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Abstract

Forest residues, in combination with more intensified timber production systems have potential as a substantial source of fuel wood. The extent and availability of this resource is discussed, with particular reference to the energetics and economics of existing and proposed harvesting systems. Utilization of residue wood fuels is considered and recent developments in small scale automatic wood chip burning heating systems for residential and commercial use are described.

1. INTRODUCTION

Compared to other alternate energy possibilities, wood has received very little attention in the overall national energy program until recently. Reasons for this are difficult to identify, but undoubtedly some gross underestimates of potential wood supply and concerns about competition with other uses have been major factors. Forest biomass is now being seriously considered as a major energy source in several parts of the country. Implementation of improved forest management techniques, including acceptance of the concept of complete tree harvesting will allow for sustainable yields many times greater than those obtained under traditional systems. A considerable portion of this increased production could be used for fuel wood if there was a market for it.

The unwillingness to make major commitments towards utilization of forest residues for fuel is a result of many factors, economic, ecological, technological and others, all interdependent. However, the technological considerations, that is, the development of suitable techniques and equipment for procurement and utilization of the resource are seen to be of major importance. The economics of residue harvesting cannot even be estimated until some idea of the type, cost and efficiency of suitable machinery is determined. For example, no investments in wood fuