaho has concentrated on the recovery of specialty products from dead western white pine (Howe 1978; Christophersen and Howe 1979). Fourteen logs that had been in the mill yard for at least three years were cut into 8/4 and 5/4 inch (5.1 and 3.2 cm) lumber on a circular sawmill. After drying, the pieces were resawn into 7/16 inch (1.1 cm) paneling. The value of the paneling and other recoverable pieces was estimated to be considerably above that of the original dimension lumber.

HOUSE LOGS

In recent years, a large number of dead trees has been used by the log home industry, and this segment of the construction industry has grown dramatically. It has been estimated that 200 manufacturers will produce about 20,000 log homes in 1979 and about 25,000 more in 1980.

Log home producers in the Rocky Mountain States are firmly committed to using dead trees. Dead tree logs are usually relatively inexpensive, and because they have a lower moisture content, they are lighter in weight than green tree logs. This factor makes them easier to handle with smaller, less costly equipment, and reduces their shipping cost. Logs with drying checks can be positioned in the building to minimize the effect of these openings, and preservative solutions or stains can penetrate and coat all exposed wood surfaces. In addition, structures made from dried, dead logs are more dimensionally stable than structures made from green logs, unless the green logs have been air-dried for a long time.

Most dead tree houselogs are either lodgepole or western white pine. Tree-length lodgepole pine logs are preferred because the longer lengths allow cutting to required sizes.

POSTS AND POLES

Because of their size, straightness, minimum taper, and ease of preservative treatment, green lodgepole pine trees have been preferred for fence posts, corral or fence rails and utility poles. The same products made from dead trees possess the advantage of having lower moisture contents, thereby eliminating a long air-seasoning period and reducing the need for a large inventory. The lower moisture content also indicates lighter weight, hence larger loads and easier preservative treatment.

Post and rail specifications are usually developed by the individual treating plants and depend, to a large extent, on local conditions and practices. Appearance is often the major consideration. Pole specifications are published by the American National Standards Institute (ANSI 1972), and although standards do not require the use of living trees, the occurrence and placement of defects may eliminate the use of some dead trees for poles. Preservative treatment specifications for posts and poles are published by the American Wood Preservers Association (AWPA 1977).

Posts

A recent publication (Lowery and Host 1979) reports on preservative treatments for posts and poles made from dead lodgepole pine trees. Two treating methods, steeping and pressure, were used to treat fence posts that had been dead for at least 4 years. The 85 peeled, pointed, and capped posts used in the steeping study were placed upright in a series of tanks, filled to a depth of 30 inches with a pentachlorophenol, a light crude oil solution. Six hours was the longest soak period used.

Analysis of the disks and borings taken from the treated posts indicated that none of the treatments gave the minimum retentions required by AWPA standards (0.30 pounds per cubic foot). A slight difficulty was encountered in peeling the dead tree posts. The posts often were stopped in the debarker, and when stoppages were not corrected immediately, an excessive amount of wood was removed. The surfaces of the dead tree posts were also rougher than the surfaces of posts from green trees.

The pressure treating study used 39 posts. These posts were subjected to an initial 30 minute vacuum period followed by a pressure period of either 15, 30, or 45 minutes. (In contrast, the pressure period used for green tree posts is 3 hours.)

An unheated water solution, 1.50 to 1.75 percent fluorchrome arsenate phenol, type B (Osmosalts), was the preservative used.

Preservative retention tests performed on samples cut from the posts showed that all posts had retentions in excess of the 0.4 pounds per cubic foot required.

Poles

A recent survey of lodgepole pine in southeastern Idaho indicated that many of the dead trees in that area were suitable for powerpoles (Tegethoff, Hinds and Eslyn 1977). Of 217 pole-size trees on 46 plots, 165 were dead and about 38 percent (63) of the dead trees yielded poles that satisfied the ANSI pole standard. The most common defect was basal decay, and for many of the dead tree poles this defect had to be eliminated by long butting.

The preservative treatment of poles made from dead lodgepole pine trees has also been reported (Lowery and Host 1979). Thirty poles were randomly assigned to one of six treatment schedules:

1. Six-hour hot bath followed by a 12-hour cold bath
2. Four-hour hot bath followed by a 6-hour cold bath
3. Two-hour hot bath followed by a 6-hour cold bath
4. Nine-hour cold soak
5. Six-hour cold soak
6. Four-hour cold soak

In contrast, the commercial schedule for green poles uses a 6-hour hot bath followed by a 6-hour cold bath. The treating solution was a 5.1 percent pentachlorophenol in a heavy oil carrier.

Measurements showed that only one pole received less than the minimum required preservative penetration of 0.75 inch. All poles, except those given a 4-hour cold soak, met the 85 percent penetration of the sapwood requirement. Preservative retention measurements showed all the study poles treated by the hot and cold bath method exceeded the specification requirement of one pound of dry pentachlorophenol in the outer 0.50 inch. However, none of the poles treated by the cold soak method retained this much preservative.

SUMMARY

Investigations have shown that there is no inherent difference between dead and green tree wood. Dead trees and logs can and are used to produce solid wood products such as lumber, house logs and posts and poles.

Grade-yield studies have shown that the lumber recovered from dead tree logs is lower in value, quality and quantity than lumber produced from comparable green tree logs. Furthermore, the longer the time interval between death and utilization, the lower the value of the material recovered. The manufacture of specialty products is one way of enhancing the value of dead tree lumber.

House logs, posts, rails and poles are other potential uses for dead trees. Dead lodgepole pine trees are preferred by many Rocky Mountain log home manufacturers. Posts and poles made from dead trees can often be treated with a preservative immediately, without a long air-seasoning period, and shorter treating schedules can be used to treat these products.

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PRACTICAL CONSIDERATIONS IN USING LOW QUALITY WOOD IN LUMBER, SPECIALTIES, AND PLYWOODS

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ABSTRACT

The initial practical consideration in using low quality wood is how we view it. Beyond this psychological point, very real problems do exist. This discussion examines some of the uses of low quality wood. The solid wood product families examined include composites, plywood, lumber, laminated lumber, and cedar products.

KEYWORDS: residue utilization, wood residues, wood products

Earlier presentations in this volume have discussed the opportunities for utilizing residue. This paper will deal with "Practical Considerations in the Utilization of Low-Quality Wood." Webster's Dictionary shows about eight definitions for the word "practical," as well as reference to the word "practicable." Practicable was said to be "used of something that has not yet been developed or tried, but appears likely." Perhaps we should say that much of what has been discussed here should be labeled practicable, that is it appears possible, but has not yet been tried.

But, since we are dealing with practical considerations, we should define the word. "Practical" is defined as "obtained through practice, workable and useful, utilitarian, experienced from actual practice," and so forth. The panel discussion on which this paper is based moved from the opportunities of the practicable to the problems of the practical.

A first practical consideration in using low-quality wood is in the description of our raw material. Elsewhere in our program we have been referring to residues. Now we are using the words low-quality. Unfortunately, it is true that much or most residue type material is not the best. But with that admission, I would like to express the view that part of our practical problem may be our label.

I believe that if the residue resource is examined, a range of quality can be found which straddles at least partially the range of more "normal" wood. For example, I suspect that some dead timber is better than some live timber; some residue is superior in size class to some of the so-called merchantable material; and some residue has higher intrinsic wood value than some merchantable timber (such as pine versus hemlock).

I want to cover here some of the experiences at Potlatch Corporation[1/] with so-called low quality wood in several product lines: cedar products, lumber, laminated lumber, and plywoods.

CEDAR PRODUCTS

This is probably the oldest product line based on a raw material that is traditionally a residue in Northern Idaho and surrounding areas. Several decades ago, split cedar products were mostly produced by individuals or families living and working in the forest. The raw material was often free, but converting it to saleable product was a business with the most basic practical consideration - staying alive under dangerous working conditions and making ends meet by hard and long hours.

Today Potlatch operates two cedar products plants as a part of integrated logging and milling operations. New problems arise although others may be solved. The variability of quality in defective cedar is surprising. Although our plant specs will allow a minimum log length of only 6½ feet, handling such short pieces out of the forest is awkward. Without a system for working out sawlogs from material delivered to a cedar products plant, one must guard against a downgrading of higher grade material into a longer piece of part-low-grade cedar products log. In other words, the move towards higher volume utilization can affect quality utilization. Another problem from such operations, which reduce forest residues, is the manufacturing waste factor. Two-thirds of the gross weight of delivered wood can become scrap. Accumulated at a mill, the resulting residue may be a bigger problem than if dispersed in the forest. Improving fuel markets is an answer to this situation, however.

LUMBER

I'm sure that most Rocky Mountain area sawmills are now using some logs today that previously would have been considered residue. Other speakers have cited this.

Species is a primary factor influencing the type of problems which enter the picture regarding using residue or low-grade logs for lumber. In the pines, which are typically cut to boards, checks, worm holes, and blue stain are common characteristics of the lumber output. These affect the basic grade of the product, usually negatively. Another problem is variable moisture content, which follows through in kiln drying as overdried lumber. A significant dollar loss in surfacing due to overdrying higher grade boards is well established in forestry literature.

1/ The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

In true firs, we find incipient and advanced decay to be the principal problem in lower grade logs. Not only is lumber grade and value lowered, there can be a breakage problem in handling, which slows production. Such pieces are preferably sent straight to the chipper, but can't always be diverted.

Douglas-fir presents relatively fewer problems in the final product, once the logs are sawn. Inherent crook in the tree is a culprit in the woods which can create low quality sawlogs. If the crooked portions aren't culled as residue, the logger may be penalized for the scale loss, and mill production can be slowed.

LAMINATED LUMBER

Here is an area where one can effectively upgrade some lumber which otherwise might be put to a lower use. It is accomplished by combining three or more pieces of varying appearance quality levels into one piece which is used according to its outer or face grade. Hoards or dimension comprised of sound solid wood can be used as center and back laminations, where visual properties can essentially be ignored. For example, knotholes are structurally equivalent to sound knots of the same size, lower value species can be used with facings of premium woods, and splits, wormholes, and other slight imperfections become relatively unimportant. Low moisture content from overdrying can be beneficial in processing and in-place product serviceability.

PLYWOODS

The plywood business has been a good one for a number of years. "Sheathing" used to mean boards, but now, as most everyone knows, it means 4x8 - CDX, or plywood.

Low quality does not present isolated problems in making plywood; essentially, it is unacceptable. The process of making conventional plywood is so standardized and streamlined that standardized raw material becomes essential. Try to run a 6-foot bolt into an 8-foot line, or put a soft-centered overmature white fir in a lathe, and everything stops. A 6-inch diameter log slows up a headrig, but is worse on a 5½-inch lathe chuck.

Potlatch faced the practical problem of using lower quality raw material, in its true sense, with our composite plywood we call "Plystran." We wanted to make more plywood without using more peeler quality logs. Some of the problems we faced, and solved, as we went from practicable to practical, were: dirt on "buckskins," mostly dead white pine; rot in defective logs, mostly true firs; achieving the excellent performance level of plywood from low-line wood; integrating log usage and conversion facilities with parallel pulp mill needs; smoothing out wood quality variation, ranging over a complete spectrum; and allowing for errors in the pioneer effort, since errors are inevitable when innovating.

Without explaining here how all these were accomplised, the conditions were: the market for the product existed, the technology was mostly available or seemed close at hand, and management was willing to take some risks. With a lot of effort by many people, success was achieved.

Using low grade wood is not done through miracles, but with the classic ingredients of most achievements: hard work, economic reality, and well-defined goals.

UTILIZING RESIDUE MATERIAL IN PULPING

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ABSTRACT

The pulp raw material shortage in 1973 and 1974 provided incentives for using whole tree chips at a number of pulp mills in the United States. Since 1974 pulp raw materials supplies have returned to more acceptable levels. As a result, whole tree chips are being used only on a limited basis. However, energy shortages during recent years have provided incentives for the utilization of whole tree chips. Currently, projects are underway in Montana, Idaho and Washington which will increase the demand for waste fuel.

KEYWORDS: residue utilization, pulping

The pulp raw material shortage in 1973 and 1974 provided incentives for using whole tree chips for papermaking at a number of pulp mills in the United States, particularly in the South. During 1973 and 1974, the Missoula pulp and paper mill manufactured chips from dead, dying, down, diseased and defective (5D) roundwood but did not utilize whole tree chips. Since 1974 pulp raw material supplies have returned to more acceptable levels. As a result, whole tree chips are being used only on a limited basis in some parts of the country.

With the 1973-74 experience for justification, the industry, along with land management agencies, educators and equipment suppliers, have defined problems associated with the use of whole tree chips, developed solutions to many of these problems, and continued to use whole tree chips in pulp and papermaking on a limited basis.

Due to continued strength in export requirements for chips and paper demand, coupled with a poor lumber market, we are again into a fiber supply shortage for pulp and papermaking. Therefore, it is reasonable to assume that substantial quantities of whole tree chips will again be used during the next two years by pulp and papermakers throughout the United States.

Benefits from whole tree chips include increased fiber utilization, increased landowner acceptance of harvesting, reduction of site preparation costs, and reduced hazard reduction costs and disturbance to top soil.

Problems in pulp and paper manufacture with whole tree chips include abnormal wear on mill processing equipment from sand and grit, rapid deterioration of whole tree chips in storage, increased fire hazard in chip piles, increased calcium scaling in digestors and evaporators, increased cooking time and alkali consumption, increased bleach consumption, digestor feeding problems, and low chip yields.

Although the list of problems is long, considerable progress has been made in solving these problems. Processes which have been developed for upgrading whole tree chips include bark separation, chip screening and washing systems, Morbark1/ dual-spout chipper, Morbark class "A" fiber system, and whole tree forwarding to eliminate impacted grit.

With expansion of Champion International's Missoula pulp and paper mill, we are rapidly approaching a shortage of sawmill residuals in the inland area.

Our expansion alone increases the demand for chips by 270 thousand bone dry units (MBDUs) or 293 thousand metric tons per year (22,000 truckloads), fines by 145 MBDUs (157 thousand metric ton) per year (12,000 truckloads) (fines include sawdust, shavings and chip screenings), and hogfuel by 220 thousand units per year (484 thousand cubic meters, or 16,000 truckloads).

First, let's discuss chips. Very few opportunities exist for increasing the total sawmill residual chip supply. We will take advantage of chip surplus situations by purchasing sawmill residual on short-term contracts; however, when chips are in short supply, we will use pulp logs as backup supply for our chip needs. We believe that pulp logs from our fee lands and from stumpage sales purchased from the USDA Forest Service will fill our needs and, therefore, do not anticipate creating a market for pulp logs.

We also believe that an adequate supply of 5D logs on forested lands exists within our operating circle to fill our expanded needs and, therefore, are not installing the necessary processing equipment for upgrading whole tree chips for use in the Missoula pulp mill.

In addition to chips, we use fine sawmill residuals for pulp and paper furnish. Unlike chips, many opportunities still exist for increasing the utilization of fine residuals. Fine residuals include sawdust, shavings, screenings and any other clean wood particles too small in size to meet chip specifications. Champion International's expansion was broken into two phases. Phase I came on line in May of 1978, increasing our use of fine residuals from 30 MBDUs (over 32 thousand metric tons) per year to our current usage of approximately 80 MBDUs (86 thousand metric tons) per year. Phase II of the expansion included the new paper machine. Increased washing and other related equipment are necessary to supply the new paper machine with pulp. After the completion of Phase II, we will be using 175 MBDUs (190 thousand metric tons) of fine residuals per year, more than double our current usage. Our projections indicate that this expansion will utilize most of the remaining fine residuals available from sawmill and plywood plants in Montana.

1/ The use of trade, firm, or corporation names does not constitute an official endorsement of, or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

The production of energy from wood fiber holds the greatest promise for utilization of whole tree chips in the Intermountain Region. Currently projects have been announced in Montana, northern Idaho and eastern Washington which will increase the demand of wood fiber for fuel by 1.3 million tons (1.2 thousand cubic meters) per year.

Champion's Phase II includes the installation of a new hogfuel boiler which increases Champion's Missoula hogfuel needs from 180 thousand (396 thousand cubic meters) units per year to 400 thousand (880 thousand cubic meters) units per year. Champion currently burns hogfuel at the pulp and paper mill, the Missoula sawmill, and Bonner plywood plant and sawmill.

In addition to our increased needs, Washington Water and Power Company has decided to proceed with development of a 40,000 kilowatt, $46.7 million steam electric generating plant fired by hogfuel. Newspaper reports say that this plant could be operating near Kettle Falls, Washington by mid-1982. The project is subject to procurement of fuel contracts and state licensing. This plant is estimated to require about 500 thousand tons, (453 thousand metric tons or 278 thousand units) of hogfuel annually. This is the first of possibly five such plants to be located throughout northern Idaho, eastern Washington, and northwestern Montana according to various news reports.

In addition, Potlatch plans to complete installation of a new hogfuel boiler by 1981.

Most of this increased requirement will be supplied by sawmills and plywood plants; however, current economics indicate that whole tree chips from thinning residuals, log yard cleanup, and road right-of-way clearing slash will compete for a limited amount of this supply. Due to some rather encouraging results from trial chipping runs on thinning residuals, Champion plans to use a limited volume of whole tree chips as furnish for their new waste fuel boiler at Missoula.

In summary, whole tree chips have been and are curently being used for the production of pulp and paper. Locally the increased demand for new energy sources will result in the utilization of whole tree chips by Champion's pulp and paper mill.

PROBLEMS IN PROCESSING LOW QUALITY LOGS

Remington Kohrt

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ABSTRACT

The sawmilling of low quality logs, often old and dead, is usually more difficult than for green, high quality logs. Machinery and processes can be adapted to accommodate low quality material efficiently, but the resulting products must be saleable. The challenge of sawing lumber from low quality logs becomes a problem of raw materials, regulations, agencies, public needs, costs, and politics.

KEYWORDS: sawmilling, residue utilization

After the first charge of old and dead logs goes through the typical sawmill, the normal question asked is, "Did she slip, did she trip, did she fall, or who pushed her?". With a forestry/logging background at the Mt. Hood and Targhee National Forests, I'm a great one to be telling you sage souls how it is to saw lumber from low quality logs. So as not to mislead you, it works this way: an efficient sawmill can manufacture low quality lumber from low quality logs efficiently. Now that I've established my credibility by telling you nothing new, I'm going to rail away at you, a captive audience. As a captive audience, you are no different than the typical sawmill, having to accept whatever is delivered to you.

The great American forest dream is one of many facets: dedicated professional foresters managing boundless forests mature and ready for harvest; eager loggers with saws in hand who leave no mark on the forest; efficient sawmills that cut endless quality products from cull logs; a happy, consuming public with money in the bank; a resource aware citizenry that feeds confused bureaucrats correct answers to short-term political questions; and a great future for all forever.

In order to place sawmilling in proper prospective, let's examine this great American dream:

<u>The dedicated pros</u> - If you go by their offices at 7:00 a.m. and come home at 5:00 p.m. you miss them. As dedicated public servants they get more pay,

more security and more benefits than any segment of the population, for less production than you can tolerate in any sawmill. They are a curious blend of good guys, bad guys, professionals, specialists and pseudopoliticians. They generally know what to do, but don't have the fortitude to do it. The result is wheel spinning, whereby procedures become more important than results.

The boundless forests - These great expanses of forests are either overused, multiply used, or unused. In any regard, they usually are undermanaged, overaged, diseased, inaccessible, and resemble grandmother's apple barrel where a rotten apple is available anytime but a good one must wait until "someday."

The eager logger - He is generally a nice guy who was too proud or too ignorant to find the gravy train somewhere, so he had to go to work. Where else could you work on borrowed money, broken equipment, and have the entire population as your absentee boss?

The consuming public - This is all of us. We want more for less, sooner than later, faster than slower and above all less government, providing you cut the other guys service, not mine. We do, however, have the same basic needs as all people do - food fiber, shelter, education, health care, and job opportunities.

Resource-aware citizens - We all read the newspaper, so we're eminently prepared to respond to agency and legislative requests for opinions concerning natural resource questions. We usually elect political representatives that promise to fulfill our desires in the short term, and "short sheet" us in the long term. You can't really blame the politician, he's human too. In meeting our demand he gives us the old pitch "Give me your hat and I'll show you a trick!", and he generally does.

The future - This a place in time we are all trying to reach with our shirt, shorts, and shoes intact. Hopefully we can use our natural resources in a prudent manner such that our citizens can have their commodity needs and amenity desires fulfilled over the long term. We know the renewable resources such as timber, water, wildlife, and forage can be enhanced as they are used. Resources will contribute to society to the extent the public understands how they provide.

This leaves the sawmill, an integral part of the sequence of processing trees to solid wood lumber products. Too often people in the academic and government worlds suspect that behind the grease, sawdust, and mechanical wizardry of a modern sawmill lurks the evasive solution to old and dead forests, shortages of petrochemicals and the national debt. Folks, it just ain't so!

The sawmill is usually a steel, concrete, and wooden complex of expensive permanence. It neither controls the raw materials delivered to it nor the demands for or the prices of the finished products it produces. The sawmill, then, is a functional tool that can be changed or adapted, but by itself is really a pass-through process.

The sawmill's problems with old and dead material begin in the log yard. The log handling process creates more than ordinary breakage. This breakage results in waste, less than optimum log lengths, and increased cleanup costs. Breakage accelerates in the debarking area also because of the brittle nature of the log. In order to get the potential lumber producing log to the mill floor, a merchandising station is needed in the log flow system. It is a place to identify, remove and upgrade the cull or problem log. This is an expensive addition to the normal mill flow.

On the mill floor, dust from the old and dead is ever present, and a problem that must be handled. The checked nature of old and dead wood is a constant hazard to saws, saw guides and splitters. Extra caution is necessary in the feeding process so saws aren't stressed, or run off the wheel from check that runs on a bias to the sawing direction. The checked nature of old and dead logs tends to pick up dirt and small stones that are held in the cracks through the entire sawing process. Damage and wear to the mill saws and planer knives is greatly accelerated. This results in increased saw purchases, more saw changes, and pressure on the filing room. The physical problem of separating good boards from cull boards or waste is greatly increased. Since more cull boards or waste is developed, means of identifying and handling must be found. Most labor-saving sawmill options that are automatic or semi-automatic are dependent on consistent log or board quality and flow. Old and dead wood is anything but consistent, and forces more manpower and judgement opportunities onto the mill floor, hence more costs.

The stacking, drying, unstacking and planer operations all must accommodate the lower quality, more variable board. Production then is more erratic and recovery tends to concentrate in the lower grades and shorts area. This necessitates carrying a larger inventory and presents the sales people a challenge. Customers accustomed to bright stock and solid stock must be educated. This education usually works in reverse, "Sure, I'll try your stained stock, but ata reduced price." Other processes, like automatic nailing, are not compatible with check. "Pick and carry" trade sees no good in stained stock. Just imagine your wife in a supermarket where someone is attempting to sell a product that is off-color, or otherwise defective.

The success of the sawmill, then, is not only one of quality and quantity of production, but of the kind of log brought to it and the demand for the finished product. If old and dead or low quality logs are the kinds of log product brought to the mill, one can usually expect reduced production, high production costs, diminished quality and lower realizations. If these circumstances can be tolerated in a balanced operation, and profit can be shown at one or more points in the process, then the operation might be termed successful. Usually the low quality, low value lumber products can be tolerated over the short term because of innovative sales promotion, high demand for the sawmill's waste, or high prices brought about by a shortage of raw material supply. Keep in mind, however, that the sawmill can't be picked up and moved easily, raw materials can't be shipped from too great distances nor can the sawmill transform culls into ladder stock, or quality dimension lumber.

In our full-stomach society, where we all seem to have plenty, problems seem to develop in relating the forests' ability to provide the public's demand for amenities. Particularly in preservationist circles, where folks are generally articulate, dedicated, well educated and involved in government or the service professions, we have lost sight of basic issues. The living forest becomes an emotional subject of mystique. This phenomena is pushed through the political process because no one can convince the preservationist he is wrong, the average citizen is too busy working or playing to be interested, and the politician wants the majority to be happy at least until the next election. The agency then charges forth with "responsive" timber management programs that concentrate on the politically acceptable facets of overall forest management - namely salvage sales, old or dead sales, and harvest of undersize, low value timber. The timber industry then struggles with the high cost, low quality logs that are forced upon them. At the same time, a forest in need of management sits nearby producing defect faster than useable wood, a nation is a net importer of solid wood products when it could be an exporter, and a resource-unaware public complains that things should be better. The problem is simple to understand; the solution is difficult.

Perhaps we should be asking "why" things are like they are. Why does the forest-managing agency ignore what's biologically rational and endorse wholeheartedly what is politically acceptable? Why is the general public resource unaware? Why is our political representation less than enlightened, and tuned to the short term? Why do we tolerate inflation, runaway federal spending, deficit balance of payments, low productivity, and withdrawal of our natural resource base? Why do we force forest utilization beyond the limits of economic feasibility on the one hand and ensure forest waste on adjacent areas with the other? Why is a sawmill expected to make something from nothing? Why are we less than honest with each other? Why can we answer these questions as individuals or in small groups, but fail to handle them in large groups such as this?

A biologically proper timber sale provides management opportunities for the forest, income for the owner, and access, jobs, taxes, and products for the consuming public. The current politically proper timber sale provides inadequate management opportunities, perpetual salvage costs, break-even opportunity for the land owner at best, minimum or no access, minimum jobs and taxes, deficit circumstances for the purchaser, and products for the consumer he may not want or cannot afford. Why? Why?

It is difficult being a resource-dependent sawmill in the Intermountain/Rocky Mountain area. We are keenly aware that our future, the future of renewable resources, and the future of dependent communities (and the nation) is dependent on how well government resource managing agencies practice professional resource management. Political forestry is generally short-term expediency, or management by reaction. We are painfully aware of the difference.

The situation is similar to the circumstances that are bringing about the "Sagebrush Rebellion." That is, the responsible agencies espouse policy, politics, and pressure that responds to the beat of a too distant drummer. The individual in the agency recognizes the problem and solution, but chooses not to act. The system is too static, the security too comfortable, and the principles involved are too easily swept under the rug. Hence we are here hung up on submarginal forest residues at the same time merchantable timber burns, dies, and rots in the ever growing wilderness system.

Make no mistake about it, the forest industry is not opposed to harvesting and utilizing of forest residue. We just see the challenge as a far more all-encompassing circumstance. We would rather solve the problems of a sinking boat by plugging the large holes rather than the tiny holes. The odds of reaching shore are much better that way.

In summary, what an efficient sawmill can do is manufacture low quality lumber from low quality logs efficiently. Our objective should be to grow and utilize sound sawlogs on the maximum amount of forest land possible and adapt the sawmill to produce economic lumber products that satisfy public needs. The applied arts of economic common sense and honesty will lead us out of the woods and into the light, if we use them. This can be accomplished by enlightened effort or by economic crisis. The choice is yours.

CHEMICAL CHARACTERISTICS OF WOOD RESIDUES AND IMPLICATIONS FOR UTILIZATION

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ABSTRACT

Wood and woody residues are chemically heterogeneous substances, being composed of carbohydrates in the polymeric form of cellulose and hemicelluloses, phenyl propanoids in polymeric lignin, extractable hydrocarbons, ash, and extraneous substances. Fresh green softwoods contain about 43 percent cellulose, 28 percent hemicelluloses, 29 percent lignin, 7 percent extractives, and minor quantities of ash and extraneous material. In the Northern Rocky Mountains, where dry or cold conditions predominate, woody residues remain sound without visual signs of decomposition for many years. The chemical composition of this weathered material does not change significantly and it can be utilized like greenwood. Since wood and woody residues are heterogeneous there are two basic approaches to its chemical utilization: (1) whole wood processing and (2) separation of the heterogeneous components followed by processing. The chemical utilization of woody residues is almost limitless, the major barrier being economics rather than technology.

KEYWORDS: residue utilization, wood composition

INTRODUCTION

Forest residues generated by natural and man-made processes can be broken down into three types of tissues: 1) foliage, 2) wood, and 3) bark. Each is distinct in its chemical composition, physical structure, and physiological function in the plant. If we were capable of complete-tree harvesting and utilization, the foliage would contribute about 3-10 percent, bark 10-15 percent, and wood 70-80 percent (Hakkila 1976), each varying with species, tree age, and other factors. The proportion of these three tissues in forest residues that is available for utilization is also dependent upon the age of the residue itself. This is particularly true for foliage (Keays and Barton 1975) which dries rapidly, falls to the forest floor, and becomes part of the litter in a very short time period. The utilization of foliage can only be practical in a complete-tree harvesting system where this tissue could be concentrated and processed immediately. Bark and wood are much slower in their rates of decomposition, and will accumulate unless disposed of by burning or some other means. Bark, however, like foliage is relatively insignificant in comparison to the quantity of wood residues available in the Northern Rocky Mountains. Commercial development of just the residual woody tissues would improve the efficiency of our forest utilization substantially.

CHEMICAL COMPOSITION

During photosynthesis plants convert light energy into chemical energy with the immediate product being sugar. This sugar is used as an energy source or can be converted to reserve food (starch), structural materials (cellulose in plant cell walls), and numerous other metabolic products (amino acids) necessary for sustaining life. Wood and woody residues are predominately cell wall tissue and are chemically heterogeneous, being composed of carbohydrates in the polymeric form of cellulose and hemicelluloses, phenyl propanoids polymerized in lignin, and also some hydrocarbons, ash, and extraneous substances (Browning 1963).

The quantity of each component varies with plant species, but in general softwoods contain about 43 percent cellulose, 28 percent hemicelluloses, 29 percent lignin, 7 percent extractives, and minor quantities of ash and extraneous substances.

Fresh or newly generated wood residues are chemically the same as the green wood in a freshly harvested tree. If these residues are left for long periods they will eventually be broken down and decomposed by microorganisms, fungi, insects, etc., causing changes in the chemical composition. In the Northern Rocky Mountains where dry or cold conditions prevail throughout much of the year, decomposition is often quite slow. Therefore, wood residues may remain sound without significant visual changes for many years, but it is possible that important chemical changes could occur. To determine the effect of long exposure time on wood residues, chemical analyses were conducted to determine the extractive content, cell wall composition and combustion characteristics of green and dead (down and standing) lodgepole pine and western white pine. Except for minor variations (see table 1), the sound dead and green wood of a species are chemically comparable even after extensive exposure of the dead wood to natural forest conditions. The dead wood residues can be used as a substitute for live timber in the production of fuels and chemicals (Lieu and others 1979).

UTILIZATION POTENTIALS

Traditionally, wood has been used for structural materials, fiber, and an energy source by direct combustion, all requiring minimal chemical modifications prior to use. For many years chemists have recognized the chemical potential of cellulosic substances which could be converted to a variety of chemicals including foods, with appropriate technology.

In recent years as the cost and our dependence on foreign oil have increased, scientists and engineers have begun to investigate alternative sources of energy. Since cellulose is the most abundant organic substance on earth and because it is renewable through photosynthesis, considerable research is being directed toward using plant biomass (predominately cellulosics) as a source of energy. In addition to its energy uses, petroleum is the foundation for the industrial production of petrochemicals, many of which could be supplemented or replaced by chemicals derived from plant sources. This has renewed the interest in converting wood or cellulose and other plant substances into fuels and chemicals.

Table 1.--Summary of the chemical characteristics of live and dead wood from lodgepole and western white pine.

Characteristics	Lodgepole pine		Western white pine	
	Green	Dead3/	Green	Dead
Specific gravity	0.367	0.367	0.442	0.366
Extractives1/				
Ether	0.61	0.25	1.21	1.28
Benzene:alcohol (2:1 by vol.)	2.23	1.35	3.62	3.08
Hot water	2.71	3.72	3.26	3.88
1% NaOH	11.22	14.30	10.81	12.49
Cell wall component1/				
Alpha-cellulose	43.59	44.49	42.81	40.84
Hemicelluloses	32.72	31.27	33.05	33.05
Klason lignin	26.70	27.21	26.90	27.32
Combustion				
Heating value2/	19.95	19.77	20.05	19.96
Yield of char %	29.82	29.08	28.54	27.96
Ash %	0.35	0.51	0.33	0.28

1/Values shown are percentages.
2/mJ/kg (Megajoules per kilogram), heat of combustion.
3/Averaged for down and standing.

Since wood residues are chemically heterogeneous there are two basic approaches to utilizing this material: 1) whole wood processing or 2) separation of the components followed by processing. In general, when wood is used for fuels whole processing is employed, while for the production of chemicals either method can be used, as discussed below.

FUELS

The use of wood residues for fuels involves either direct combustion or conversion to another form, which is then burned (Tillman 1978), (see figure 1).

Direct Combustion

In direct combustion, the heat applied to the wood causes either direct combination with oxygen in the solid phase to give glowing combustion, or thermal breakdown of the wood components (pyrolysis) to give gases, which burn in the presence of oxygen to produce flaming combustion. This has been used as the method for releasing the energy of wood since man discovered fire, and although we have made tremendous scientific and technological advancements in recent years, this is still the principal means for using wood as a fuel.

I. Direct Combustion

II. Conversion Processes

A. Thermal

1. Pyrolysis (destructive distillation)

2. Gasification

3. Liquifaction

B. Nonthermal

Hydrolysis and fermentation

Figure 1.--Methods of obtaining fuels from wood.

All forest residues, foliage, bark, and wood can be processed by combustion, but give different quantities of energy on a weight basis. The heat content for the foliage, twigs, and bark of nine western conifers was recently measured. In most instances these tissues had a slightly higher heat content than the corre-esponding wood, (see table 2) (Kelsey and others 1979, Shafizadeh and DeGroot 1976). Also, the heat content of sound dead wood is the same as the original green wood (see table 1) (Lieu and others 1979).

Conversion Processes

In fuel conversion processes, wood components are changed into a different form, either gas, liquid, or solid, and then burned. These processes can be divided into two general categories, thermal and nonthermal.

Thermal methods include pyrolysis, gasification, and liquifaction (Tillman 1978). Pyrolysis, also known as destructive distillation, is merely the heating of substances in the absence of oxygen. The products from wood pyrolysis are gaseous volatiles and charcoal, both being useful as fuel. It is possible to fractionate the volatiles and isolate methanol and other useful chemicals (see table 3). This is the oldest method of conversion known, having been used to produce charcoal for metal smelters as early as 3500 B.C.

Gasification and liquifaction are extensions and modifications of the pyrolysis process. In gasification, like pyrolysis, the initial products are gaseous volatiles and charcoal, but the process is often carried out in the presence of a limited amount of oxygen. The volatile tars and oils are removed to leave producer gas, a fuel composed of differing levels of CO_2, CO, H_2, CH_4, N_2, and H_2O. The tars, oils and charcoal can be recycled to enhance the conversion to producer gas.

Liquifaction can provide two types of fuels, methanol or heavy oil. To obtain methanol, the CO and H_2 from the gasification producer gas described above, are combined using heat and a catalyst. For heavy oils, producer gas, steam, hydrogen, and finely ground wood are heated to high temperatures under pressure in the presence of a catalyst. The heavy oils are somewhat like heating oil.

Table 2.--Heat of combustion for various fuels.

	BTU/lb
Softwood Forest Residues	
Wood	8,000 - 10,000
Bark*	8,500 - 11,000
Twigs*	8,500 - 10,000
Foliage*	8,500 - 9,500
Other Fuels	
Coal	6,500 - 14,000
Methanol	9,000 - 10,500
Ethanol	12,000 - 13,000
Gasoline	21,000

*Determined for nine conifers in the Northern Rocky Mountains (Kelsey and others, 1979).

Table 3.--Yield of pyrolysis products from 100 kg of softwood.

Product	Yield (kg)	Product	Yield (kg)
Charcoal	32.0	Turpentine oil	0.6
A-Tar	7.0	Light oil	0.4
B-Tar	3.0	Methanol	1.0
Acetic acid	1.7	Uncondensable gases	22.0
Acetone	0.8		

Ethanol, a liquid fuel, can be obtained from wood residue by nonthermal means, and primarily involves conversion of the cellulosic fraction, which is hydrolyzed to glucose sugar with acids (Rogers 1979) or enzymes (Nystrom and others 1978). With the aid of microorganisms the sugar is fermented to alcohol, which after purification can be burned directly or combined with gasoline for gasohol.

In view of the large energy requirements of the forest products industry, perhaps the best means of utilizing wood residues is through partial gasification, where the gases are burned for industrial energy and the char is sold as a solid fuel.

CHEMICALS

The type and variety of chemicals that can be produced from wood residues is almost unlimited. Edwards (1975) indicated that from a casual survey of 50 chemicals produced in the greatest quantities in the United States in 1973, 35 of them could be made from cellulosic materials. Obviously it is not economical to produce all of the compounds at the present time, because of less expensive alternative sources, but the potential is available. For the production of chemicals, the components in the woody residues can be treated together or separated and then processed into useful substances.

Pyrolysis, as discussed above, can convert wood into fuels, or it can be used to produce various chemicals. The compounds obtained are determined by the pyrolytic conditions. The old destructive distillation processes gave methanol, acetone, acetic acid, turpentine, light oil, and tars in proportions listed in table 3. By carefully controlling conditions it is possible to produce high yields of tar that are rich in anhydrosugars, which can be isolated or hydrolyzed to glucose (Shafizadeh and others 1979), (see table 4).

Table 4.--Pyrolysis of wood-derived materials at 400°C under vacuum. (Shafizadeh and others, 1979).

	Percent yield from substrate				
Substrate	Gas	Char	Tar	anhydro-1/ sugars	D-glucose (after hydrolysis
Cottonwood					
Untreated2/	37	16	47	3 (6)5/	5 (12)
1% H_2SO_4 wash	36	12	52	10 (22)	14 (31)
Cottonwood lignocellulose3/	11	18	71	37 (63)	46 (78)
Cottonwood holocellulose4/	25	9	66	32 (57)	40 (71)

1/Combination of levoglucosan and 1,6-Anhydro-β-D-glucofuranose.
2/Extracted and washed with water.
3/Prepared by prehydrolysis with dilute H_2SO_4, washed with water to neutrality.
4/Washed with 1% NaOH, then 1% H_2SO_4.
5/Percent yield based on cellulose content of substrate.

The H_2, CO, CH_4, and N_2 in producer gas can be recombined by various synthetic methods to yield ethylene, ammonia, or methanol. In turn these can then be further modified into numerous useful chemicals (Edwards 1975).

The other approach is to separate the extractives, cellulose, hemicellulose and lignin, and then convert each into desired products. The separation could be achieved by weak acid prehydrolysis to remove the hemicellulose and some extractives. The lignin and cellulose (called lignocellulose) could be separated by pulping or converting the cellulose to sugars by hydrolysis or pyrolysis.

The extractives in wood are predominately volatile oils, fatty acids, and resin acids (Zinkel 1975, Ward 1975). These materials or products derived from them have found a variety of uses down through the ages, and although they can be obtained by several different methods, today most are produced as a by-product of kraft pulping in the form of sulfate turpentine and crude tall oil. These can be further refined into numerous products. Turpentine (volatile oils) can be converted to pine oils for use in mineral flotation, solvents, and synthetics. Fatty acids are commercially important for intermediate chemicals, protective coatings, and the manufacture of soaps and detergents. Resin acids are valuable for paper sizing, and rosin soaps are used in the manufacturing of synthetic rubber. They also have uses in adhesives, chewing gum, and other similar materials. All of these extractives could be obtained from wood residues, and the markets are already established for the products.

Cellulose is a polymer of glucose sugar units, linked together in a linear chain. The polymeric products include paper, or through regeneration, rayon, cellophane, and other derivatives. Cellulose can be hydrolyzed to glucose sugar by acids or enzymes (Rogers 1979, Nystrom and others 1978), and interesting anhydrosugars can be formed by pyrolysis (Shafizadeh 1975, Shafizadeh and others 1979). These anhydrosugars can be isolated or converted to glucose by a mild hydrolysis step. The glucose can be used as a sweetener or it can be enzymatically converted to a mixture of glucose and fructose in a honey-like syrup. The glucose solutions can also be used as an energy source for the growth of microorganisms, such as yeast. Specific components of the microorganisms could be isolated including protein, nucleic acids, fat, vitamins, and other organic molecules. Fermentation can convert the glucose to ethanol for fuel or a feedstock for other chemicals such as ethylene, a starting material for a variety of chemicals including synthetic fibers and plastics (Edwards 1975).

Hemicelluloses are short polymers of five and six carbon sugars, which unlike cellulose are usually branched (Schuerch 1963). These are easily hydrolyzed, xylose being the most common five carbon sugar, and mannose the most common six carbon sugar obtained in this way. Mannose can be fermented to ethanol or converted to mannitol, a dietetic sweetener (Herrick and others 1975). Xylose can be made into xylitol, also an artificial sweetener, or to furfural (Harris 1977) for use in adhesives, resins, and polymers.

Lignin is a three dimensional polymer composed of phenyl propanoid units which acts as a cementing material in plant cell walls (Sarkanen 1963). Unlike cellulose and hemicelluloses, lignin is chemically heterogeneous, and cannot be readily converted or broken down to a single component, but instead yields a complex mixture of phenolics. The mixed phenolics can be obtained by destructive distillation, hydrolysis, pyrolysis, and hydrogenation (Goldstein 1975). Lignin and its degradation products have been used in forming resins, thermoplastics (Lindberg and others 1975), polyurethane foams (Hsu and Glasser 1975), and speciality chemicals such as vanillin (Goheen 1971).

CONCLUSION

Wood residues are a chemically heterogeneous renewable resource that can be used for the production of fuels and chemicals. Because of their complexity, they have the potential to be converted into a wide variety of products that could replace many of the chemicals currently supplied by the petroleum industry. The realization of a wood chemicals industry is hindered more by the economics of the processes rather than by the technology.

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TECHNICAL AND ECONOMIC ASPECTS OF HARVESTING DEAD LODGEPOLE PINE FOR ENERGY

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Forest and Range Experiment Station

ABSTRACT

This study highlights the results of a study of the economic feasibility of harvesting dead lodgepole pine for fuel and products. Costs, production rates, and recoverable wood volumes were obtained from a 3-month study of a whole-tree logging operation in which dead lodgepole pine was harvested for fuel and products.

KEYWORDS: Lodgepole pine, harvesting, energy, residues

National energy problems have drawn attention to wood as a source of energy. At the same time, wood residue in dead timber is creating serious forest land management problems in the West. An obvious and desirable solution is to utilize the dead timber for energy and other products. The solution, however, requires that the dead timber be harvested, transported, and converted to products including fuel, in an economic and environmentally acceptable manner.

The USDA Forest Service, in cooperation with the Department of Energy, is studying the economic feasibility of harvesting dead lodgepole pine timber for energy and other products. Harvesting operations using mechanized equipment for falling, yarding, delimbing, bucking, sorting, chipping, and loading were studied for three months this past summer in the dead lodgepole pine stands of eastern Oregon. Cost, production rate, recoverable wood volume, wood fuel characteristic, and environmental effect data were obtained. This presentation focuses on technical and economic aspects of harvesting dead lodgepole pine for energy. It is based on personal observations and some preliminary analyses of information gathered during the study. Since study analysis and reporting are in progress, the information presented here is preliminary and subject to change.

The logging contractor for the study was Crisstad Enterprises, Inc.,1/ which has considerable experience in harvesting dead lodgepole pine timber from northeastern Oregon. It is a whole-tree chipping operation. The chips are trucked to the U. S. Gypsum plant at Pilot Rock, Oregon, where they are used in manufacturing fiberboard.

The basic harvesting equipment used by Crisstad includes John Deere 544B/Rome feller bunchers, Caterpillar 518 and Clark 667 skidders with Esco 36 grapples, and Morbark Model 18 and Model 22 chippers. Support equipment includes shuttle trucks for vans, crawler tractors, water pumper trucks, fuel trucks, crew rigs, and mechanic's truck. Chip and log trucking are contracted.

A Hahn tree-length delimber and a log loader were added to the equipment array during the study. This equipment was used in several different configurations or systems to recover logs of sufficient quality, diameter, and length for available markets. The log markets included house logs and dead and green saw logs.

During the study, cutting units on timber sales in the Umatilla and Wallowa-Whitman National Forests were harvested. The units ranged from about 15 to 35 acres in size. All of the lodgepole pine trees on the units were clearcut, green as well as dead. The average diameter at breast height (d.b.h.) of the lodgepole stands ranged from 5 to 9 inches. Most of the lodgepole pine had been dead for 4 or 5 years.

Initially, the Hahn delimber was operated alongside a chipper. The skidder brought turns beside and in between the two machines. The loaders on the machines sorted and fed tree stems as appropriate, and tops from the Hahn were chipped as they developed. Time spent in sorting and waiting for input material slowed production in both machines.

The Hahn delimber was also operated separately from a chipper. To speed production, the feller-buncher operator separated stems by diameter as much as possible for the skidder. Trees that contained no logs and tops from trees that did were decked by the Hahn for later chipping. The Hahn also sorted the manufactured logs according to market specifications. This sorting slowed production.

On some cutting units, no logs were produced due to small stem size. The 3-month period of the study covered a variety of stand conditions as well as harvesting procedures.

The chip material probably has the most potential for being used as an energy source. Lodgepole pine wood has a heating value of about 8600 Btu/lb. (over 3,800 Btu per kg.).

The average weight of the wood in the chip vans was about 42,500 lbs. (19,000 kg.) as loaded, and 32,500 lbs. (14,700 kg.) bone dry. So there were about 13.5 bone dry units (2400 lbs. or 1,080 kg.) per chip van.

About 20 to 55 dry tons/acre of chips and logs were removed. Approximately 7 to 27 dry tons of wood were left on the ground as slash or logging residue. Much of this was already down prior to harvesting and caused problems for the feller/buncher and the skidder operators.

1/ The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Machine production rates were quite variable because of a number of factors. Production ranges were:

	(Dry tons/hour)
Chipper	5 to 20
Feller-Bunchers	8 to 18
Skidder	10 to 13

With no delays and everything working right, the Model 22 chipper could produce about 40 dry tons/hour.

The diesel fuel used in producing chips was monitored. It appears that the diesel fuel requirements per van load of chips (13.5 bone dry units) are:

Chipper	12.5 gallons
Feller-buncher	7.0 gallons
Skidder	8.2 gallons

This presentation has discussed some highlights of the harvesting study underway on dead lodgepole pine in northeastern Oregon. Work on a comprehensive report on the study is in progress. The report should be published by the USDA Forest Service, in 6 to 9 months.

INTERMOUNTAIN REGION WOOD UTILIZATION
AND WOOD ENERGY APPLICATION PROGRAM

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ABSTRACT

There continues to be a high level of interest nationally in accelerating the use of wood residue as an energy source. On September 15, 1978, the U.S. Forest Service initiated a National Wood Utilization and Wood Energy Application Program to focus attention on application of existing and developing technology. The mission and goals of this program are discussed.

On March 20, 1979, the Regional Forester, Region 4, approved a Wood Utilization and Wood Energy Application Program for the Intermountain Region. Highlights of the program are reviewed, including mission and goals, planned wood energy symposium, firewood programs 1976-79, conflicts between home and industrial use, forest residue inventory, and priorities of forest residues utilization.

Problems that need to be faced, such as access, economic feasibility, and long-term guarantees are discussed.

The benefits and hazards of utilizing forest residues are summarized and the paper closes with mention of the U.S. Forest Service and Regional commitment and the future opportunities for wood energy.

KEYWORDS: wood energy, wood residues, firewood, wood utilization

INTRODUCTION

Many people have recently come to recognize wood as a potentially important source of energy that can be substituted for scarce fossil fuels. In fact, substitution of wood for fossil fuel is now occurring at an accelerating rate. The emergence of wood residue as an important forest product in the United States can be very important to the Country. It can be a valuable adjunct to forest management or it can be a major management headache. In any case, the increasing use of wood as fuel is here and not likely to disappear.

There is a high level of interest nationally and in the Intermountain Region in further accelerating the use of wood residues as an energy source. Currently, unused residues represent a significant potential energy resource. The major components of the residue resource are (1) logging slash and cull material, (2) dead timber considered unmerchantable and (3) submerchantable small trees. Opportunities for using this wood to generate energy include direct use as a fuel, modification to create more efficient solid fuels, or conversion to methanol or other liquids or gas forms.

Proposed Legislation

Some of the national interest is evidenced by a number of bills being presented to both the House and Senate--six bills are now before Congress. On September 19, 1979, Senator Talmadge introduced Senate Bill S-1775 on behalf of himself and 28 other senators, including Senators Melcher of Montana and McClure of Idaho. This bill is called the Agricultural, Forestry and Rural Energy Act of 1979.

The purpose of the bill is to:

(1) Establish the USDA as the lead agency for development and production of alternate fuels from biomass.

(2) Assure the development and implementation of energy production and conservation programs in agriculture, forestry, and in rural communities. The explicit goals are to achieve (A) net energy independence for agriculture and forestry and (B) a 50 percent reduction in petroleum and natural gas use by rural communities by the year 2000.

(3) Create an agricultural, forestry and rural energy board within the USDA.

National Wood Utilization and Wood Energy Application Program

On September 15, 1978, the Chief of the Forest Service and his staff agreed to initiate a National Wood Utilization and Wood Energy Application Program to focus attention on the application of existing and developing technology. The mission of the program is to increase the potential for intensive management of forest lands through commercial use of wood products and energy.

The goals under this program are:

(1) To establish markets for residue created by thinnings, timber sales operations, and fire, insect, and disease prevention and suppression activities.

(2) To apply the latest technology to establish and assure the profitability and stability of new residues-related industry.

(3) To provide technical assistance to land managers for use in planning appropriate levels of utilization.

(4) To make optimum use of biomass for energy.

A major aspect of the program is the identification and development of promising energy project demonstrations. One possible activity is the conversion of Federal or other public facilities to wood-based heat and power. The development of wood utilization centers that produce a broad mix of wood products and utilize residues for heat and electricity is another possibility.

All Forest Service Regions and Areas have designated wood utilization and energy coordinators, and have established wood energy committees that include representation from all branches of the agency.

INTERMOUNTAIN REGION WOOD UTILIZATION AND WOOD ENERGY APPLICATION PROGRAM

Over the past several years there have been few areas within the Intermountain Region that have been utilizing wood residues for energy, and this primarily in the form of firewood for home heating and cooking. In 1978, the oil crunch jolted many people to the realization that the days of free and easy energy were limited. In December of 1979, the Regional Forester appointed me as the Regional Wood Energy Coordinator and also appointed a Wood Energy Committee. On March 20, 1979, the committee presented the Regional Forester with the Intermountain Region Wood Utilization and Wood Energy Application Program plan, which he approved.

Intermountain Region Wood Energy Goals

Four goals of our program are (1) through cooperation with the private industry sector, establish markets for wood residue resulting from cultural and fire, insect and disease prevention and suppression activities, (2) to minimize the use of fire in residue disposal activities, enhancing air quality and favoring recovery of residues as an alternative energy source, (3) to assist and encourage potential users and proponents of alternative wood energy products by providing information and technical assistance, assuring that utilization optimizes benefits to the public, and (4) to assure that Forest Service equipment, facilities, and programs are used to demonstrate energy conservation and application of alternative energy source technology.

In order to achieve some of these goals at the earliest possible date, several actions have been taken. We asked four Forests to prepare a preliminary analysis of wood energy projects using a minimum of 2,000 cords of wood per year. We are in the process of analyzing these proposals at the present time. Another of our objectives was to assist the Forests in a review of forest residues and wood energy potentials. A coordination workshop was held in Salt Lake City in May of 1979, with members of all National Forests in attendance. At that workshop we discussed current technologies, resource evaluations, preliminary feasibility analyses, and project preparation. In addition, the attendees were divided into work groups and asked to identify major barriers to the use of residues, and develop strategies for resolution. Of the long list of barriers, problems with budgets, time and personal attitudes were the most frequently cited barriers. The attitude barrier reflects the old way of doing business, such as burning the residue rather than utilizing it.

We are presently planning an energy conference in Salt Lake City for spring. The conference will be mainly on land management problems associated with the use of forest residues for wood energy.

PROBLEMS IN UTILIZING RESIDUES FOR WOOD ENERGY

The Intermountain Region Wood Utilization and Wood Energy Application Program faces many fundamental problems. One of the major problems in promoting increased residues utilization in the industrial sector is the lack of a reliable forest residues inventory. There are inventory models in other regions that predict the amounts of residue resulting from timber sales which we feel might be adapted to Region 4. We are also looking at the possibility of making predictions from the stand inventories conducted as a part of on-going forest management activities. However, to date we do not have a good idea of the amount of residues in the form of dead timber, logging slash and insect and fire-killed material that is available or will be available for energy use. In this Region particularly, the distance between the forest residues and potential markets can also be economically prohibitive.

There is a lack of long-term guarantees of continuous supply. These factors coupled with the question of economic feasibility of wood energy leads to another concern: where is the capital investment for experimental energy projects going to come from?

Currently, the biggest use of forest residues in the Intermountain Region is for firewood. In 1976 the Intermountain Region issued 39,572 permits for free firewood. The total volume cut was 95.9 million board feet or 191,000 cords. In 1977 the number of permits jumped to 50,836 and the volume to 156.6 million board feet of firewood. In 1978, the number of permits increased to 69,400 for a total of 179.4 million board feet or 359,000 cords. In 1979 there were 101,791 permits with a total permitted volume of 251.5 million board feet of timber cut. Overall, there was a 262 percent increase in the number of permits in three years. This points to several very pressing questions. Could a moderate charge for firewood-cutting permits be instituted? If so, can a sound residues management program be developed to deal with the size of the firewood program? I think the answer is "yes" in both cases. Also, the question of increased public access to existing residues, especially where temporary roads are involved, must be considered. Determining the priorities for increased wood utilization between potentially competing public and industrial users is a related problem.

In spite of these problems, there are several proposed energy projects being evaluated at this time in the Region that will utilize mill and/or forest residues. There is a potato-processing plant at Rexford, Idaho that has received funding for a feasibility study of conversion of their Wisconsin and Idaho plants to wood heat. In southern Utah, a forest products firm is studying the feasibility of a pyrolysis process for making charcoal and oils from mill residues. One of the major timber companies in southwestern Idaho has installed a fluidized bed wood-fired bark boiler system for heating their dryers. There are two power companies within the Region that have done feasibility studies on the use of wood for co-generation of electrical power. There is also a proposed gasahol operation in southwestern Idaho. In addition, there are a growing number of commercial woodcutters to meet the heavy consumer demand for wood stove fuel.

BENEFITS AND HAZARDS OF UTILIZING FOREST RESIDUES

Some of the benefits and hazards of increased utilization of forest residues are already apparent. Residue utilization can help accomplish site preparation for regeneration; reduce dangerous fuels accumulation and fire hazards; and provide, through thinnings, a silvicultural benefit. Outside of the forest, residue utilization can improve the local economy by creating employment opportunities in new industries. Most importantly to our program, it can reduce our reliance on fossil fuels.

However, intensive utilization could affect future soil fertility by interrupting the recycling of nutrients; create extreme surface temperatures that might inhibit regeneration; and pose coordination problems involving wildlife habitat.

Commitment to Wood Energy Programs

In closing, let me say that the Intermountain Region is committed to an energy program using wood residues, and while we are a long way from having all the answers, we are putting forth our energies to make this program work for the benefit of all. It is my personal belief that there are many opportunities to use wood residues to help in the fuel crunch. I also think there are many opportunities, small and large, for both individuals and companies to use some imaginative thinking that will pay off in both social and economic benefits.

REVIEW OF BIOMASS GASIFICATION

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ABSTRACT

This paper reviews the topic of biomass air gasifiers. The gasification process chemistry is outlined and the operating characteristics of two types of gasifiers are presented. A few typical applications are discussed and the economics for a particular system are presented in comparison with the costs of natural gas. Finally, the appendix gives a list of biomass research, demonstration projects and manufacturers.

KEYWORDS: gasification, biomass fuel

Biomass air gasifiers offer one of the many contributing solutions to our current energy problems. Interest in these devices increases when more convenient energy sources, such as oil and gas, become scarce or very expensive. Air gasifiers must still compete, however, with other energy uses for biomass, such as heat and steam from direct combustion, pyrolysis processes and even methanol production. Moreover, biomass feedstock end uses must compete in the economic market with requirements for lumber and fiber.

GASIFICATION PROCESSES

The gasification process is simply one of converting a solid fuel into a gaseous fuel. However, there is often some confusion between the terms pyrolysis, gasification and combustion. The distinguishing quantitative characteristic between these conversion processes is the amount of air (oxygen) used relative to the quantity of fuel. One study (Reed and Jantzen 1979) determined that pyrolysis predominates when the air used to convert a given quantity of fuel is less than 20 percent of the theoretical air required for total combustion. The main product from a pyrolysis process is char along with some gases and oils. The gasification process predominates when 25-50 percent of the theoretical air required is used, resulting in a low to medium Btu gas. Finally, the combustion process predominates when the air supply is equal to or greater than 100 percent of the theoretical air required for total combustion. This process results in total conversion of the fuel's chemical energy to thermal energy.

The conversion of solid biomass material to a gaseous fuel involves many separate chemical reactions. The more important of these reactions are given in table 1 along with the heat from the reaction. Besides actual chemical transformation, the physical process of drying wet biomass also is included. All of the reactions, of course, do not yield a gaseous fuel and the main example is reaction 1 (table 1).

TABLE 1.--Thermo-chemistry of gasification.

No.	Reaction	ΔH, BTU/lb-mole	ΔH, kJ/gm-mole	
1	$C + O_2 \quad CO_2$	-169,288	-392.7	Exothermic
2	$C + \frac{1}{2}O_2 \quad CO$	-47,556	-110.6	Exothermic
3	$C + CO_2 \quad 2CO$	+74,160	+172.3	Endothermic
4	$C + H_2O \quad H_2 + CO$	+56,437	+131.2	Endothermic
5	$CO + H_2O \quad H_2 + CO_2$	-17,723	-41.2	Exothermic
6	$C + 2H_2 \quad CH_4$	-32,198	-74.8	Exothermic

When air is used to provide the oxygen source, a large quantity of nitrogen remains after combustion and the nitrogen acts as a dilutant to the resulting gaseous fuel. As can be seen in table 1, some of the reactions are endothermic, and thus, require a heat input from some other reaction before they can occur. This heat input generally is supplied from the highly exothermic reaction #1.

Another important thermodynamic variable that effects the product distribution in the gasification process is the chemical equilibrium constants. While actual equilibrium is seldom attained in an operating gasifier, the equilibrium values and their temperature characteristics are very important. Figure 1 illustrates the equilibrium effects for the reduction of carbon dioxide with charcoal at various temperatures and various gas velocities. The factors to note are the rather large changes in CO concentration as the temperature increases at a fixed flow rate and also the effect of the gas flow rates themselves.

The composition of the product fuel gas will depend on such factors as the type of gasifier, the moisture content of the biomass feedstock, the gas flow rate, the operating temperatures, and the oxygen concentration of the air. The total enthalpy of the gas will depend on the above factors as well as the gas temperature, when it is used, and its moisture content.

Most air-blown gasifiers yield a gas composition within the ranges shown in table 2. The updraft gasifiers also contain tars that increase the chemical energy content of the gas if they remain in the gas phase before being burned.

The effect of biomass moisture content on the heating value of the gas is shown in figure 2. This reduction in heating value limits the material with use of biomass in downdraft gasifiers to about 30 percent wet basis. Updraft gasifiers can accept material with a moisture content up to 50 percent before the thermal performance is severely affected.

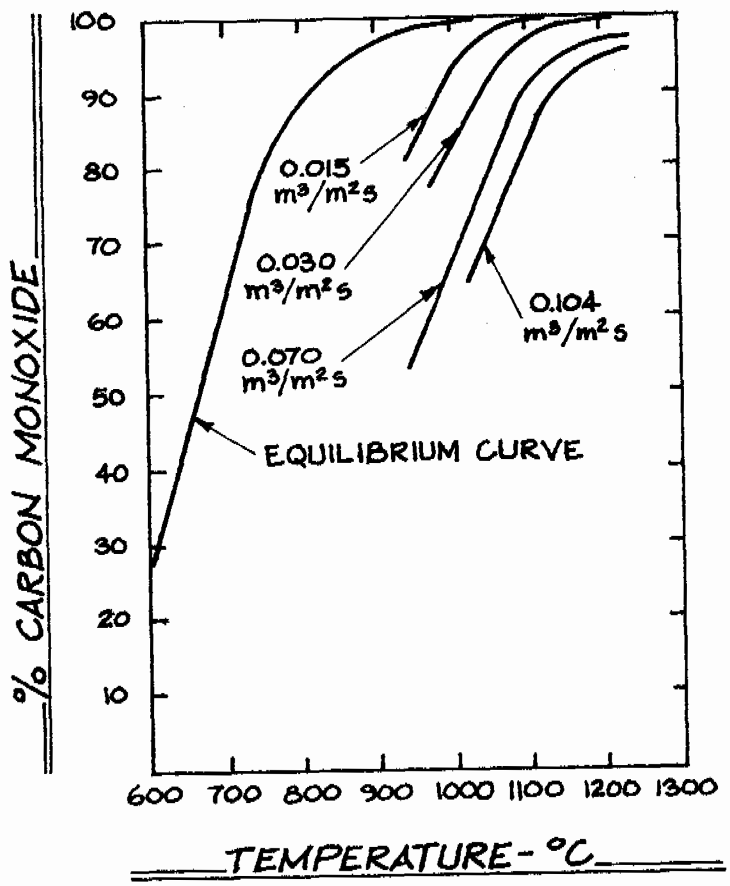

Figure 1.--Carbon monoxide concentration as a function of temperature and flow rates over heated charcoal (Widell 1950).

Table 2.--Typical gas analysis from downdraft gas producer using wood (Allcut and Patten 1943)

Gas		Range % by Volume
CO_2		9.5 - 9.7
O_2	Non-Combustible	0.6 - 1.4
N_2		50.0 - 53.8
Hydrocarbons		0 - 0.3
CO		20.5 - 22.2
H_2		12.3 - 15.0
CH_4		2.4 - 3.4
Heat Content, HHv		138 - 149 BTU/SCF

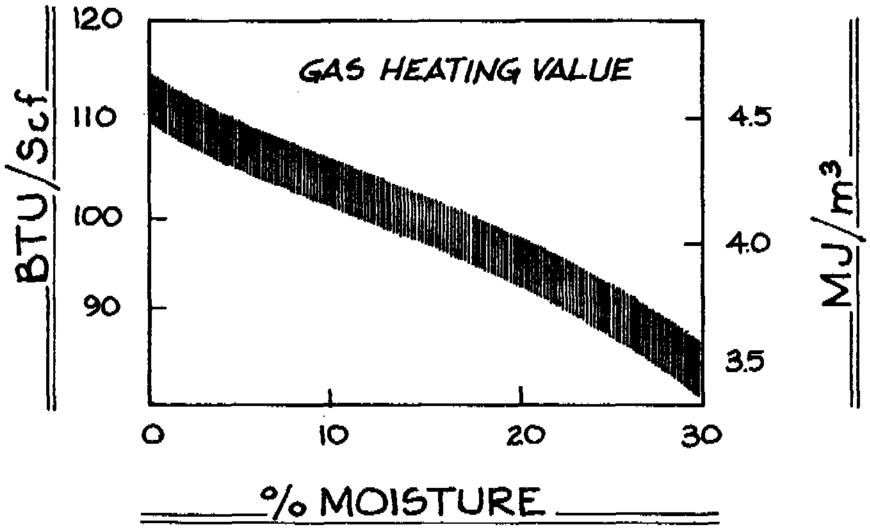

Figure 2.--Effect of moisture content on gas heating value for downdraft gasifiers. (Gumz 1950).

GASIFIER CONFIGURATIONS

Many different configurations have been used for gasifiers and the main differences are where the air is introduced and where the resultant fuel gas is extracted. The classical gasifiers, the updraft and downdraft types, are shown in figures 3 and 4. In the updraft gasifier, the air is introduced into the combustion zone immediately above the ash pit. Oxidation reactions 1 and 2 (table 1) occur, generating CO and CO_2 plus a great deal of heat. These gases pass upward through the biomass and their temperature is continually reduced. Some of the gases further react and generate H_2 and additional CO. Volatile oils are driven from the incoming biomass and these, along with the moisture, leave the gasifier.

The downdraft gasifier differs in that the reduction zone is the last one encountered by the existing gas. This process results in much lower volatile oil and tar content of the gas since these compounds crack into gases as they pass through the hot reduction zone. The reaction zones and predominate reactions that occur there are shown in figure 5 for a downdraft gasifier.

There are many variations on these basic designs. Biomass gasifiers range in size from 10^5 Btu/hr to 10^8 Btu/hr. The system design is highly dependent upon the end use and the desired or required heat content of the gas.

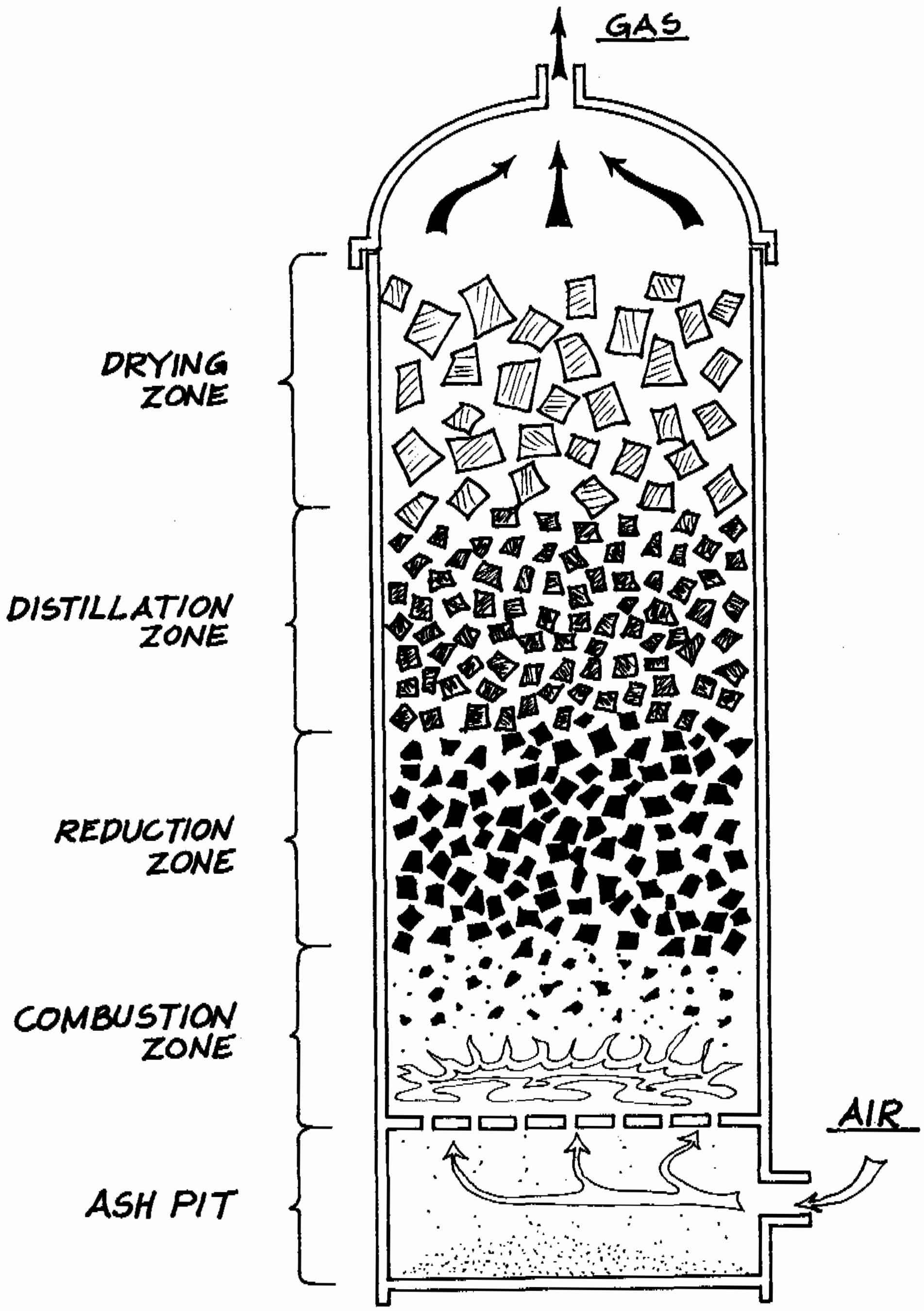

Figure 3.--Updraft gasifier.

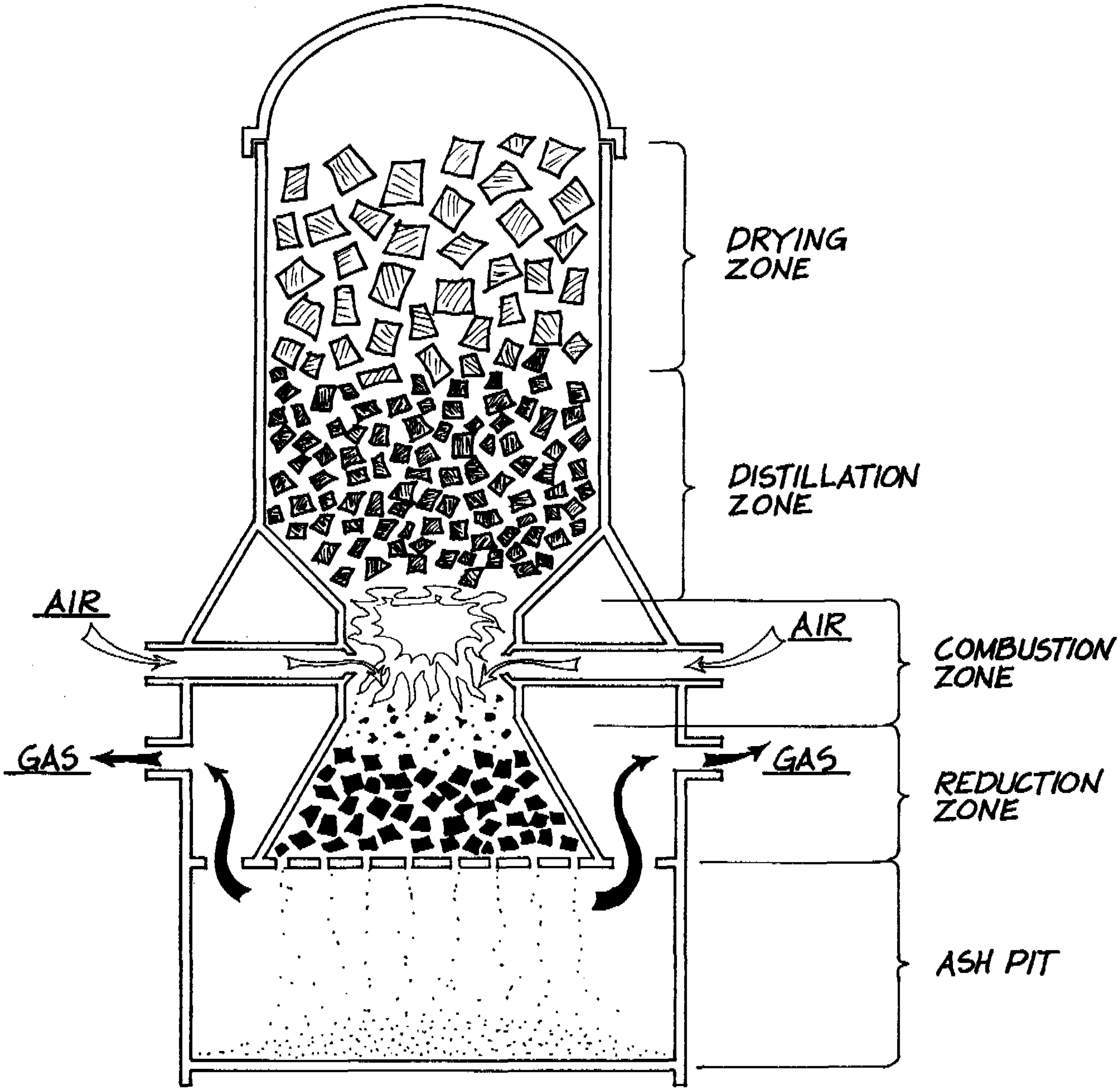

Figure 4.--Downdraft gasifier.

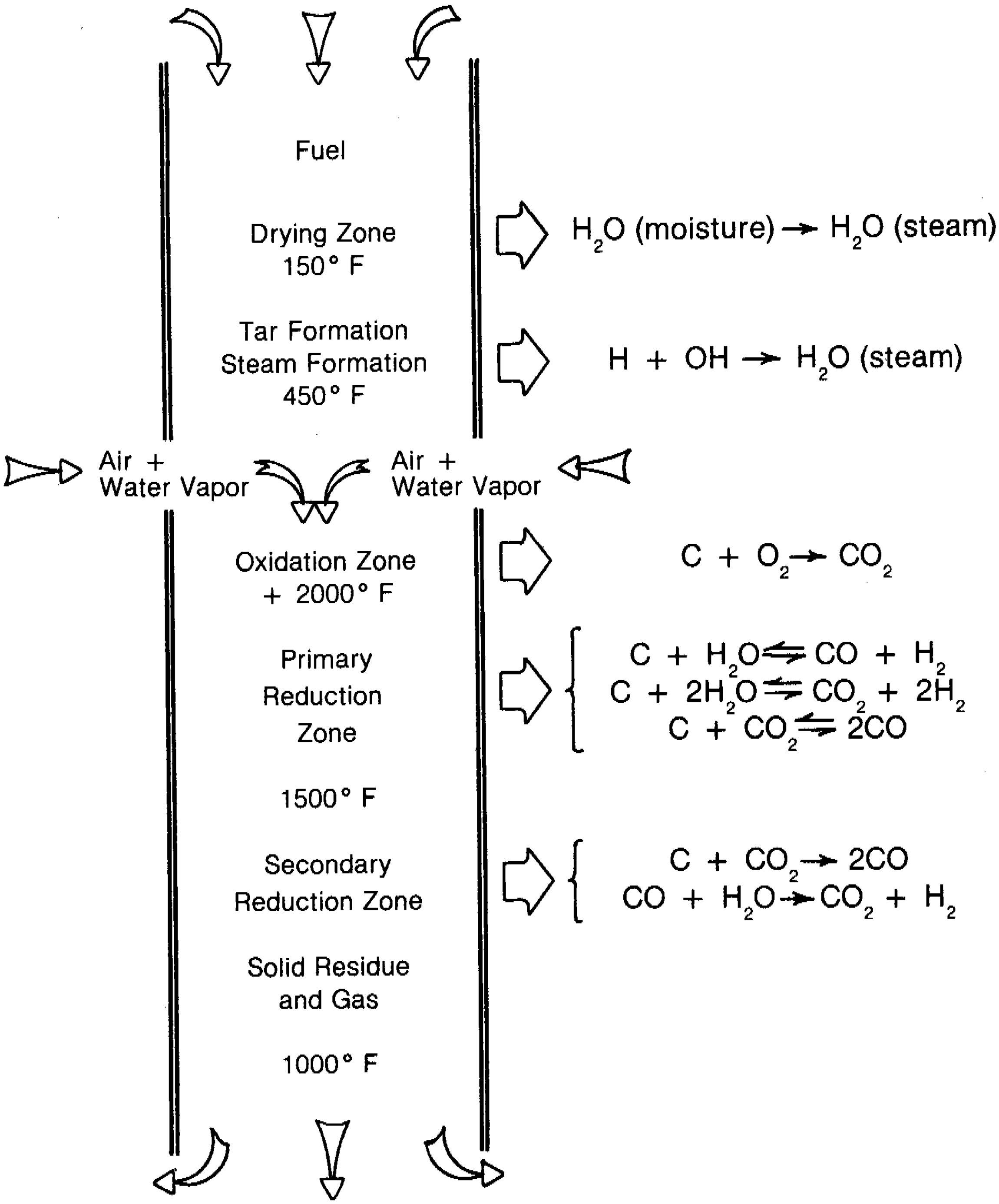

Figure 5.--Reaction zones in a downdraft gasifier.

APPLICATIONS

Gasification of organic materials for power and fuel have been utilized since 1857 when the Siemens brothers in Germany developed a successful gasifier using coke for fuel. By 1923, stationary gasifiers had been designed for and operated with many forms of cellulosic residue. During World War II, up to 700,000 vehicles were equipped with gasifiers to meet the problem of liquid fuel shortages. Today gasifiers are being developed for applications ranging from home heating systems to portable and stationary electrical generators.

One of the most efficient uses of a gasifier is to produce gaseous fuel for an existing gas burner. As shown in figure 6, a boiler's efficiency depends upon the energy content of its fuel. However, for gases with a heating value greater than 200 Btu/scf, the efficiency is essentially constant and equal to that for natural gas. By close coupling the gasifier to the boiler all of the generated fuel gas as well as the sensible heat of the gas stream is utilized. Of course, the size of the fuel line would have to be increased since the fuel gas only has about 150-200 Btu/SCF compared to natural gas with 1000 Btu/SCF.

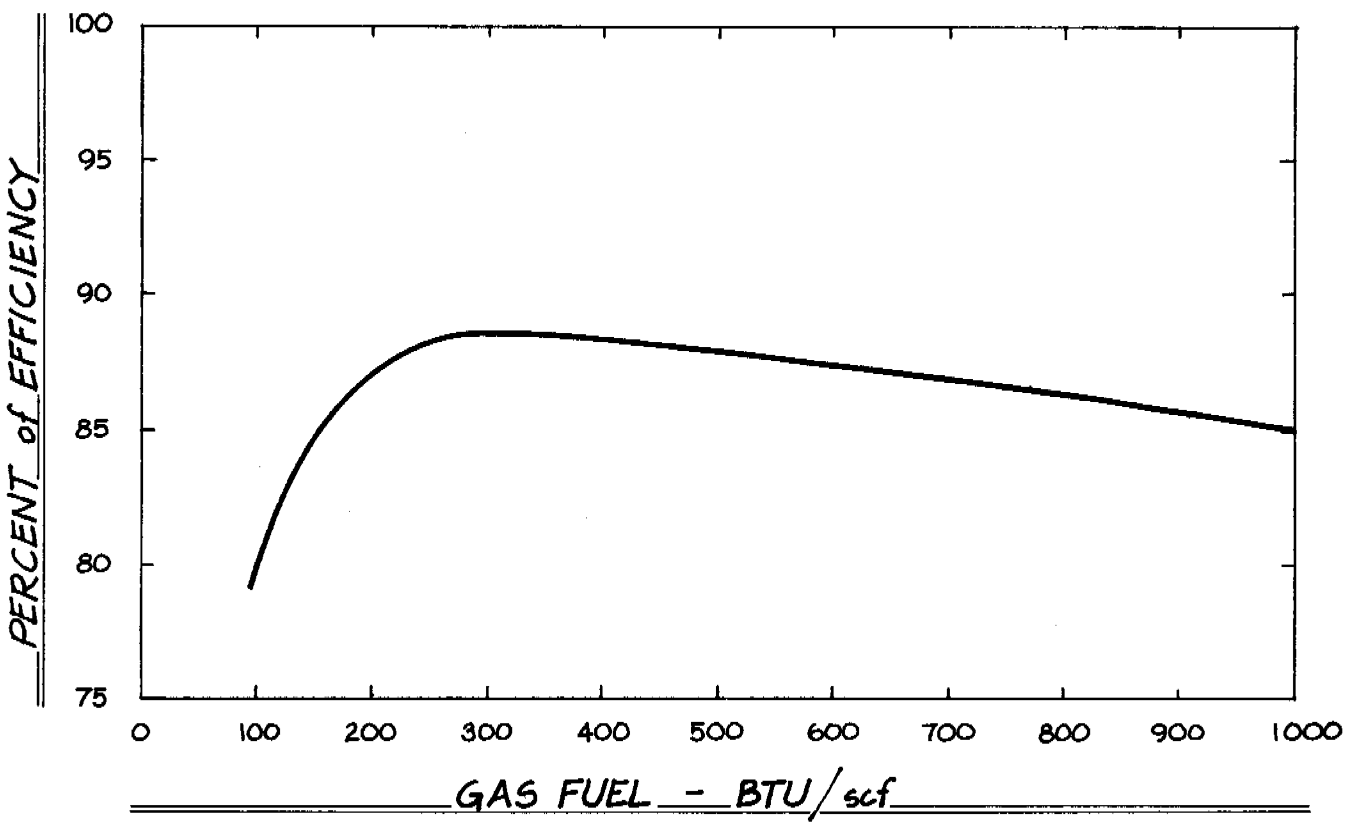

Figure 6.--Gaseous burner efficiencies (Bechtel 1975).

Another application of biomass gasifiers is to produce fuel for an internal combustion engine, either spark or compression ignition types. The Swedish experience with gasifiers providing fuel for vehicles shows both the technical feasibility as well as the many drawbacks. Thus it is not expected that gasifiers will find much general acceptance for mobile applications.

In general, though, there is a great deal of interest in developing and testing biomass gasifiers. Appendix A lists biomass air gasifiers research, development, and demonstration programs around the country. The University of California - Davis gasifier has been demonstrated at the state heating plant in Sacramento as well as at the Diamond/Sunsweet walnut processing plant as a source of fuel for steam generation. Moteurs Durant units have been delivered and installed in Europe, Africa, Asia and Central America to provide electrical power from biomass via an air gasifier.

ECONOMICS

The accurate determination of fuel gas costs from a biomass gasifier is a very complicated exercise. The capital cost for the gasifier is probably the easiest parameter to determine, but the cost of capital, which depends on many arbitrary decisions, is very difficult to determine. For the purposes of this review paper, only the operating cost of gasification will be compared with that of natural gas. In this analysis, assumptions must be made, including an assumed cost of the biomass feedstock (table 3).

Table 3.--Assumptions used to determine operating cost of gasifier.

Peak demand for heat	15×10^6 Btu/hr
Capital Cost of gasifier and installation (ref. 6, 7)	$340,200
Cost of Capital	15%
Operating Costs (ref. 6, 7)	$37,010/yr.
Operating Cost inflation factor	7%
Heat content of feedstock	17×10^6 Btu/ODT
Gasification efficiency	80%
Yearly heat demand	118.8×10^9 Btu
Feedstock inflation factor	10%

The most sensitive economic factor in all end uses of biomass is the cost of biomass feedstock. This is true for gasification processes as well as ethanol production from grain. There have been many studies of the cost of delivered forest residues (Pratt 1978, Johnson 1978, Mattson 1978) and the values range from $15 to $35/ODT.

Figure 7 shows the operating cost of gasification for three selected biomass feedstock costs as a function of year. Compared to each feedstock cost are the future prices of firm industrial natural gas assuming various rates of increase. The 24 percent increase per year reflects the history of natural gas prices over the past nine years (Montana Power 1979). As illustrated, the cost of gas from biomass gasification is less than the industrial rates for natural gas for all years at a feedstock cost of $20/ODT. However, for a feedstock cost of $45/ODT, the crossover points are 5 to 10 years into the future before gasification can compete with natural gas.

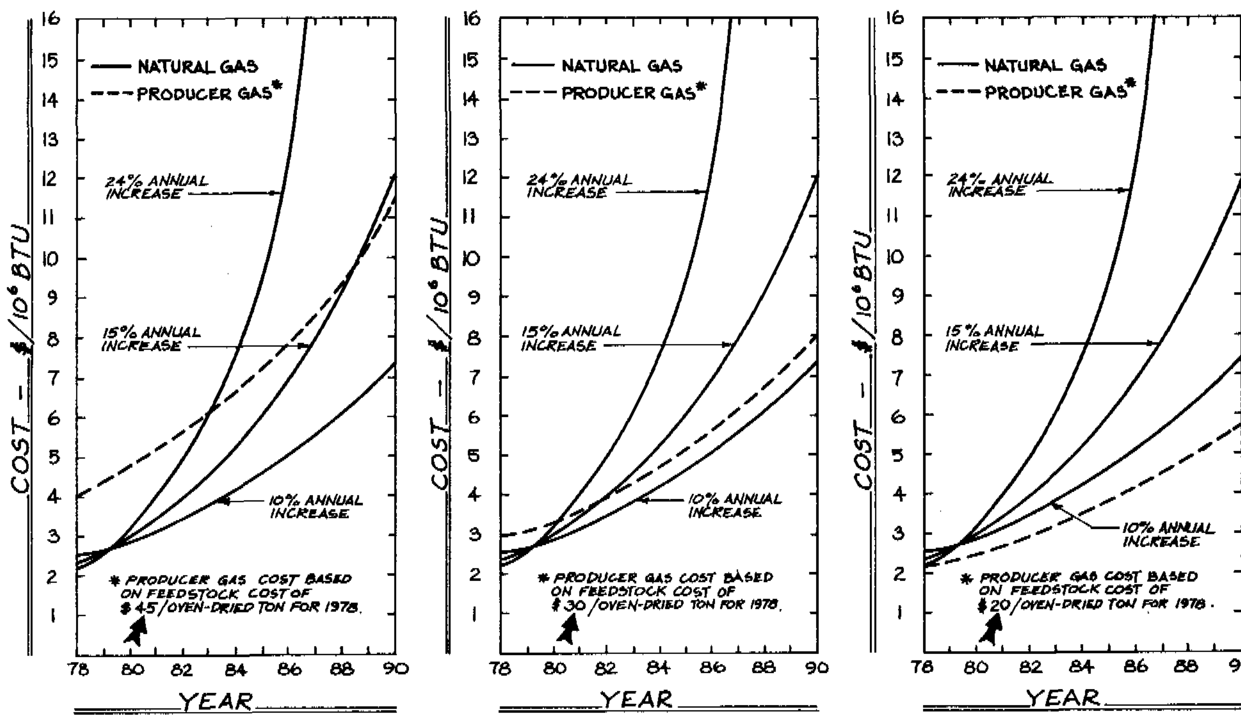

Figure 7.--Cost comparison curves, natural gas and producer gas.

In any event, each potential user of biomass as a fuel must determine his own economic situation and operating costs. There are many factors to consider from both a technical and an economic viewpoint.

CONCLUSION

1. The gasification of forest residues is a proven technology.
2. Commercial biomass gasifiers are available but not yet widely accepted.
3. Low Btu-gas can be used for heating and for power end-uses.
4. The cost of gas from biomass gasifiers is strongly dependent upon the cost of biomass feedstock.

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APPENDIX

Biomass Gasifier Projects

Organization	Status
Alberta Industrial Developments Ltd. 704 Cambridge Building Edmonton, Alberta Canada T5J 1R9 (403) 429-4094	Fluid bed reactor 30 x 10^6 Btu/hr Prototype ready for commercial use.
Applied Engineering Co. Orangeburg, SC 29115 (803) 534-2424	Updraft, 5 x 10^6 Btu/hr commercial demonstration.
Bio-Solar Research & Development Corp. 1500 Valley River Drive Eugene, Oregon 97401 (503) 686-0765	Updraft, small pilot scale.
P.C. Walkup Battelle - Northwest P.O. Box 999 Richland, WA 99352 (509) 946-2432	Updraft, commercial and research stage.
B.C. Research 3650 Wesbrook Mall Vancouver, B.C. Canada V6S 2L2 (604) 224-4331	Fluidized bed, 10^6 Btu/hr, research.
Department of Agricultural Engineering University of California Davis, California 95616 (916) 752-1421	Downdraft, 6 x 10^6 Btu/hr, demonstration.
Century Research, Inc. 16935 S. Vermont Avenue Gardena, California 90247 (213) 327-2405	Updraft, 50 x 10^6 Btu/hr, commercial.
Davy Powergas, Inc. P.O. Box 36444 Houston, TX 77036 (713) 782-3440	Updraft, commercial.
John Deere & Company Technical Center 3300 River Drive Moline, Illinois 61265 (309) 757-5275	Downdraft, 100 kW generator, research.

Eco-Research, Ltd. P.O. Box 200, Station A Willodale, Ontario Canada M2N 5S8 (416) 226-7351	Fluidized bed, 15 x 10^6 Btu/hr pilot plant.
Environmental Energy Engineering Inc. P.O. Box 4214 Morgantown, West Virginia 26505 (304) 983-2196	Fluidized bed 3 x 10^6 Btu/hr pilot plant.
Forest Fuels, Inc. 7 Main Street Keene, New Hampshire 03431 (603) 357-3319	Updraft, 1-30 x 10^6 Btu/hr pilot-commercial.
Foster Wheeler Energy Corporation 110 S. Orange Avenue Livingston, New Jersey 07039 (201) 533-2667	Updraft, research.
Biomass Corporation 951 Live Oak Boulevard Yuba City, California 95991 (916) 674-7230	Downdraft, 1-15 x 10^6 Btu/hr commercial.
Engineering Experiment Station Georgia Institute of Technology Room 1512 A C&S Bldg. 33 N. Avenue Atlanta, Georgia 30332 (404) 894-3448	Updraft, 0.5 x 10^6 Btu/hr research.
Halcyon Associates, Inc. Maple Street East Andover, New Hampshire 03231 (603) 735-5356	Updraft, 6-50 x 10^6 Btu/hr commercial.
Imbert Air Gasifier 5760 Arnsberg, 2 Steinweg Nr. 11 Germany	Downdraft, 10-10,000 kW generator commercial.
Lamb-Cargate Industries 1135 Queens Avenue New Westminister, B.C. Canada V5L 4Y2 (604) 521-8821	Updraft, 25 x 10^6 Btu/hr commercial.
Moteurs Duvant Industrial Development & Procurement One Old Country Road Carle Place, NY 11514 (516) 248-0880	Downdraft, 1-8 x 10^6 Btu/hr 100-750 kW generator commercial.

Pioneer Hi-Bred International 4700 Merle Hay Road Johnston, IA 50131 (515) 245-3721	Downdraft, 9 x 10^6 Btu/hr research.
Vermont Wood Energy Corp. P.O. Box 280 Stowe, Vermont 05672 (802) 253-7220	Downdraft, 8 x 10^4 Btu/hr development.

ECONOMIC AND MANAGEMENT CONSIDERATIONS

Proper management of forest lands involves the integration of many disciplines. When dealing with the utilization of forest residue, principles of economics and business in relation to costs, benefits, and to allocating scarce resources to competing uses are very important. There are, however, numerous other social and biological sciences which the forest manager must use to evaluate harvesting and utilization opportunities for forest residues.

The program participants in this section examine not only economic considerations but also some of the other biologic and social sciences most essential to the proper management of forest lands for multiple and sometimes conflicting purposes as they relate to harvesting the forest residue resource.

VALUE RANKING
FOR UTILIZING LODGEPOLE PINE RESIDUES

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ABSTRACT

Relative values per ton of log input are developed for poles, corral poles, house logs, lumber, studs, veneer, chips, and fuel on a current market basis. The techniques to reevaluate on different markets are demonstrated. Product specifications, demand, and potential to salvage significant volumes are also addressed.

KEYWORDS: Residues, forest products, lodgepole pine, poles, house logs, lumber, veneer, chips

VALUE RANKING FOR UTILIZING RESIDUES

As the title implies, there are many ways of utilizing wood residues. There are also several classes of wood residues. I am going to talk primarily about dead lodgepole pine because there is so much of it available and because there is quite a bit known about the resource.

There are several classes of residues. What was at one time a mill residue problem has become the resource for the paper and particleboard industries. It was almost inevitable that the demand for forest products would force people to look at forest residues as a possible resource base.

There is a huge volume of dead lodgepole pine in the intermountain region and the Rocky Mountains. Virtually all of it could be used for fuel or more valuable products if it were accessible and had a ready market. There are, however, several constraints on use. Each class of possible product has specifications which vary from very stringent (power poles) to almost none (fuel), that affect how much of the product can be used. In addition, some of the products have limited markets or cost more to produce than their current value. This paper will examine the relationship between specifications, value, market and the feasibility of using significant volumes of dead lodgepole pine.

To set the stage for what is too come, I want to start with a 1970 base. At that time, Arabian oil was $1.80 per barrel and other energy sources were priced competitively. Such cheap fuel caused some strange situations. Sawmills were disposing of wood waste in wigwam burners while piping in natural gas to supply energy because the natural gas furnaces were simpler and cheaper than wood burners. The October 1979 issue of Forest Industries has an article on a mill that switched from oil to wood for energy and mentions that the mill switched from wood to oil and gas in 1970.

Federal stumpage then was also relatively cheap. In fact, one of the things that has nearly kept pace with the inflation in energy costs is Federal stumpage rates. (fig. 1)[1]

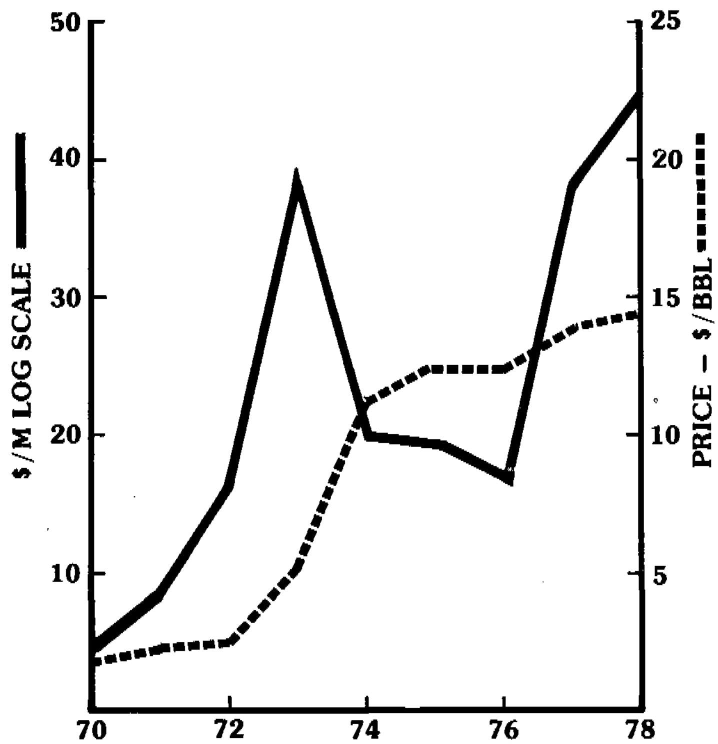

Figure 1.--Stumpage prices, Region 1 lodgepole pine compared to crude oil prices 1970-1978.

The forest products industry has undergone a quiet revolution the past 10 years. Scarcity of wood, which is really only a shortage of preferred species and sizes, plus increased stumpage and energy costs, have changed both the resource base available to mills and to some extent the products produced. Some products such as underlayment particleboard require so much energy (Koch 1976) that production will be converted to more valuable industrial grades or the price will rise to a point where it is no longer competitive.

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[1]Sources: Ruderman 1979 and American Petroleum Institute. 1975 Basic Petroleum Data Book. API, Washington, D.C.

DERIVING VALUE OF FOREST PRODUCTS

To establish a value for a product, a standard unit of measure is needed. The best unit to use would be cubic volume or ovendry (O.D.) weight. Because all composition boards and any processed fuel product involves increased density, I will evaluate everything in dollars per O.D. ton of logs.

Ovendry weight of logs requires cubic feet to derive, but makes it possible to include bark volumes as an integral part of wood volume. It also allows for pricing of all products on the same basis.

The reported wood density of lodgepole pine differs among various sources of information (Foulger and Harris 1973; Maloney 1978). I am going to use 24 lbs per cubic foot ovendry for both wood and bark for either live or dead. The value is in the range for lodgepole pine, and real density varies among different sites as well as among information sources. In addition, dead trees tend to lose bark, not only while standing but during logging and yard handling, so I will use 5 percent of volume for bark on dead lodgepole.

Values used as points of reference are:

B.T.U./lb O.D. wood	9,000	(20 920 kj/kg)
Lb/ft^3 O.D. lodgepole	24	(384 kg/m^3)
Moisture content dead timber (percent)	20	
Bark as percent of stem volume	5	

The main advantage of dead timber over live timber is that the low moisture content is superior for fuel. Low moisture content is advantageous for dry process composition boards and reduces cost of drying lumber or veneer. There is little or no advantage in other products, and there are a great number of disadvantages to logging and processing dead timber (Kohrt 1978; Work 1978).

Potential Products from Dead Timber

There are several products that can potentially be produced from dead timber.

Classes of Forest Products

Round Wood	Solid Wood	Fiber
Poles	Lumber	Particleboards
House Logs	Veneer	Paper
Corral poles		Fuels

Round wood products require sound straight trees over a limited diameter range. Many trees are not large enough or straight and sound enough to produce a product.

Solid wood products have less stringent tree size and quality restrictions than round wood and can, in most stands, remove considerably more volume per acre.

The fuel and fiber products have almost no specifications and could use virtually 100 percent of the volume on an acre.

ROUND WOOD PRODUCTS

Power Poles

Poles are potentially very high value products which can be produced from dead lodgepole pine. Tegethoff et al. (1977) ran a series of plots and destructively sampled to prove that it was possible to produce poles from dead lodgepole. Their plots averaged 43 trees per acre of power pole size but at least 16 were not suitable because of defect or deformity.

The value of 1 ton of a class 2 treated power pole is very high.[2]

O.D. Wood basis:

	40-foot class 2 pole size			
	Minimum		Median	
Large-end diameter (in)	13.0	(33 cm)	13.5	(34 cm)
Small-end diameter (in)	8.0	(20 cm)	8.3	(21 cm)
Volume (cu. ft.)	26.7	(.75 m^3)	28.8	(.82 m^3)
Weight (O.D. lbs)	642	(291 kg)	692	(314 kg)
Price per pole[3]	$140		$140	
Value/O.D. ton	$436	($480/tonne)	$404	($444/tonne)

I have included an example of the minimum size pole and a pole of median size for a class 2, 40-foot power pole which is near the top end of the size and value for poles. The average sized poles are worth slightly more than $400 per ton ($440 tonne). The volume of bark and trim that develops is not enough to use for fuel on any commercial scale, so there is little or no anticipated by-product value.

Corral Poles

Corral poles are an accepted product from dead lodgepole pine. Value of corral poles including bark:

Length (feet)	16	(4.9 m)
Diameter-average (in)	4.0	(10 cm)
Weight (O.D. lbs)	35	(16 kg)
Price per pole[4]	$2.50	
Value/O.D. ton	$143	($157/tonne)

The value of corral poles is considerably less than the value of power poles; and again, there is no by-product value associated with corral poles.

There are several problems with using timber for poles. Currently few places are accepting power poles from dead timber. They are permitted under pole standards; but buyers usually specify poles from live trees. One problem of dead trees is that blue stain fungus improves permeability (Lower 1978) so treating schedules would have to be changed for dead timber.

Assuming you could get 30 power poles and 300 corral poles per acre, you would be removing less than 15 tons per acre (34 t/ha) of wood. In stands of dead lodgepole pine, volumes approach 100 tons per acre (Dell 1978). Finally, you could meet the demand for small power poles and provide every horse in the West with a private corral and still not touch the acreage that is available.

[2]Cubic volume of wood (Smalian's formula) x 0.95 = volume wood + bark x 24 (lbs/ft^3) = weight.

[3]Price per pole from Cowboy Timber Treating, Inc., November 1979.

[4]Price per pole supplied by Fenus Lumber Co., November 1979.

House Logs

The house log is a relatively popular use for dead timber. The specifications (Peckinpaugh 1978) for logs are quite stringent but vary slightly among manufacturers.

Specifications for House Logs

Minimum diameter		7 inches (18 cm)
Minimum length		16 feet (4.9 m)
Rot allowed		None
Checks	1/4" wide	1 full turn SPIRAL
Crooks		None
Sweep		Minimal
Taper		1 inch in 10 feet (2.54 cm in 3 m)
Bole deformities (cankers, etc.)		Minimal

The minimum diameter, length, and rot restrictions are quite rigid. The other specifications on crook, sweep, and deformities vary slightly with the type of house log being produced (fig. 2). The slabbed four-sided log can accept a small canker or a degree of sweep that would be totally unacceptable for the hand-peeled whole log.

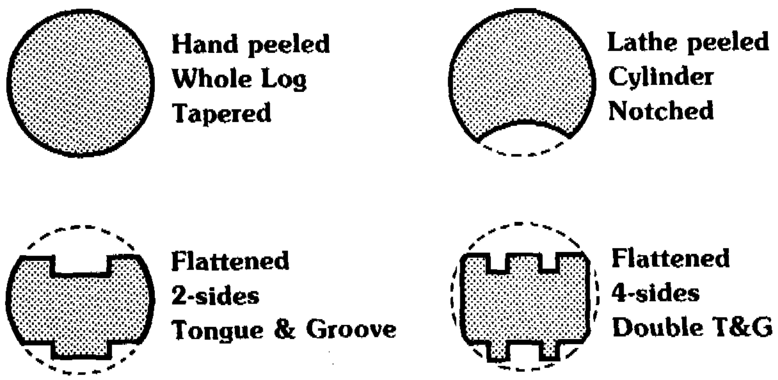

Figure 2.--Some fairly typical profiles of house logs and variations.

The house log price quote used here is for the flattened four-sided tongue and groove log. Round log value varies with log diameter, but no prices were available. Few companies sell house logs; most of them sell only complete house kits.

Value of House Log (Four Sided)

Length-30 feet (9.1 m)

	Minimum		Average		Maximum	
Small-end diameter (in)	7	(18 cm)	8	(20 cm)	11	(28 cm)
Large-end diameter (in)	9	(23 cm)	10.5	(27 cm)	14	(36 cm)
Volume (cubic feet)	11.2	(.32 m^3)	14.9	(.42 m^3)	25.9	(.73 m^3)
Weight-(O.D. lbs)	268	(121.6 kg)	359	(162.8 kg)	653	(296.2 kg)
Value @ $1.20/lin ft[5] ($3.94/lin m)	$ 36		$ 36		$ 36	
Value/O.D. ton	$268	($295/tonne)	$200	($220/tonne)	$110	($121/tonne)

For the minimum size log the values are quite high--$268 per ton. For the average size log the value is down around $200 per ton. The largest logs accepted by house log makers are worth $110 per ton of O.D. wood. In a timber stand of low defect, harvesting house logs could remove 40 to 50 tons per acre at best. Potential by-products from house logs are some chips from squaring log sides and bark and trim for fuel. Most log house operators are too small to install chippers. The predominant by-product sold is the round log trim sold locally as fireplace wood.

The number of log houses built in the United States per year is estimated to be between 20,000 and 50,000. Many of these are smaller second homes in recreation areas. The number of acres that can be used annually by the house log market is large enough to have a significant impact on the problem but falls short of either full utilization or total stand treatment.

SOLID WOOD PRODUCTS

As part of the discussion of solid wood products, it is necessary to establish values of wood as fuel because a real part of the value derived from either peeling or sawing dead timber will be the opportunity to use or to produce fuel as a by-product.

The value of fuel can be estimated from the value of competing fuels although any new energy source would have to be cheaper to offset the cost of new equipment before it would replace the fuel currently being used. In addition, some fuels are cheaper to use because they are cleaner to burn and require little or no storage space.

Natural gas is the perfect fuel. It comes from a pipe with no storage facilities required and is clean burning in simple standardized furnaces.

Oil is only slightly more expensive to use. It varies from slightly dirty to very dirty to burn, and both storage and supply can be problems. Coal and wood burn in similar furnaces.

Coal is dirtier to burn and handle but is more concentrated and easier to store than wood. The following tabulation shows the curent value of wood as a fuel on a heat content basis, using 18,000,000 B.T.U. per ton of O.D. wood.

[5]Price supplied by Cody Lumber, Inc. for flattened four-sided double tongue and groove log, November 1979.

Cost/Million B.T.U. Basis for Wood Fuel Value

			Values per ton O.D. Wood
Natural gas	@ $.38/therm	$3.80	$68.40 ($75.24/tonne)
Oil #6	@ $.55/gal	3.67	66.00 (72.60/tonne)
9,000 BTU Coal	@ $30/ton	1.67	30.00 (33.00/tonne)
12,500 BTU Coal	@ $40/ton	1.60	28.80 (31.68/tonne)

This establishes a value of wood at fuel as $29 to $30/O.D. ton when compared to coal. It is worth considerably more if substituted for oil or natural gas.

Lumber

Research by the Timber Quality Project at the Pacific Northwest Forest and Range Experiment Station has resulted in a series of dead timber recovery studies throughout the West. In every study, we determined that it is possible[6] (Woodfin 1979) to make lumber from dead trees. The margin available for stumpage is always less than live trees because the volume recovered as lumber is always lower, and the lumber grade or average lumber value is always lower.

The results of most of these studies are just being prepared for publication. We have learned that dead timber suffers severe losses in value when made into 1-inch boards. This results from lumber grading rules which severely limit the amount of blue stain in grade 2 Common and Better.

The value loss at a random dimension mill is much less than at a board mill. Blue stain is not a grading factor for dimension lumber.

At a stud mill, the value lost is even less. Because the price of studs is currently much lower than the price of dimension lumber, a dimension mill is the optimum place to process dead timber right now. If the stud price recovers relative to dimension prices, there would be little difference; but both would have an advantage over a board mill.

What does a sawmill produce from a ton of dead logs? If 30 percent of log volume is recovered as surfaced dry (S.D.) lumber and density is adjusted for shrinkage, the approximate weight of various products results in the following values:

Value Recovered From a Ton of Logs at a Stud Mill

Average lumber value $160/MBF = $236/ton[7]

Lumber	625 lbs (284 kg)	@ $236/ton ($260/tonne)	$73.70
Chips	925 lbs (429 kg)	@ 40/ton (45/tonne)	18.90
Fuel	430 lbs (195 kg)	@ 30/ton (33/tonne)	6.50
Value/ton of logs			$99.70 ($109.67/tonne)

[6]Snellgrove, T. A. 1979. Product value from dead lodgpole pine at three mill types. Unpublished talk, FPRS Annu. Mtg., San Francisco, CA.

[7]Lumber continues to shrink while drying so density of S.D. lumber is 24.8 lbs/ft^3. There are 18.3 bd ft in a cubic foot of S.D. stud volume so 1 MBF lumber = 1,355 lbs. One ton O.D. of studs = 1,476 bd ft of lumber tally.

This value is low because the price of studs is at an all-time low in relation to random length dimension. Recovering the same weight at a random length dimension mill yields a much higher value.

Value Recovered From a Ton of Logs at a Random Length Dimension Mill
Average Lumber Value $198/MBF-$286/Ton[8]

Lumber	625 lbs (284 kg)	@ $286/ton ($315 tonne)	$ 89.40	
Chips	945 lbs (429 kg)	@ 40/ton (45/tonne)	18.90	
Fuel	430 lbs (195 kg)	@ 30/ton (33/tonne)	6.50	
Value/ton of logs			$114.80	($126.54/tonne)

It should be stressed that neither of the mills used in this analysis were near the peak of what is technically possible. The stud mill was an old four-saw Scragg and has since been replaced by a modern mill at the same site. The random length dimension mill was a chipping headrig type and was one of the first of that type ever built. Most mills currently in operation could recover more lumber than either of these mills from the same log.

Veneers

Veneer sounds like an implausible use for dead lodgepole pine. The Timber Quality Research group recently ran a veneer study using dead lodgepole pine as the resource. The lathe was a small diameter, high speed, 4-foot lathe. Recovery was much better than we anticipated. The veneer did not fall apart at the checks even during lay-up. It dried on a shorter schedule than the veneer from the live control and laid up into panels so well that the lay-up crew did not recognize that the veneer came from dead timber.

If 40 percent of log volume was recovered as dry veneer, the value would be slightly more than dimension lumber. Veneer does represent a possible use for logs larger than 8 inches in diameter. The following calculations show the value of veneer:

Value From a Ton of Logs in a Veneer Operation

3/16" CD core pine at $261/ton

Log value/ton	800 lb (363 kg) veneer	@ $260/ton ($287/tonne)	$104.40	
	800 lb (363 kg) chips	@ 40/ton (45/tonne)	16.00	
	400 lb (181 kg) fuel	@ 30/ton (33/tonne)	6.00	
	Value/ton of logs		$126.40	($142.29/tonne)

The major advantages to peeling dead lodgepole are the high recovery potential from peeling small logs on a core lathe and fuel from bark because the residues from the relatively dry logs could be worth more as fuel than as chips to a plywood plant using natural gas for driers.

To wrap up on solid wood products, there are several points to keep in mind. The specifications vary by mill type and product. Veneer plants and board mills tend to require larger diameters than dimension and stud mills. Lumber or veneer manufacture produces large amounts of fuel and fiber products.

Although up to 70 percent of the wood volume is primarily fiber, more than 70 percent of the value is derived from the lumber or veneer.

[8]Actual lumber volume at the dimension mill was 17.9 bd ft/ft^3 of surfaced lumber so 1 MBF of lumber = 1,385 lbs. One ton O.D. dimension lumber = 1,444 board feet of lumber tally.

Solid wood products could utilize from 70 to 85 percent of the total logs available. The fine fuels that are left should be fairly well flattened and susceptible to rapid biological degradation. Also, there are enough potential users to have a significant impact on the acreage of dead timber that is available.

FUEL AND FIBER PRODUCTS

Several fiber products can be produced from dead timber. These products come in many grades and values, but the raw materials used are either chips or particleboard furnish. Because values are low, logging costs become critical and will be considered in fiber products.

Paper

Paper is a relatively high value high cost product. Yields range from about 40 to 95 percent of the wood volume brought into the plant. Prices range from about $375 to $1,000/ton ($413 to $1,102/tonne). The raw material from most paper is chips, a commodity that has established markets and prices.

Chip value	$40.00/ton	($44.10/tonne)
Harvesting	31.40/ton	(34.67/tonne)
Margin for chipping, transport, profit	$ 8.60/ton	($ 9.49/tonne)

A value of $40/ton for chips leaves very little margin for stumpage, logging, and transportation costs. Logging costs range from approximately $20 to $40/ton (Howard 1979) with a fairly realistic estimate for logs to the railhead of approximately $31.40/ton (Grantham 1978). Truck haul costs are approximately $.10/ton mile so a relatively small increase in chip prices can have a large impact on the area which can effectively be logged for chips.

The Champion International mill has a relatively long-standing salvage log chip program (McMichael 1978), which they refer to as the 5-D program, used when sawmills cannot meet their needs from mill residue chips. Use of larger quantities of wood residue by paper mills could be as fuel to meet energy needs.

Particleboards

Particleboards offer a relatively limited opportunity for using any significant volume of dead timber. Underlayment grade particleboard is presently worth $115/ton ($127/tonne) of wood furnish used. Currently, particleboard plants are paying between $5 and $10/ton ($5.50 to $11/tonne) for furnish.

Particleboard furnish	$10.00/ton	($11.00/tonne)
Logging costs	31.40/ton	(34.67/tonne)
Margin	-$21.40/ton	(-$23.44/tonne)

With logging costs at present levels, particleboard is not a viable outlet for forest residues. Its position in the mill residue market is threatened (Fahey and Starostovic 1979) by the value of wood as a fuel.

The development of a structural particleboard industry would allow the use of large volumes of dead lodgepole. A structural particleboard that was directly competitive with plywood CD Exterior sheathing at .6 density and could use 90 percent of log volume would have an upper limit on value of $240/O.D. ton ($265/tonne). The cost to produce this board would be relatively high. Dead timber would be particularly appropriate because particleboard furnish has to be dried to very low moisture content to glue properly.

Fuels

Using no other consideration than B.T.U. values, the maximum value for wood fuel is about $30/ton. There are other considerations, however. Wood burns cleanly, particularly when compared to some coals and oils, and requires no complex air pollution control mechanisms for sulfur compounds.

At large industrial installations, there is no value to processing fuel beyond chipping or hogging the wood to a uniform size.

Fuel Values/Ton

Type	Hog	Briquetted	Pelletized
Value	$30.00	$40-55	$40-55
Logging cost	31.40	31.40	31.40
Preparation	4.00	12.00	12.00
Margin	-$ 5.40	-$ 3.40 to $11.60	-$ 3.40 to $11.60

The potential market for processed wood fuels is limited to small industrial users and institutions (schools, hospitals) which require large amounts of energy but are subject to meeting clean air standards. Processing increases the B.T.U.'s/units of volume. This is a definite advantage in shipping and storing fuels.

SUMMARY

The ability to make commercial products from forest residues depends on the market for products and the ability of the product to compete with existing sources of the same product. The potential to remove significant volumes depends on how well the resource meets specifications of products and the volume of products that the market will accept.

Potential for Using Woods Residues

Product	Value/ton	Demand	Effect on fuel loading
Power poles	$300-400	Small	Little
House logs	110-260	Moderate	Moderate
Corral poles	120-150	Small	Little
Dimension Lumber	90-130	Large	High
Studs	70-100	Large	High
Veneer	90-130	Small	Moderate
Paper (chips)	35-50	Moderate	Very high
Particleboard (furnish)	5-15	None	None
Fuel	15-40	Small	Very high

There are problems with any of these approaches. The most profitable outlets for dead timber have very limited or, at best, moderate demand and leave large quantities of wood residue on the ground. The best solutions in terms of land management have relatively limited demand and, therefore, little potential for treating very many acres. Lumber and veneer have some potential for removing relatively large volumes from a whole lot of acres, but mills are really more profitable operating on green timber sales.

The solution, if one is arrived at, will require cooperation and some creative timber appraisal and sales contract approaches. Sorting, log concentration yards, and land management contracts are the most common suggestions and probably the most appropriate.

Complete tree logging, with separation of the more valuable logs for roundwood and solidwood products, would allow an in-the-woods chipper to operate on concentrations of wood that would not otherwise be commercially possible.

Development of a structural particleboard and fuel market shows the greatest potential for increased demand for forest residues.

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ALLOCATION OF RAW MATERIALS TO ALTERNATIVE PRODUCTS

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ABSTRACT

In traditional timber harvesting operations, the allocation of raw material to alternative products is most often made at the mill. However, in western Montana, because there are no processing facilities equipped to utilize the full range of residue material, the landowner or land manager must make the allocation decision. The allocation process should also be an integral part of sale preparation and not occur as an afterthought at the conclusion of harvest. This paper discusses the utilization of ponderosa pine residue created by a locally severe outbreak of mountain pine beetle in the Blackfoot River drainage northeast of Missoula, Montana.

KEYWORDS: residue utilization, residue harvesting

The allocation of residue to alternative products is a topic which implies a range of markets for the various classes of material. Rather than treat this subject in a general or theoretical manner, I will relate the personal experiences I have had with logging and utilization of residue from second-growth ponderosa pine stands infested by the Mountain Pine Beetle (Dendroctonus ponderosae Hopkins.) Although I may repeat some of the material presented yesterday, I will stress the problems and opportunities of allocation as they presently exist in our area.

As manager of the 28,000-acre Lubrecht Experimental Forest, a facility operated by the School of Forestry, University of Montana, my experience is centered in the Blackfoot River drainage northeast of Missoula. The Blackfoot Valley has a history of extensive early logging. As a result, the valley foothills are covered with stands of second-growth ponderosa pine ranging in age from 49 to 90 years, and in diameter breast height (d.b.h.) from 10 to 16 inches--perfect habitat for the mountain pine beetle. The infestation became serious in 1975, and has increased rapidly, reaching epidemic proportions in some locations. Although the outbreaks are not as severe as those in lodgepole pine in other areas of Montana, they are of serious local concern.

For the past five years, the Lubrecht Forest has worked closely with neighboring landowners, public agencies and private industry to effectively salvage and utilize trees killed by the pine beetle. Mr. Bill Potter of the nearby E-L Ranch has been a pioneer in this effort. Not only has he developed and refined a logging system uniquely suited to utilize the various types of residue but he also has willingly provided timber, machinery and personnel for cooperative experiments. At present, to successfully market a variety of residue, the landowner must make a commitment to utilization, must employ an effective logging system and must allocate the material to a variety of outlets.

COMMITMENT TO UTILIZATION

The basis of an effective residue utilization program is a commitment by the landowner to recover the material. Notice that the decision is by the landowner, because residue allocation differs significantly from normal timber harvesting operations where the allocation of raw material (logs) to alternative products is most often made at the mill. The processing facility matches the species, size and condition of the log to the most profitable recovery at current market conditions. The landowner or logger is only peripherally involved by cutting logs to specifications determined by the mill. The manufacturer also makes the decision regarding residue created by the milling process.

However, in dealing with forest residue, the landowner in western Montana must make the allocation decisions because there are currently no facilities which are equipped to utilize a full range of forest residue. In addition, because existing outlets for residue are limited, allocation can be a time-consuming and often frustrating experience. It may even be necessary for the landowner to give raw material to a processor, who can then through trial and error determine its potential marketability. If central residue collection yards were available, the landowner could spend less time on allocation and concentrate on the silvicultural and logging aspects of the program. Once a landowner is committed to using residue, this decision must be implemented early in sale preparation and not at the conclusion of logging. Because of the marginal profitability of the operation, it is necessary to use a closely coordinated logging system which will minimize handling of the raw material.

LOGGING SYSTEMS

There are two basic approaches to harvesting or gathering forest residue. Most classes of material can be removed in an operation either completely separated from or in conjunction with commercial logging. Within the second method, which previous studies have demonstrated to be the least costly, there are also variations.1/ In another paper in these proceedings, Mr. Barger described an approach that used conventional logging machinery to gather residue immediately following the removal of commercial timber. In our operations we remove as much residue as possible prior to commercial harvest. Whichever approach is taken, I believe that it is essential to use a well-planned and systematic logging method to minimize handling and sorting of the residue.

1/ Johnson, Leonard R. Potential for Forest Residue Recovery. Thirty-Fourth Annual Northwest Wood Products Clinic Proceedings. 1979. Engineering Extension Service, Washington State University. Pullman, Washington.

As an example, I will describe the full-tree method developed by Potter which uses machinery consistent with the size and value of the product removed. Although this system is designed specifically for commercial harvesting and salvage operations in second-growth stands of ponderosa pine on gentle terrain, it is applicable to stands of any species under comparable conditions.

In the preparatory step, trees smaller than five inches d.b.h. are hand-felled and piled into bunches for removal to a central landing by a grapple-equipped tractor. Of course the specific trees cut will depend on silvicultural objectives. In our application all dead, infested, leaning and down trees are bunched by a crew consisting of one sawyer and from two to four stackers. Skid trails are cleared in a veined pattern into the stand and the bunches are pointed, butts first, to these prepared trails. Stumps are cut flush to the ground and the size of the bunches depends on the timber and type of skidding machine used. Although production is proportional to the size and density of the timber, the crews average approximately 45 stems per hour per individual.

We have used a variety of machines to move the bunches to a central landing. The first is a Melroe Babcat, Model 722, steer-skid loader, equipped with a homemade grapple.2/ Although this machine is very maneuverable, its relatively low ground clearance and slow travel speed limit its effectiveness to a prebunching role or to very short skids. The second skidder is a small 30-horsepower farm tractor equipped with the same grapple attached to the three-point hitch. This machine has a lower initial cost, higher ground clearance and greater travel speed. In addition, most woodlot owners already have a tractor of this type which could easily be adapted for woods use. Potter uses a grapple-equipped 75-horsepower tractor and its increased size, stability and power enable him to clear two acres per day. For longer skids with large bunches, he uses a standard rubber-tired skidder with a fixed grapple.

The first step prepares the stand for easy entry and enables more efficient operation in the second phase in which dead and designated trees from approximately 5 to 14 inches d.b.h. are harvested with a Model 1075 Melroe Bobcat Feller-Buncher If stand conditions allow, the trees are sorted by size into commercial sawlogs and pole-sized material. In other instances, they are piled together. Production with the Feller-Buncher in a thinning operation ranges from 40-80 stems per hour.

The bunches are then skidded to a landing for processing. Potter has also found that the speed and maneuverability of the farm tractor makes it an economical machine to move the bunches on shorter skids. Over the past five years, he has skidded over two million board feet of logs with this machine. However, for rough terrain and longer distances, he uses the rubber-tired skidder. After limbing and bucking, the stems are sorted and decked according to the end product. Operators in our area have used a variety of machines for sorting and decking; including front-end loaders, skidders and grapple loaders. The limbs and tops can then be allocated to either a burn pile or to a mobile chipper.

2/ The use of trade, firm, or corporation names does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

The third step of the operation consists of directionally handfelling timber too large for the Feller-Buncher. In a coordinated logging system, it is possible in the first two steps to prepare openings for this timber so damage to the remaining trees is minimized. It is also helpful to equip the grapple skidder with a small winch and line to reach the occasional inaccessible tree. These larger trees are also skidded full-length to the landing for processing.

In addition to the management benefits of a slash-free stand that may be easily re-entered for future harvest, this coordinated logging system has a distinct advantage for the optimum use of forest residue. The raw material is concentrated at a central landing where it can be segregated into a variety of end products, chipped or (as is currently the case) burned. Even burning is facilitated because the large hot fire will consume green material with a minimum of air pollution. I have described this logging system in detail because it is essential to the discussion of product allocation which follows.

ALLOCATION OF PRODUCTS

Once the forest residue is collected at a landing, the landowner or logger can make allocation decisions. In our situation, the use of the previously described logging system resulted in large accumulations of material so we attempted to utilize rather than burn it. As mentioned earlier, we have had to develop a variety of markets which are based on the size and condition of the residue.

Class 1 Dead Small Sawtimber

The first class of material includes trees which have been dead for up to three years and are 9 to 13 inches d.b.h. I consider green trees in this size range and larger as commercial timber, although I am sure that many of you mill people consider "bull pine" in any size class as residue. Strictly speaking, we do not view dead small sawtimber as residue because it is the "bread and butter" of our operation and the successful marketing of this material allows us to utilize the other classes of raw material. This timber has been allocated to two primary markets: dimensional lumber and houselogs.

A basic and continuing use of these smaller trees is for dimensional lumber, mine stulls and railroad ties. However as Mr. Kohrt discusses in another paper in these proceedings, there are many problems associated with the processing of low-quality logs. As a potential remedy, the University of Montana School of Forestry is currently experimenting with a small, mobile dimension sawmill to determine production and recovery. It may be more profitable to saw the low-grade logs on site and haul finished or semi-finished products from the woods.

Profit opportunities for dead small sawtimber were enhanced when we developed a market which uses these stems in the round--primarily as houselogs. The major processor is the K & L Mill, which cuts the logs into two, three and four-sided cants for further manufacture by the Real Log Home Company of Missoula. The Real Log house uses sections of logs, rather than full-length logs, in the walls thus enabling the effective utilization of ponderosa which as a rule has more taper than lodgepole. As structural differences between the species are not significant, the major obstacle in using blue-stained ponderosa for houselogs was its appearance. However, after a successful test-marketing period, Real Log began selling houses made from the beetle-killed trees and many people preferred the more rustic appearance of the stained logs. As a benefit to the manufacturer, the partially dried logs are lighter and easier to handle, and the finished two and three-sided cants are more stable than cut green wood and not as susceptible to twist and warp. From an economic standpoint the dead logs are worth approximately the same ($2.40 to $2.50 per stem delivered to the mill) for dimensional lumber or houselogs. However the lower cull percentage in the round log application makes it a more profitable market.

We have also sold dead ponderosa to builders of traditional saddle-notched log houses and to one individual who lathes the logs prior to assembly. Another carpenter cut and hand-planed four-sided cants from the blue stained logs for use in post-and-beam construction. The structural members were left exposed and lent a very colorful and pleasing appearance to the finished building. We also attempted to utilize recently dead trees in the 12-to 17-inch d.b.h. range for utility poles. However, after a few test loads, we abandoned this application because of the high cull percentage. In general these specialty markets offer a much higher return per stem, but the demand is too limited for any sustained operation.

Class 2 Pole-sized Stems

The primary allocation of the second class of residue--green and dead stems in the five-to-nine-inch d.b.h. range--is to posts and rails. Because this market in western Montana has been traditionally dominated by lodgepole pine, it was once again necessary to provide both free material for testing and also information on structural characteristics. The post-yard operator had to experiment with treat schedules to ensure that the dead material would meet standards without costly overtreating. He overcame initial consumer resistance by full-treating the posts and selling them in eastern Montana and the Dakotas where people were more accustomed to ponderosa pine products.

We have used two different methods to manufacture this material into posts and rails. In the first instance the pole-sized trees are decked at the landing, and then as time is available, the stems are bucked to length and hauled to the post yard. In this system, the net return per stem is approximately $0.65 (excluding felling and skidding costs) but it is time-consuming for the crew whose time can be more profitably spent removing commercial logs. To reduce manufacturing time, we also haul the material to the post yard in tree lengths which are cut to a 3½-inch-top diameter. The operator using a conventional logging truck has averaged 243 stems per load for 6 loads. The average value per stem delivered to the mill has been approximately $1.00 ($0.43 after deduction for loading and hauling). The full-tree system, although net return is lower, requires less landing area and allows the crew to concentrate on larger trees. It appears that a combination of the two systems may be the most efficient.

We also attempted to utilize these small trees with a portable studmill. On an experimental basis, we cut 20,000 board feet, lumber tally, of studs from the dead ponderosa pine. Although the lumber was generally of low quality, it was acceptable; and use of the tree shear did not require additional trim allowance. However after the initial test, we did not pursue this market because the taper of ponderosa reduced overrun to an unacceptable and unprofitable margin. It was also difficult to dispose of the mill wastes.

Class 3 Small Trees, Limbs and Tops

Usually this class of residue is burned at the landing. However, in anticipation of a pulp/chip or hog-fuel market, we have experimented with three different machines that will chip this material in the woods. The first machine, a Model 24 Morbark, produced chips that with further screening would be suitable for pulp, or as hog-fuel if left unscreened. At the end of the test we felt that the high initial cost, high operating expense and lack of maneuverability would preclude using a model of this size for small stems. The second chipper was a small, trailer-mounted model, similar to those used by tree-removal and utility companies. This machine was not practical because it was very slow and labor-intensive, and would not process material greater than five inches in diameter.

In March 1979 we experimented with a medium-sized machine that appears to be suitable for our operation. This was a Model 12 Morbark, which is capable of chipping 11½-inch diameter trees, yet is small enough to be moved in the field by a farm tractor. Based on an average of 120 tons, the net chipping time per ton, for trees four inches in diameter and smaller, was 5.75 minutes. For trees that would not make a 16-foot houselog and from tops of larger trees, the Model 12 chipped a ton of residue every 4.13 minutes, based on a total of 103 tons. Potter fed the chipper directly with his skidder from material pre-bunched in the woods. The average skidding distance was 250 feet, with the longest skids ranging out 250 yards. By selecting turns from a variety of distances, he was able to efficiently feed the machine with the one skidder. On a three-acre test plot, 3,000 board feet of houselogs and 47.6 tons of chips were removed per acre--all dead ponderosa pine.

This small study was designed to test the ability of the machine to produce chips at the landing using the logging system described. It was not actually a cost feasibility study. However, when we chipped the post-sized trees, it took an average of 10 stems to produce a ton of chips. If these stems, which are currently worth from $0.40-$0.65 each at the landing for other products, were allocated to chips, the landowner would have to receive approximately $5.50 per ton of chipped material. The landowner, however, can realize other values from whole tree chipping chipping. He would not have to process the trees at the landing and could log pine stands when fire dangers and potential insect build-up may otherwise preclude operations thus gaining additional profits from a longer operating season.

The landowner will also have to consider the management implications of full-tree logging and utilization on log-term site productivity. Studies are currently underway at the School of Forestry by Dr. Nellie Stark to determine if full-tree logging and the subsequent removal of slash may be detrimental to the forest nutrient regime. If this proves to be the case, the chipped material (or a portion of it) could be returned to the woods to replenish lost nutrients.

Class 4 Older Dead Trees

The last class of residue includes trees of all sizes that are unsuitable for other products because of excessive check rot, deformity and so forth. With the exception of the chipper studies, we have either burned this material or sold it as firewood. Presently we are marketing the stems larger than six inches d.b.h. by the truckload to a commercial firewood dealer. Based on the limited number of tree-length loads sold to date, the return per stem at the landing is $0.65--a value higher than that realized for posts and rails.

CONCLUSION

In conclusion, to successfully utilize forest residue, the committed landowner must use a coordinated logging system and be willing to develop a variety of markets. Even when these factors exist, residue utilization is only marginally profitable and is subsidized by the harvest of larger trees. By working with this material now, we plan to be better prepared when large-scale opportunities arise.

FOREST MANAGEMENT IMPLICATIONS OF IMPROVED RESIDUE UTILIZATION: BIOLOGICAL IMPLICATIONS IN FOREST ECOSYSTEMS

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ABSTRACT

Various forms of residue provide parent materials for the development and function of the organic mantle of forest soils. Organic matter provides either the environment or the energy source for a variety of microorganisms which are critical to continued site productivity. Of the many organic materials added to forest soils during a stand rotation, the woody component is, in many respects, the most important. To protect the productive potential of a forest soil, a continuous supply of organic materials must be provided.

Intensive wood utilization may interfere with the supply of appropriate quantities and types of organic materials being cycled on certain sites. Providing adequate organic supplies could, therefore, impose constraints on harvesting intensity and residue utilization standards. Current research has provided some insights into this potential problem in the northern Rocky Mountains. Research indicates no serious shortage of organic residues with current management practices on productive sites in the northern Rocky Mountains. Substantial increases in utilization intensity, extremely hot wildfire, or excessive site preparation could reduce stand productivity, particularly on harsh, cold or dry sites.

KEYWORDS: forest soil, organic reserves, microbial activity, ectomycorrhizae, nitrogen fixation, non-symbiotic, intensive utilization

INTRODUCTION

As practicing biologists, forest managers intuitively realize that wood and other tree organic components may have specific functions in forest ecosystems. Since the economic and technical practicability of using intensive or near-complete utilization of on-site fiber appears imminent, we investigated the potential for such practices to interfere with the critical roles woody residues and other organic materials might have in the function of forest soils. We discovered that various organic residues--especially wood--do have integral and sometimes critical biological functions in forest soils of the northern Rocky Mountains.

BIOLOGICAL ROLE OF RESIDUE

Residues have many physical and chemical characteristics which make them important to biological processes in forest soils (Larsen and others 1980). Dead plant bodies tie up substantial quantities of nutrients, tend to retain large quantities of moisture, and can restrict air, sunlight and large animal movement (USDA For. Serv. 1980). Buried in the soil profile, organic detritus improves aeration, tilth, and moisture retention, thus protecting the soil from compaction (Lull 1959). In the form of accumulated surface debris (bound carbon), residues represent fuel for wildfire, an important force in the development both of northern Rocky Mountain forests and of the soils in which they grow (Habeck and Mutch 1973; Harvey and others 1976a).

The chemical energy bound in the carbon compounds of plant residues fuel a number of important biological activities. Some organisms supported by residues function only as nutrient and organic matter recycling agents. Others represent major factors in the development of soils (decay fungi), plant nutrition (N-fixation, mycorrhizae) or the spread of insects and diseases (USDA For. Serv. 1980).

Perhaps most important among the organisms supported by forest residues are microorganisms that serve critical roles in soil development and plant nutrition. Decay fungi, for example, have four major roles in soil development: 1) to break down plant bodies and recycle carbon; 2) to release nutrients bound in plant bodies for use by living plants; 3) to contribute energy to nonsymbiotic N-fixing bacteria, which increase soil N supplies; and 4) to control the character of the soil organic matrix. Decay fungi have a unique ability to break down the complex molecular structures of wood and other organic materials, leaving a lignin matrix that serves as a building block for soil humus. In the organic matter breakdown process, some of the energy released is diverted into fixation of atmospheric nitrogen (N) through the action of bacteria associated with the rotting materials (Larsen and others 1978).

Forest soils of the northern Rockies usually contain five easily recognized profile components: 1) the litter layer, consisting of recognizable plant litter (leaves, etc., usually designated as the O_1 horizon); 2) the humus layer, consisting of extensively decayed and disintegrated organic materials sometimes mixed with mineral matter (usually designated as the O_2 horizon); 3) decayed wood, consisting of the residual lignin matrix from decaying woody material that has been incorporated into the soil profile (we have designated this the O_3 horizon); 4) charcoal, or extensively charred wood mixed in soil as a result of historical fire activity (we have designated this the O_4 horizon) and 5) the mineral soil base material (we have designated this the M horizon). The surface 5 to 10 cm of the mineral layer usually has a small amount of incorporated organic material, normally less than 10 percent. Each of these horizons, or components, supports specific microorganisms that improve the quality of the soil as a medium for plant growth.

The amount of organic material in our forest soils is limited. Usually organic matter makes up less than 15 percent of the top 15 inches (36 cm) of our soils. Nevertheless, this organic matter can support up to 95 percent of the ectomycorrhizal activity that occurs on roots of existing tree crops (fig. 1). Ectomycorrhizal fungi are symbionts particularly important to the growth and survival of conifer species in infertile forest soils (Hacskaylo 1973).

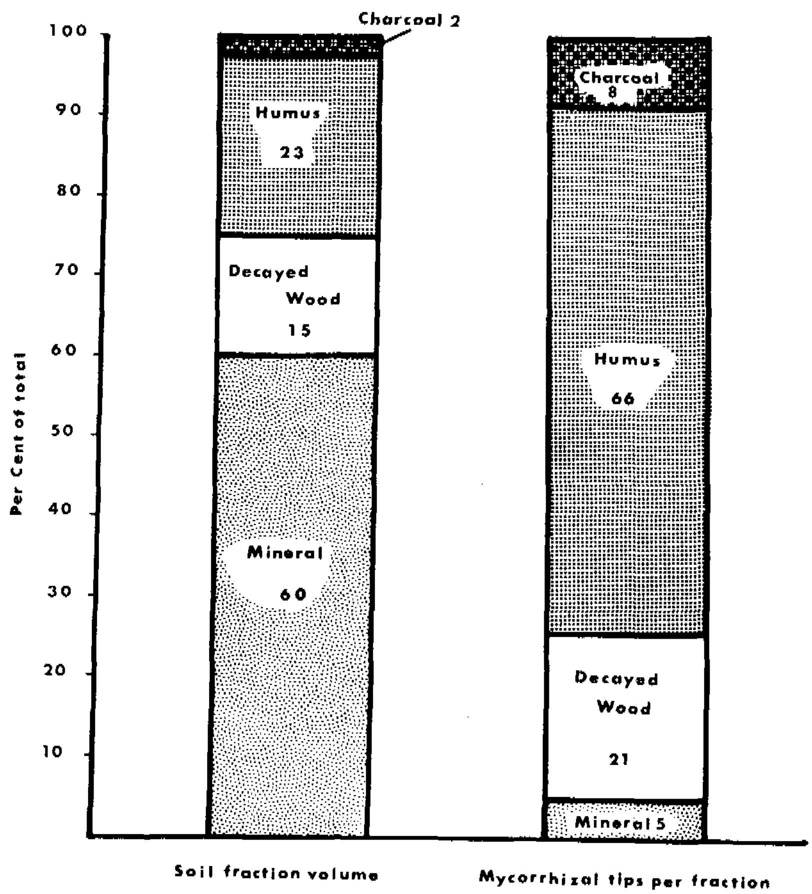

Figure 1.--Soil fraction volume (in percent of the top 15 in (30 cm)) and percent of active ectomycorrhizae found in soil core samples from a research plot in a 250-year-old Douglas-fir/larch forest in western Montana, Abies lasiocarpa/Clintonia uniflora habitat type (Harvey and others 1976).

Free-living soil N-fixing bacteria depend on the carbon components of soil organic matter for energy. Although mineral soil supports a substantial amount of N-fixation, it probably does so because of the organic matter it contains. On a weight-to-weight basis, free-living N-fixers are much more active in organic soil horizons. The rate of activity is normally between 5 and 10 times greater in organic versus mineral soil horizons (Jurgensen and others 1979, 1980).

Residue and residue-derived soil organic matter can also harbor harmful microorganisms. Woody litter, stumps, roots and other materials may contain inoculum that can spread and intensify various tree diseases, particularly root pathogens (Nelson and Harvey 1974). Residues can also harbor harmful insects that can serve as focal points for future damage to forest stands (Fellin 1980). In addition, accumulations of residue and soil organic matter can provide cover and nesting sites for various small animals that feed on young trees (Gruell and Ream 1980).

ACCUMULATION AND CYCLING OF RESIDUES

As pointed out above, residues in the form of various kinds of organic matter in or on forest soils, can have either or both positive and negative biological impacts on forest ecosystems. The balance between good and bad depends on a host of factors, including site history, type of vegetation, existing soil structure, and presence of pests. In other words, organic matter must first be produced if it ultimately is to be incorporated into the system. Secondly, this organic matter must be converted into a functioning soil component. The processes of decay and physical oxidation (fire) convert this biomass into appropriate chemical constituents. There is a balance between the processes of tree growth and the decay and disintegration of the resultant residues. In the northern Rockies biomass production usually exceeds rates of decay and disintegration (Olson 1963). Although excess materials (fuel) are partially recycled by periodic fires, decayed soil wood can persist in northern Rocky Mountain soils for periods of at least 500 years (unpublished data).

There are sites where fire cycles are frequent or rare; where organic materials accumulate and where they do not; where the soil organic structure is well developed and where it is poorly developed. Such characteristics reflect site specific differences in timing and amount of precipitation and soil temperature regimes, which in turn affect production and recycling processes (Harvey and others 1979b). Since moisture-temperature balances are an inherent part of the historical development and evolution of our forests, it seems reasonable that the function of various amounts and types of organic materials would change according to the specific ecosystems.

A CHANGING ROLE FOR RESIDUES ON DIFFERENT SITES

There is an obvious effect on the role of residues from sites that have a history of insect, disease, or animal predation problems. Residues have the potential to increase damage caused by these organisms and possibly contribute to further spread of the problem. Even if problem organisms are not causing damage, residues may still contribute to development of damage by providing an environment that attracts insects or animals, or that supplies inoculum sources of pathogenic fungi.

Although less conspicuous, the role of residue in supporting beneficial microorganisms also is subject to change. This is the case with both ectomycorrhizae and nitrogen fixation. For example, when we compared relatively harsh, dry sites to more moderate, moist sites, we found the relative importance of organic materials in supporting beneficial microorganisms was substantially higher on the harsher sites. This was particularly true of woody materials in supporting ectomycorrhizae (Harvey and others 1979a, 1979b). We also found the extent of microbial activity on our experimental sites reflected the sites' productive capacity (Harvey and others 1979a; Jurgensen and others 1980).

Soil organic materials supported a larger portion of the beneficial activity than mineral soil on harsh sites where the potential for such activity was lower (fig. 2). This represented a domino effect--a greater portion of lesser activity depended on the organic materials that harsh, cold or dry sites could not produce in volume. Harshness leads to a low productivity potential.

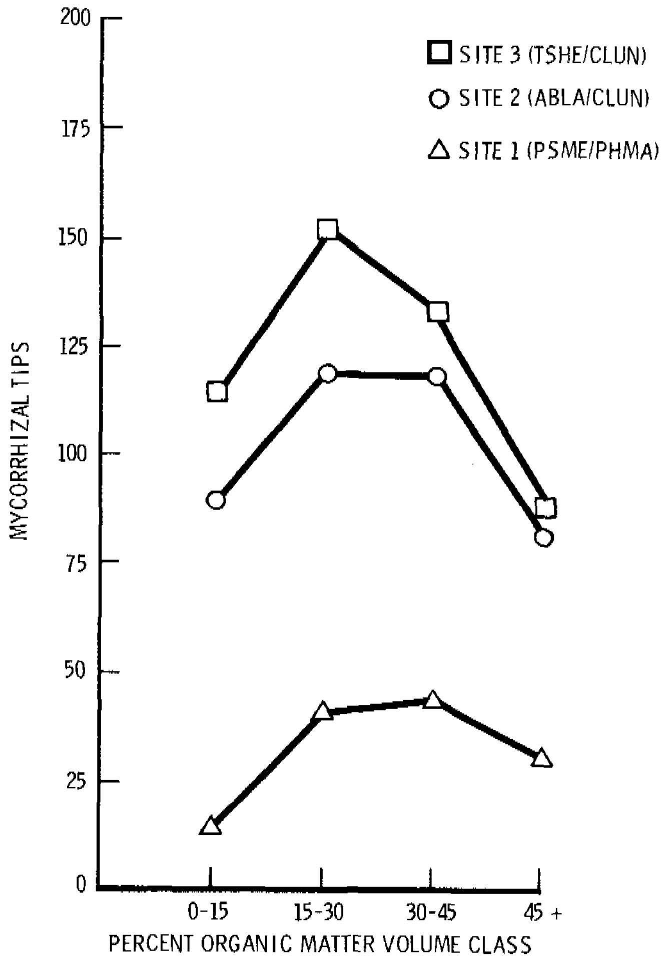

*Figure 2.--The average number of ectomycorrhizal root tips per liter of soil from three forest sites in western Montana.**

Some samples are grouped into classes according to their organic matter volume. Sites are as follows: site 1--warm, dry Pseudotsuga menziesii/Physocarpus malvaceus habitat type; site 2--cool, moist Abies lasiocarpa/Clintonia uniflora habitat type; site 3--warm, moist Tsuga heterophylla/Clintonia uniflora habitat type. See Pfister and others (1977) for additional details on habitat types.

RISK OF TOO LITTLE, TOO MUCH, OR THE WRONG KIND OF RESIDUE

Biomass production in northern Rocky Mountain ecosystems is at least partially dependent on the ability of soils to support N-fixing and ectomycorrhizal organisms. The ability of soil to support these organisms can, in turn, be largely dependent on the presence of organic matter. Inherent to such interrelationships is the obvious fact that total or near total loss of soil organic reserves is likely to reduce productivity in terms of tree growth. Less obviously, these interrelationships offer an answer to the question of how much and what kind of organic reserves our ecosystems require.

Our research on the ecology of ectomycorrhizal activity in forest soils of the northern region has provided some initial data on levels and types of soil organic matter required to support modest levels of ectomycorrhizae in mature ecosystems. Since the behavior of beneficial microbes such as non-symbiotic N-fixing bacteria is similar to that of ectomycorrhizal fungi, ectomycorrhizal activity provides a useful "barometer" for assessing microbial health of soil systems.

By dividing soil samples containing ectomycorrhizae according to quantity and type of organic material in which they reside, and then relating organic matter volume to ectomycorrhizal activity, we were able to derive a set of data representing initial parameters to the question of how much is enough. We feel organic matter is usually deficient when it occupies an amount of less than 15 percent of a 12-inch (30 cm) soil core. No additional benefits were realized from organic matter levels in excess of 45 percent of the core (fig. 2). These percentage figures are equivalent to a continuous surface layer 1.8 inches (4.3 cm) and 5.4 inches (13 cm) in depth, respectively.

In the Rocky Mountain ecosystems we sampled, the ratio between humus and soil wood usually approximated 1/1. As proponents of increased wood utilization, however, we are most concerned with the larger woody materials. Due to the infertility of Rocky Mountain forest soils, we oppose removing high nutrient content foliage or small residues in any case (DeByle 1980, Stark 1980). The nutrient content of tree boles is much lower and, therefore, their removal represents a lesser hazard (Stark 1980). By conservatively assuming that most soil organic matter required for future stand growth must be derived from woody residues, we can calculate a residue loading level below which long-term productivity of the soil may be impaired.

By assuming a 40 percent loss of volume from the time a log becomes fresh residue to when it begins functioning as a soil component (based on field observations), and by converting the 45 percent soil organic matter content figure noted above to volume, then to residue weight, we calculate that 10-15 tons per acre as a continuous supply of fresh residues (less than 25 years old) should be left after any cutting, burning or other site treatments to maintain soil organic reserves. We further suggest that since larger volumes are generally more effective, that this tonnage consist primarily of larger residues, perhaps 6 inches in diameter or larger. Because Douglas-fir (*Pseudotsura menziesii*), western white and lodgepole pines (*Pinus monticola* and *Pinus contorta*) appeared more frequently in the soils we studied, despite the presence of other species on the sites, we recommend that residues of these species make up the bulk of the material left on harvested sites.

RESIDUES AS A MANAGEMENT OPPORTUNITY

Forest residues provide a major tool for manipulating harvested stands. In many ways residue manipulations represent the only practical management tool available for mitigating physical effects of harvesting systems that remove most of the standing tree crop, or effects of harvest and post-harvest procedures that require extensive soil disturbance (Hungerford 1980).

Residues provide a barrier from wind, sun, and erosion; and they can control large animal movement and feeding patterns. Residue removal can minimize the propagation of insects, diseases or small animal problems, but their continued presence can provide a major input to soil nutrient quality through support of benefical organisms (USDA For. Serv. 1980). Resolving potentially complex trade offs in order to successfully manage residues to achieve one or more of the above objectives will require careful examination of individual stands. Knowledge about existing site residues, about residues and soil disturbances caused by harvest method and silvicultural prescription, and about soil organic reserves and past pest problems will provide a good base. With such information trade-offs can be determined, and residue inventory specifications and`utilization or prescribed fire standards can be established to elicit the most beneficial biological response from the ecosystem.

Perhaps most beneficial among the positive results of residue manipulation is the opportunity to enhance soils as a medium in which to grow trees. Without an adequate soil base, the potential for a good tree crop simply does not exist, whether or not other important factors, such as seed availability, rodents, insect, disease or grazing damage, also exist. One exception would be a situation where a soil could use additional organic reserves, but the available materials are infested with insect or disease inoculum. In such a case it may be better to remove or burn the infested residues and accept the added time required to rebuild organic matter levels. For the soil wood component, this may require periods well in excess of one hundred years.

CONCLUSIONS

Current research indicates potential hazards and opportunities from the practice of intensive fiber utilization in northern Rocky Mountain forests. The need to maintain minimum reserves of soil organic matter may constrain utilization practices but probably only in harsh, cool or dry ecosystems or in ecosystems with a severe fire or intensive logging history.

Recognition of the important role residues play in northern Rocky Mountain ecosystems will help avoid site degradation caused by excessive fiber removal. Using a reasonable biological perspective to guide our residue manipulations would represent an opportunity to maintain or even improve our harvested sites and their soils as a firm foundation for future forestry.

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THE IMPLICATIONS OF IMPROVED RESIDUE UTILIZATION ON TIMBER SALE ACTIVITIES

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ABSTRACT

Improved residue utilization on timber sales requires new and innovative economic and practical approaches on timber sales. Varying uses, resource needs, and economic limitations complicate the land manager's task of salvaging this material.

KEYWORDS: residue, utilization, economics, complicate

My purpose is to discuss some of the implications of improved residue utilization on timber sale activities. It would be convenient to simply equate that subject with the day-to-day business of harvesting National Forest timber. However, it is not quite that easy. In many respects it is a whole new ball game.

For that reason my comments on a residue utilization program will be directed toward the economic and practical side of getting material moved with a minimum of problems for both the seller and the buyer. They are also directed principally toward the removal of dead timber, rather than to tighten utilization specifications on otherwise merchantable trees.

First, I must digress a bit. Each time a land manager decides to offer a timber sale, he presupposes he can sell it. Otherwise he accomplishes nothing. While successful sales are the general rule with standard timber and products, a residue utilization program can easily become an administrative nightmare. Ideally, the land manager is not supposed to let economics influence his environmental ethics. Yet in the business of residue utilization, he must do precisely that!

I am not here to recommend national policy to you. Realistically, however, residue is residue only because economics say so! There are most certainly methods of improving the economic picture, but in many ways, there is no golden fleece. With government timber, and perhaps with private stock, residue utilization depends on how much we are willing to pay for it. We have many options, but in general, each one costs the taxpayer money, at least in today's dollars.

We must also be careful not to restrict our thinking to timber sales themselves. It may be necessary for the government to pay the user, instead of the user paying the government for removing this material. This might be done through land management contracts with salvage provisions. It may be in the form of augmentation, supplementation, or outright construction of road access to the material. Perhaps a less painful way to make ends meet would be through tax incentives to industry. No matter what, if we want to move more residue, the user must somehow gain by his participation, and the government must ultimately pay for any deficit.

THE NATURE OF RESIDUE UTILIZATION SALES

A number of points must be considered in preparing residue utilization sales. First, a sale of residue by itself is usually a sorry situation. The operation which left the residue is the basic mistake, and the residue sale only the consequence. Removal of the only the high-value element of a stand, such as green timber or cedar salvage, may very well leave behind an economically impossible residue removal chance. The need for advance planning and integration with regular sale programs is obvious.

At first thought complete utilization sounds simple to specify--just take everything down to a minimum size. Let me assure you a deadwood contract is much the opposite. Describing several products, many of which overlap, in a way which is practical and nondiscriminatory to all potential buyers, is a difficult task. It seems each buyer has a different set of product specifications he wants the land manager to use, and nearly all of them result in incomplete utilization. No matter what choice is made, someone is unhappy.

A partial answer to this is a wide variety of sale sizes with varying specifications. Perhaps specifications should not be ironclad, and permit bidders to propose their own utilization standards along with their bid. It is easy to see how such a program would give a manager headaches and a good deal more work.

Measurement of residue is another bugaboo. Conventional scaling is often meaningless. From the government's standpoint, an easy remedy is sale by weight. I am convinced that weight is the best common denominator, but do not overlook the plight of the user who has to deal with inventories, payrolls, and production targets.

Even then the land manager cannot simply ignore end-product estimates. Since Forest Service timber appraisal methods are usually based on traditional measurements such as board feet, conversion to weight in the appraisal process is often troublesome.

One more generality which may be useful is to recognize that yarding unmerchantable material (Y.U.M.) is a key part of the battle. Y.U.M. with optional removal will accommodate industrial specialities, but still permit subsequent resale or use by others of the remaining material. This method has proven merit.

Still, complete utilization is seldom a realistic goal. One simply cannot and probably should not get it all. Even in small-diameter species such as lodgepole pine, only a small percentage of the total bulk is in small diameter logs and short pieces. You can often afford to specify a larger top diameter or a longer log length on dead material, and still get 90 percent of the volume. Overly restrictive standards can very easily devastate an otherwise good offering.

LAND MANAGEMENT IMPLICATIONS

Residue utilization proposals often present uncomfortable situations to the land manager. The real stickler is that once a tree dies, the alternatives dwindle to either cutting it or leaving it. Since total utilization is not a realistic objective, managing residues becomes a pick-and choose proposition. What works well in one situation may be a complete failure elsewhere. Such things as regenerative systems, slash disposal methods, esthetics, wildlife needs, and fuels management are only examples of the complexities.

All this adds up to a time-consuming and burdensome addition to the land manager's regular work. The temptation is, of course, to go on as always and let improved utilization fall by the wayside. In some situations this would matter little, except in the size of the slash piles. At other times, wood utilization problems are inescapable, such as in the Targhee National Forest. In any case, the land manager must display initiative and imagination if meaningful changes are to be realized.

I also suggest that we have at times created our own residue problems. How often have we cut through a stand which is 60 or 70 percent defective, and then wondered what to do with the residue? Perhaps we should have stored that wood on the stump until technology and economics had caught up with us. Wouldn't we love to have back what we used to waste, even five or ten years ago?

ECONOMIC GUIDELINES

The subject of waste wood economics is a two-edged sword. As I mentioned earlier, we need to be conscious of the tax dollar. On the other hand, we must offer a profitable venture to prospective buyers. There is no better way to thread this needle than to involve industry all the way. Alternatives are often abundant, if we will only search for them.

You will commonly find that road access is the key to success or failure of a program. An already deficit sale simply cannot support the needed road construction. A well-planned access program supported by appropriated funds solves a myriad of problems and affords many more options to the land manager.

The same principle applies to reforestation. Although the Chief's policy normally requires that reforestation costs be included in minimum charges for timber, this cost can be a backbreaker. It can also be administratively overcome!

The October, 1979 Journal of Forestry contains a thought-provoking editorial on salvage sales in the Rocky Mountain states. It seriously questions the propriety of salvage on marginal sites requiring these high road development and reforestation costs. Indeed, the National Forest Management Act mandate to identify marginal timber sites could very possibly change the entire picture.

Still, we may be wise to look somewhat beyond the end of our noses in evaluating costs and benefits. The eventual cost of high intensity wildfire may make current investments in salvage efforts seem insignificant.

THE LAND MANAGER'S STRATEGY

If I had to condense my advice to both land managers and to industry on utilization of residues, I would have to simply say "hang loose". Maximize the involvement of all parties. The buyer and seller should regard each other as equal partners in this game. After all, if one loses, so does the other. Don't worry about being accused of "being in bed" with one another. You'd better be, if you expect to succeed! Search for new ideas, but be wary of big, new deals. Try instead to work with established markets and local industrial outlets. Expect a strong resistance to change. I can assure you that you will encounter it from all sides.

Last of all, don't ever say it can't be done. If you do not take positive steps toward improved utilization, you will soon find that the good old days are gone, and you are left behind. There is no middle ground.

AN ECONOMIST'S PERSPECTIVE OF RESIDUES

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ABSTRACT

As the values of wood products increase, there are more economic opportunities to utilize residues. This is true both for dead-and-down materials and for previously unharvested stands which, together, make up the potential economic residues resource. A variety of research efforts are developing the information and technology necessary to take advantage of these opportunities. The key to minimizing future residues problems is to fully integrate residues considerations with overall forest resource planning.

I will speak to residues from the perspective of an economist, and most particularly from the perspective of a Forest Service economist working in Washington, D.C. From that vantage point, it seems apparent that:

--the values of wood products are increasing,
--increases in values are leading to fewer residues,
--the key to minimizing new management problems is to plan eventual residue treatments before the residues are created, and
--carefully directed research will help managers deal with potential residue problems.

I define forest residues as forest trees and parts of trees that are available for conversion to marketable products but are not now being used. This is an economic rather than a traditional definition, for the economic question is whether a larger portion of the available wood fiber that is grown can be used. Both in the Rockies and in the eastern United States, relatively low-value stands are currently major components of economic residues. In the long-run, nature will ensure that unharvested trees become indistinguishable from other kinds of "residues".

VALUES OF WOOD PRODUCTS ARE INCREASING

Others have presented statistics that indicate there are large volumes of both standing and down softwood and hardwood residues in the United States. In contrast, there are essentially no residues of any kind in the closely tended stands of Europe. A major reason for this difference is, of course, economics. A unit of wood is more valuable in Europe than here. As values and prices go up, a larger share of the available quantities of any commodity, including wood, will be used.

The most obvious evidence of increasing wood values in the northwest is the increasing average bid price for public stumpage. Prices of $400 per thousand board feet are no longer uncommon for coastal Douglas-fir. Recently, the Willamette National Forest in Oregon sold 10 million board feet for over $750 per thousand. The Tahoe National Forest in northern California recently sold 5-1/2 million feet of mixed ponderosa and Jeffery pine for $590 per thousand. In this Region, bids for ponderosa pine have approached $200 per thousand. But the cyclical, boom-and-bust history of the timber industry requires caution in projecting a continuation of extraordinarily high prices for wood products and for stumpage.

Indeed, housing starts are currently decreasing. It appears there will be a decrease from the 2.0 million starts of 1978 to about 1.7 million this year, and projections suggest there will be a further decrease in 1980 to about 1.4 million housing starts. These decreases have been primarily due to historic high costs of borrowing money. However, we know there is an accumulating and unsatisfied demand for housing by those born since the second World War which will peak in the late 1980's. In spite of a growing trend towards close-in multi-family dwellings, greater volumes of wood will be required to meet these demands. There most likely will be another expansion in housing starts--in part, as a result of deliberate national policy. The nation-wide trend towards families with two wage-earners and a willingness to accept mortgage interest rates of 12 or 14 percent, which have long been common in other countries, will produce the necessary purchasing power.

Demands for other uses of wood will also be high. For example, rising domestic demands for pulp will increase the competition for softwood fibre, including that which is currently fabricated into solid wood products.

One other piece of evidence may be of interest. In Vermont, which is at the end of the fuel oil pipeline, perhaps half of all homes are completely or partially heated with wood. In November the Washington Star reported that more than 1-in-20 families throughout the Nation now have woodburning stoves. Aside from creating a haze over towns like Missoula, these demands have driven up the price of fuelwood. In Missoula, a full cord of firewood will be delivered for about $45. In Washington, D.C., a face cord costs about $100. While such prices seem extraordinary, the Department of Energy estimates $100 per cord will be a good buy when the price of home heating oil reaches $1.00 per gallon. Fuel oil has now risen to about 85 cents a gallon in Washington.

In total, in spite of market fluctuations, there are numerous indications that demands for wood and wood products will remain strong for the forseeable future.

INCREASED VALUES ARE LEADING TO INCREASED USE

Increasing demands and prices for wood have led to responses on the supply side. Until perhaps 30 years ago, the principal response would have been to move timber harvesting into previously unexploited areas. Now new sources of wood products must be developed from residues remaining after harvesting and from forest stands previously passed over, either because those stands were uneconomic to log or because they could not be logged without posing the danger of intolerable impacts on other forest values. Indeed, the Missoula research program sponsoring this Symposium has been directed towards determining the extent to which such potential resources or residues might be transformed into actual resources and wood products.

The starting point for determining how more wood might be produced has been to focus on removing a larger share of the total wood from harvested areas. The relative benefits and costs to the landowner and stumpage purchaser are both critical. On the National Forests and some other lands, the "landowner's" concern is expressed through contractual standards that define how logging is to be done.

A number of published studies have dealt with the economic realities of physical opportunities to utilize residues in particular situations. For example, Snellgrove and Darr (1976) discussed the prospects for producing lumber from cull logs in the northwest. This type of study is particularly important because a side effect would be a reduction in present accumulations of residues that pose substantial management problems. In the southeast, Goldstein and others (1978) examined possibilities for utilizing low-grade hardwoods. Given the millions of acres in the east containing such stands, their economic utilization would provide substantial benefits to landowners and make future stocking with better quality trees more likely.

The formulation of standards that specify how logging is to be carried out and, more particularly, that define the wood that must be taken and the treatment of residues on the National Forests has generated continuing controversies. On one side are arguments that almost any "non-market" standards impose unfair economic burdens on timber operators or require loggers to waste their time or waste dollars that should go to the Federal treasury. On the other side are arguments that standards are necessary to ensure that all resources are adequately protected and that the forest retains its long term productive capacity.

As John Robatcek of this panel discussed earlier, creating the ideal sales contract to deal with residues is a complex business. In general, that set of standards is sought that will yield as high a volume of products as possible, that will realize the ecological benefits of leaving residues on the ground, and that will minimize the problems caused by too many residues, including:

- --the risk of wildfire or the subsequent need for controlled burning or other treatment of residues,
- --damaging ecological effects of residues,
- --impediments to management activities or to the long-term productive capacity of the forest,
- --physical barriers to recreationists, and
- --the creation of aesthetically unappealing scenes or a basis for a public perception that wood is being wasted.

The importance and difficulty of achieving these objectives have been discussed elsewhere in the Symposium, but one point is worth restating here. Some have argued that subsidizing practices such as YUM yarding (that is, yarding unutilized materials) is uneconomic. To the extent that leaving residues where they fall requires later corrective activities, an initial subsidy may, in fact, be the less expensive course to follow (Adams and Smith 1976). The continual refining of such practices and the determination of just when they are most appropriate will become increasingly important.

Another approach on the National Forests has been to reexamine the possibilities of harvesting timber from areas that had been judged earlier to be uneconomic to log or where substantial impacts on other resource values were feared. In the early 1970's the Forest Service proposed a major effort (termed the FALCON program) to define ways to harvest timber from such areas. The basic components that were to be included in that effort were subsequently incorporated into the programs now centered in Portland and in Missoula. These components include improving our understanding of the ecological and economic implications of alternative residue treatments and developing efficient logging systems for use in environmentally sensitive and relatively low-value stands.

Expectations of increasing stumpage prices, coupled with environmentally gentle and more efficient logging systems, will make it more feasible to harvest timber, for increasing margins between costs and product values increase the areas that are economic to log.

From the perspective of a public agency, expanding the areas where timber harvesting is practiced in the eastern United States also requires dealing with the special circumstances and frequently unsympathetic attitudes of numerous owners of relatively small areas. Nonindustrial private lands generally do not produce timber products at a level commensurate with the land's productive capability (U.S. Department of Agriculture 1978; for a dissenting viewpoint, see Clawson 1978). There is partial evidence that pine production from these lands might eventually decline. Particularly in the southeast, harvested forest lands are frequently not being restocked with pine and shifts of such lands to farming or to urban-related purposes continue. One area of emphasis of the Forest Service is to work with the States in developing comprehensive forest land plans and carefully defining how assistance might best be targeted to land owners.

The third approach to increasing the production of wood products has been to develop new techniques both to fabricate more products from a given supply of wood and to use currently underutilized materials in production. Speakers from the Madison Forest Products Laboratory have outlined the implications of new products technologies for residues. To me, it is self-evident that the United States will have to rely more heavily in the future on technological innovations to meet increasing demands for wood. We can afford neither the time nor the space nor the capital that would be required if we were to rely solely on growing more trees.

INTEGRATED PLANNING CAN MINIMIZE PROBLEMS

Existing residue problems are going to continue to be difficult and expensive to treat. Each option available to managers is likely to have some sort of undesirable side-effect. The trick is to make certain that all of the important benefits and costs are recognized before selecting a treatment (Bare and Anholt 1976). For example, the likelihood of losses to wildfires in untreated slash should be weighed against the costs and smoke management problems of burning that slash. As our understanding of the ecological implications of residues increases, it will become possible to expand such considerations.

As the values of wood products increase and intensive management becomes more common, residues will gradually become less of a problem because there will be fewer of them. Frequent thinnings will capture mortality; trees will be harvested before they deteriorate; and utilization opportunities will increase.

More immediately, though, the key to minimizing future residue problems is to include planning for residues as an integral part of total resource management programs (Jemison and Lowden 1974). In the current round of land and resource management planning, the Forest Service is integrating planning for fire protection and management into overall Forest planning (Nelson 1979). The advantages inherent in moving from fragmented to holistic or over-all planning are also applicable to planning for residues management. Specifically, timber management planning should include explicit consideration of how residues that result from future harvesting and cultural activities will be treated, and the costs of those future treatments should be counted as costs when calculating whether timber production is economically and environmentally viable. Only through close integration of all planning can the most advantageous combination of management activities be selected to meet overall forest management objectives.

DIRECTED RESEARCH WILL CONTINUE TO HELP

It is much simpler to talk about the need for integrated planning than it is to do that planning. The new Regulations guiding planning on the National Forests call for enormous quantities of all sorts of information and analysis. At least in the short run, there will continue to be many professional judgments that can and should be criticized, although they will be based on the best information that is available (Committee of Scientists 1979). In the long run, directed research will provide a firmer basis for that planning, including planning related to residues.

There have been many references to the ways in which research and development activities are contributing to reducing residue problems. Major efforts include:

- --products research, which is directed towards developing new uses of wood fibre that cannot now be economically utilized;
- --development of logging systems, so that logging costs are reduced and environmentally sensitive sites can be harvested; and
- --determination of the effects of residues and of residue treatments on forest resource values.

Other kinds of research will also have some effect on residue utilization. Earlier I mentioned the usefulness of economic evaluations of converting residues to marketable products. Another need is to continuously update imaginary lines on the ground that separate those stands that are economic to harvest from those that are not. In a somewhat different vein, increased understanding of wildlife habitat needs and of wildlife values will make it possible to identify situations where commercial timber products might be harvested as a by-product of habitat management, even though such areas might not otherwise provide economic harvesting opportunities.

I do not intend to imply that every stand should be harvested if economic requirements can be met. Rather, within the context of the increasing values of wood products, carefully directed research can provide a firmer idea of what is possible. Then it is up to the planners and managers to display the production possibilities and their budget and tradeoff costs and to work with the States, organizations and concerned individuals to determine where and how products should be produced.

SUMMARY

There are substantial economic and environmentally acceptable opportunities to convert some portion of existing residues into marketable wood products. This is true whether the focus is on dead-and-down timber or on available but as yet unharvested stands. Opportunities to most significantly add to our national reserves of commercial timber seem to me to be greatest in presently unharvested stands, whether reference is to the millions of acres of lodgepole pine in the west or to the millions of acres dominated by hardwoods in the east.

The principal force at work that is leading to changing the potential resources of residues into actual resources is the increasing demand for wood products. This increasing demand has led to higher public stumpage prices and has stimulated reexaminations of sales procedures and applied research efforts.

Products research is leading to new markets for wood fibre that would otherwise become residues. Research such as that centered in Missoula is providing the information necessary to take advantage of those markets.

The key to minimizing future management problems associated with residues is to fully integrate explicit consideration of residue treatment alternatives into overall forest resource planning. Management decisions will then be more likely to be effective in producing the flows of wood products and the forest conditions that are desired.

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LEGISLATION AND POLICY INFLUENCING WOOD RESOURCE UTILIZATION

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ABSTRACT

The framework for harvesting and utilization opportunities for forest residues includes a number of long standing as well as recently enacted statutes. Air and water quality standards as set forth in additional legislation also have an affect on utilization opportunities. A further emerging factor pertaining to the harvesting and utilization of the forest biomass is our land base, and its availability. Recently the Senate has enacted a number of bills dealing with the question of timber economics.

KEYWORDS: residue utilization, forest policy, legislation

National materials policy has, as a framework for harvesting and utilization opportunities for forest residues, long standing as well as recently enacted statutes. Beginning with the now repealed Organic Administration Act of 1897, it has been made clear that the establishment of national forests is "...to furnish a continuous supply of timber for the use and necessities of citizens of the United States." The Monongahela court decision, which raised questions about the Forest Service's ability to sell timber unless it consisted of, "...the dead, matured, or large growth of trees found upon such national forests as may be compatible with the utilization of the forests thereon," caused Congress to enact the 1976 Forest Management Act. Originally Congress merely wanted to clear up the uncertainty created by the Monongahela issue; however, in the process a major piece of legislation emerged, supplementing and amending the historic Forest and Rangeland Renewable Resources Planning Act. During the legislative process leading to the passage of the 1976 Forest Management Act a wide range of forest users and other interested members of the public contributed. This interest has carried forward in the preparation of regulations, which it is fair to say, has been highly controversial.

It is useful for our purposes to quote from Section 3 of the 1976 Forest Management Act:

> Reports on Fiber Potential, Wood Utilization by Mills, Wood Wastes and Wood Product Recycling
> (c) The Secretary shall report in the 1979 and subsequent Assessments on:
> (1) the additional fiber potential in the National Forest System including, but not restricted to, forest mortality, growth, salvage potential, potential increased forest products sales, economic constraints, alternate markets, contract considerations, and other multiple use considerations;
> (2) the potential for increased utilization of forest and wood product wastes in the National Forest System and on other lands, and of urban wood wastes and wood product recycling, including recommendations to the Congress for actions which would lead to increased utilization of material now being wasted both in the forests and in manufactured products; and
> (3) the milling and other wood fiber product fabrication facilities and their location in the United States, noting the public and private forested areas that supply such facilities, assessing the degree of utilization into product form of harvested trees by such facilities, and setting forth the technology appropriate to the facilities to improve utilization either individually or in aggregate units of harvested trees and to reduce wasted wood fibers. The Secretary shall set forth a program to encourage the adoption by these facilities of these technologies for improving wood fiber utilization.
> (d) In developing the reports required under subsection (c) of this section, the Secretary shall provide opportunity for public involvement and consult with other interested governmental departments and agencies.

The Forest Service reports it is not ready with an assessment on this section at this time. The Resources Planning Act (RPA) Assessment is due to be submitted to Congress on January 22, 1980.

The Resource Conservation and Recovery Act, also known as the Solid Waste Disposal Act, was enacted in 1976, and it has caused concern in other industries because of the tentative regulations concerning the definition of hazardous waste. The implications in the wood fiber field are yet to be assessed, but because of the volume of fiber involved, as well as the diverse conditions, the impact on future use and planning is likely to be significant. Clean air and water laws will continue to have a major impact on all phases of forestry activities.

Energy programs and policy are developing rather rapidly as we grapple with our goal to be less dependent on foreign sources of oil. The Society of American Foresters in a study report of a task force titled <u>Forest Biomass as an Energy Source</u>, reports:

> Forest biomass--a renewable, versatile source of energy--can contribute the equivalent of approximately 9.5 quads to U.S. energy needs. (This value is exclusive of wood required for conventional products, but includes

aboveground biomass in net growth from commercial forests; mortality; and wood from land clearing, noncommercial lands, urban tree removals, and urban wastes.) If commercial forestland were fully stocked and intensively managed, biomass available for energy could increase to the equivalent of 18.9 quads by mid-21st century.

Biomass can be burned directly or converted to gas, oil, and char. Many forest industries, particularly pulp and paper manufacturers, now burn biomass for up to half their fuel needs. Blending biomass-derived alcohol with gasoline and using biomass in electrical generation may become practical.

The Federal Energy Administration (FEA) estimated in 1976 that annual energy use in the United States was about 75 quadrillion BTUs (or 75 quads), and that use in 1985 would be 98.9 quads. The agency also estimated that even under the most favorable conditions the United States cannot expect to gain more than six quads from emerging technology by 1990. A more realistic figure, it indicated might be two quads.

The emerging technologies evaluated by FEA included solar, geothermal, and synthetic fuels, but evidently excluded forest biomass. Energy currently obtained from wood is estimated at 1.1 to 1.7 quads. Members of the task force are confident that wood use for energy is increasing greatly, but we have no way of knowing the extent.

The comment that FEA evaluation excluded forest biomass potential reinforces similar comments, which emphasized the lack of attention by FEA to forest biomass potential. Despite the apparent lack of overall planning and assessment of this energy resource, there are many local and regional examples of increasing utilization of fiber for energy production. Studies and actual use of efficient wood stoves are being conducted by the Tennessee Valley Authority. The Eugene (Oregon) Water and Electric Board1/ uses large amounts of sawmill residue (hog fuel) for steam generation. Washington Water Power in Spokane has announced plans to build a wood fired generating plant. Pullman Swindell Company gave a presentation to the U.S. Senate staff last summer on their woodex pellet production from wood waste. More and more individuals are discovering the small chain saw and using spare time to gather firewood from a variety of sources.

Private companies have expressed interest in installing medium-size power generating plants using wood waste transported for up to 50-mile radius. The main problem in finalizing plans is the inability to reach agreement between the land manager and the power company over a long term supply of fiber at an assured price.

Pending legislation, including Synfuels, the promotion of the development of energy from agricultural commodities, forest products, and their wastes and residues, and rural energy conservation practices, and windfall profits (biomass property), which allows 20 percent tax credit, provide more substance for utilizing the energy potential of wood.

1/ The use of trade, firm, or corporation names does not constitute an official endorsement of, or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Discussions with the staff members in the office of the Chief of the Forest Service in the past few years indicate they have about all the authority they need to develop a more comprehensive utilization of wood fiber for our energy needs. The key factors involved in moving ahead seem to be economics, and supply and demand. One has only to note the rapid change in the price of foreign oil--and our dependence on it--along with Middle East uncertainties to estimate where our energy situation is heading. A prudent person would have to consider all of our energy options, especially underutilized domestic options such as wood biomass.

Forest products industries continue to face the roller coaster effect of the price of money and its relation to the housing market. With the interest rates at 15 percent and up, some experts predict housing starts at a 1.1 million level next year. Should the price of lumber and plywood drop, mills having timber sales with super-high bid prices, and no cheap timber to mix, will have a tough time during this economic period. Since the only certainty in the lumber business is "uncertainty," the secondary source of wood biomass is likely to be affected. Our softwood imports have recently risen from 20 to 26 percent of United States consumption, which becomes more of a factor in our balance of payments.

There are other factors that have an effect on our land base, its availability, and the potential for utilization of wood biomass. The ultimate disposition of the Forest Service roadless areas (RARE II) is yet to be determined. The Senate recently passed a central Idaho wilderness bill, followed by an Oregon wilderness bill. The Idaho bill ordered RARE II lands in central Idaho released with report language, while the Oregon bill released remaining RARE II lands with statutory release language. It is likely the disposition of RARE II by the Congress still has a long way to go. This, of course, leaves a cloud over the planning process for wood fiber management.

A bill by Montana's Senator Melcher authorizes the recovery of wood residues in the national forests for use as fuel, and for conversion to use as petrochemical substitutes or wood products. This is done through the use of residue removal incentives. Residue recovery as a function of brush disposal, slash disposal, site preparation, timber stand improvement, and other relevant forest practices has not yet been thoroughly examined. Again, markets, costs, supply and demand, and other factors need to be thoroughly examined.

A current battle is emerging over timber economics, especially in the Northern, Intermountain, and Rockies areas of our National Forest system. Whether timber management can meet a test of 5 percent or 10 percent on investment is being challenged. This is another important factor in the fiber potential picture. Along with this goes road construction policy and other harvest requirements under the 1976 Forest Management Act and subsequent regulations.

The previous discussion suggests there are many conflicting and vague policies that address, or fail to, the opportunity for wood biomass management. We have a new challenge to be creative, and unique new markets to consider that are in the national interest. Wood biomass management can have a beneficial effect on tomorrow's forests. We hope we can develop a positive policy to utilize this opportunity.

WOOD PRODUCT AND MARKET TRENDS INFLUENCING RESIDUE UTILIZATION

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ABSTRACT

Of the four major potential uses for forest residues, none offer any immediate prospects for large scale use. We can expect cyclical demand for residues to supplement the material supply to the pulp and paper industry. The rising cost of energy could generate the greatest potential demand for residues.

KEYWORDS: residue utilization, residue markets

The potential markets for forest residues can be classified into four primary categories. They are:

A. Reconstituted panel products, such as particleboard.
B. Pulp, paper, and chemical extractives.
C. Post, poles, and house logs.
D. Fuel.

I will deal with each of these separately, and attempt to indicate some of the major influences which are expected to change the trend of forest residue utilization for each of the potential uses.

PANEL PRODUCTS

The particleboard industry, (which includes medium density fiberboard), grew up on wood residues. However, the basis is not forest residues, but mill residues. The difference is critical to the industry. Mill residues are convenient, already dry, and are available at a cost which is little more than the cost of transportation. The only problem with mill residue is that there is not much left. With uncommitted mill residue no longer available, it would appear that any growth in the production of panel products would need to be based on forest residues, as they are the least expensive alternative. However, the Northern Rocky Mountain region is at a distinct disadvantage compared to the rest of the country when it comes to making panel products of forest residues. Local markets are not large enough to absorb any significant increase in production, and the large markets are all quite distant.

It simply makes no economic sense to manufacture a product in the Rockies for shipment to the Mideast and East, when the same product could be made closer to the market. Forest residues are widely available, so there is no need to locate in the Rocky Mountains.

The cost of energy will also have a significant effect on the potential production of panel products, and for plants located in the Rocky Mountains, rising energy costs are a double curse. In addition to the direct energy consumption of manufacture, the panel products also use energy indirectly through the resins used to glue the particles together. The resin is produced from natural gas, so that the cost of resin is directly related to the cost of gas, which has about doubled in the past four years, and can be expected to continue to increase faster than other costs. Resin accounts for about one-third of the total cost of manufacturing particleboard, so that rapid increases in resin costs will place particleboard at a competitive disadvantage with other panel products.

As energy costs rise, so do transportation costs, which places an extra burden on reconstituted panel products from the Rocky Mountain area. Because of the long distances to market areas, an increase in transportation costs has a greater effect on products from this area than it has on similar products produced closer to the market.

All in all, the prospects for using forest residues to produce reconstituted panel products in the Northern Rocky Mountain region are not bright. There are many locations in the country which have adequate supplies of raw material, where the costs of materials and transportation are lower, so that we should expect any significant growth in the use of forest residues for panel products to occur not here, but in the South, the Midwest, and the Pacific Southwest.

PULP, PAPER, AND CHEMICAL EXTRACTIVES

Within the past two decades, the pulp and paper industry in the Northwest has shifted from a supply based primarily on roundwood to one based on mill residues. The shift has gone far enough that local pulp production and chip exports now use virtually all available supplies of chippable mill residues. There are, in the Northern Rockies, still a few small mills that do not sell chips, but they are scattered and isolated, and do not produce enough volume to provide a basis for an expansion in pulping capacity. Any increase in pulp production in the Northwest must be supplied from forest residues.

This is not to say, however, that the pulp and paper industry will be a major user of forest residues. The industry can be expected to use the cheapest material available to it, and that is not likely to be forest residues from the Northern Rockies. Existing mills that may require additional chips will go to forest residues close to them, and new mills will be built close to residues and markets. This means that the demand for forest residue chips from the Northern Rockies will come from existing mills in or close to this area. Since these mills are already well supplied with mill residues, it would appear that there is no impetus for using forest residues.

In the long run, there may be enough mill residues, but there are often short-run shortages, and we can expect to see these shortages filled with forest residues. There have been recurring patterns of periods when the demand for chips stays high while the output of lumber and plywood mills (including chips) is down, so that the pulp and paper mills are faced with raw material shortages. During these periods, there will be a demand for chips from forest residues, not only from local mills, but from the surrounding area. It should be recognized that these periods of demand for forest residues will be temporary, and although they may last several years, they will come to an end, perhaps abruptly.

The use of wood residues to produce chemicals, (including alcohol for fuel), has received a considerable amount of attention, but we should consider the total volume involved before speculating on the possible effect on forest residues. The total volumes for all the chemical extractives is very small when compared to the volumes of residue available, so that we can be sure that no matter what happens with extractives, the effect on forest residues will be negligible. Only the production of wood alcohol for fuel has a promise of significant volume, but there are technical and economic problems that are not yet resolved, so that it is too early to speculate on the prospects. The only thing we can be sure of is that it will not come soon.

POST, POLES, AND HOUSE LOGS

These three products have been combined, as all of them require sound wood in round wood form. All may be made of dead material, and posts can be either dead or can be small green trees.

The demand for posts and poles has been fairly steady over the past decade, and there seems to be no reason to expect any dramatic changes. The demand for posts may get a small boost from higher energy costs, as the cost of producing and transporting steel posts will go up more than will the costs for wood posts. This effect may be very important to an individual producer, but won't have a large effect on the total use of forest residues for these products.

Trends in the demand for house logs are very difficult to predict. Interest in log houses grew dramatically during the past five years, to the point that some producers were having difficulty in finding enough suitable logs. However, with the recent drop in housing, the log house market tumbled like everything else. It would appear that log houses follow about the same patterns as conventional housing, but may have more severe swings. Many of the log homes are used for vacation homes, where the demand may be very high in good times, and almost nil in bad times.

The house log industry has the potential for using significant quantities of the standing dead residues. With a steady source of material supply and efficient production techniques, log construction can compete economically with conventional housing construction.

FUEL

Energy production represents the greatest potential market for forest residues in this area, and although it is not currently feasable to use forest residues for fuel, we can expect that it will be in the near future. The process of converting to wood fuels is already well underway. Many of the larger forest related industries have already made the necessary changes to convert from natural gas or oil to wood. All of the current use of wood in this area, however, is based on mill residues (hog fuel) which are available for little more than the cost of transportation. We can expect a continuation of this trend until the available mill residues are all being used, which will not be long. At that time, there will not be a shift to forest residues relative to mill residues.

Instead, the process of conversion to wood will end, until rising prices for fossil fuels push the cost of energy high enough to make forest residues attractive.

In order to predict when forest residues will become economical fuel, one must forecast the price rise of fossil fuels relative to other costs. I have not seen anyone willing to attempt it. We should expect, though, that it will not happen within the next five years, but is quite likely within the next ten to twenty. It has already happened in the Northeast, where energy costs are much higher than they are here, and the costs of collecting forest residues are lower. There is at least one public utility, and several large industrial plants that are currently using forest residues to supply all of their energy.

To summarize, the four major potential uses for forest residues, none offer any immediate prospects for large scale use. We can expect cyclical demand for residues to supplement the material supply to the pulp and paper industry. These periods will occur when the demand for paper products remain high while the demand for lumber and plywood are down. We are now entering such a period, and may soon see an increased use for chipped forest residues. Posts and poles represent a fairly small but steady demand for standing dead residues, and a recovery at the housing market should revive the demand for house logs.

The rising cost of energy could generate the greatest potential demand for residues. Although forest residue is not currently an economical fuel in this area, we should expect that it will become so in the near future.

RESIDUE UTILIZATION AND THE REGIONAL ECONOMY

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ABSTRACT

The wood products industry is vitally important to the economy of western Montana. Forty to forty-five percent of the earnings in western Montana's basic or export industries comes from the wood products and paper industries. Whether or not forest industries in the Rocky Mountain region hold their own, decline, or expand in future years depends mostly upon the area's ability to compete in the national market, and upon the availability of raw materials. Increased residue use may prove to be Montana's only chance of maintaining the forest industry at or near its present level of activity.

KEYWORDS: residue utilization, timber availability, Montana

During this symposium we have discussed a topic of great importance to the forest industries and to the Rocky Mountain states: better utilization of raw material resources through the harvesting and use of forest residues. Residues are important to the industry because it needs the raw materials and important to the region because it needs the jobs and income the industry provides. In this paper, I will discuss the significant role of the forest products industry in western Montana, its prospects for the future, and the importance of these discussions to that future. My hope is that these comments will provide an economic perspective for the papers presented previously.

Perhaps no part of the Rocky Mountain region is more dependent upon the forest industries than western Montana. The private forest products sector alone has provided from 40 to 45 percent of the economic base of this area in recent years. By that I mean that 40 to 45 percent of the earnings in western Montana's basic or export industries comes from the wood products and paper industries. Earnings include both wages and salaries and proprietors' income. If the salaries of federal and state employees in forest industry-related jobs were added to industry earnings, the combined figures would approach or exceed 50 percent of total earnings in the area's basic industries.

Those of you who have not been in western Montana or Missoula recently will have noticed some changes. The growth that has occurred here in the past few years -- the substantial number of new employment opportunities which has been created -- is largely attributable to the forest industries. Their growth has made possible much of the expansion in retail trade, services, and other consumer-oriented businesses. We needed those jobs, as large numbers of young people entered the labor force and as more women sought employment.

Yet industry spokesmen and economists interested in the forest products industry have for some time been concerned about its long-run prospects in western Montana. There still is a real question as to whether the industry can maintain its relative contribution to the area economy during the next twenty years.

The events of the past decade in western Montana will help put the present situation in perspective. They are not so different, I suspect, from what has happened in other parts of the Rocky Mountain area. Certainly the early 1970s were not an auspicious time for the industry. After a rapid expansion in the sixties, it was clear that times were changing. There was no longer any doubt that the supply of federal timber available to the industry would decline. Despite a booming U.S. housing market, lumber and plywood production in this area just held its own between 1970 and 1973. Total industry employment and earnings showed little change. Then in late 1974 and 1975, the national recession hit the forest industry. Employment and earnings fell off sharply. The year 1975 was a dismal one for the industry and for western Montana.

And then a funny thing happened, just when some people assumed the industry was on its way to a permanent plateau or a downhill slide: its recovery from the recession turned into a period of rapid expansion. Total 1978 earnings of workers in the forest industries were up about 44 percent from 1975, after adjustment for inflation, while employment was growing by 32 percent. As a result of the rapid post-recession growth, forest industry employment in 1978 exceeded 1969 levels for the first time in this decade by about 1,800 workers, and that's a substantial number in this part of the world.

Raw materials for the expansion have been provided by a large increase in the timber harvest from private lands, both industrial and nonindustrial, beginning about 1974. According to forest service estimates, the total cut on private lands increased by almost one-half -- 46 percent -- between 1973 and 1978. Going back again to 1969 for comparison puts the situation in perspective: the 1978 harvest from private lands is estimated to have been 73 percent higher than the 1969 harvest, while the cut from federal, state, and Indian lands was down 42 percent. Without the increase in private harvest, total timber cut in Montana in 1978 would have been 30 percent below 1969, and western Montana would have been quite a different place from what it is today. Traffic congestion in Missoula would have been less of a problem, but the lines at the unemployment office would have been considerably longer.

While a substantial shift has been taking place in the timber harvest during the past decade, significant changes also have occurred in the structure of the industry. Employment estimates leave a lot to be desired, especially the industry breakdowns. But they do provide a tentative measure of changes in structure, and in the economic contribution of various segments of the industry.

Sawmills, plywood, and millwork plants, together with logging operations, continue to employ the great bulk of industry workers in Montana. Their proportion of the total, however, has declined from around 93 percent during the early seventies to from 86 to 89 percent in the past few years. Within this group, plywood has assumed greater importance. Employment in plywood plants has doubled since 1969, with more than 1,000 new workers. The numbers of logging and sawmill workers appears to be slightly smaller, and the number of sawmills has declined significantly.

The other segments of the industry -- mostly plants producing pulp and paper, particleboard, and fiberboard -- have added several hundred new jobs since 1969. These plants' share of total employment -- which recently has varied from 11 to 14 percent -- should increase a bit more when a Missoula paper mill expansion is completed next year. The growth of these industries is significant, of course, because they use mill or forest residues. With the pulp and paper mill expansion, we may see the first large scale use of logging residues in western Montana.

So as the 1970s end, despite all the problems of the past decade, the forest products industry in Montana is more diversified and is employing more people than it did ten years ago. But, what about coming decades?

We all know that the short run outlook for the industry is not good. We already are seeing short work weeks and layoffs in response to a falling U.S. housing market. But we are more concerned with the longer term prospects in our discussions today. Whether or not forest industries here in western Montana, and in the Rocky Mountain region, hold their own, or decline, or even expand, in future years, depends mostly upon the area's ability to compete in the national market, and upon the availability of raw materials.

Large numbers of young people from the high birth rate years of the fifties and sixties will reach the home buying age during the next decade. There is not much doubt that a strong national demand for new housing will exist during the 1980s, if construction funds are available. This means that the demand for lumber, plywood, and board products also should be strong; how strong depends upon the relative price of wood compared to other building products.

The demand for Rocky Mountain wood products may well hinge upon what happens in other parts of the country. Will the Rocky Mountain region be able to hold its share of the national market? We don't know. Certainly not if adequate timber resources are not available.

Will adequate raw materials be available to the industry in Montana? There is general agreement, I think, that the high level of harvest on private lands, which made possible the expansion during the late seventies, cannot be maintained during the eighties and beyond. Users of private timber will be gradually forced to look to public lands for a larger share of their raw materials. Given present legislation and national policy, apparent public opinion, and probable funding levels for public land management agencies, it seems to me unrealistic to expect any significant increase in public timber harvest in the 1980s.

Paul Polzin, an economist in our Bureau, has prepared some projections of the demand for softwood sawtimber from Montana forests to the year 2000 and beyond. One set of these projections assumes that prices for wood building products continue to rise faster than prices of competing building materials (a reasonable expectation) and that Montana holds its 1970 share of the national market. His estimates indicate that under these conditions we would need to harvest timber at about the same rate in both the 1980s and 1990s as we did in 1978. That probably will not happen. Before the year 2000 rolls around, our supply of timber may fall short. It may not be a severe shortfall, but it likely will be enough to cause some severe problems for individual mills.

To assume that Montana can hold its share of the national building material market may be unrealistic; certainly some economists think so. But from the standpoint of the economic welfare of western Montana, it is a goal worth shooting for.

The fact that it is quite possible that over the next twenty years there will not be enough timber to hold our share of the market gives greater urgency to the topics discussed in these papers. An area heavily dependent upon a single industry with an uncertain source of materials, an area with a growing labor force, and few prospects for expansion of its economic base through growth in other activities, has a right to be concerned about its future. So, of course, does the industry.

Certainly the industry should continue to press for as much public timber as good land management will permit. Realistically, however, increased use of forest residues may prove to be Montana's only chance of maintaining the forest industry at or near its present level of activity. Increasing residue use may be a long, slow process; it will require further structural changes within the industry. If the forest industry employs 10,000 or 12,000 people in Montana in 1995, it will be a different industry from the one we know today.

As a Montanan and an economist, I am pleased to have participated in this discussion of the prospects for utilizing forest residue in the Rocky Mountain region. I hope that decision makers in both the private and public sectors will continue to look at options for using these materials, and for restructuring the forest industry in a way that will permit it to continue in its important role as a source of employment and income.

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KEYWORDS: timber harvesting, timber processing, utilization, forest residues

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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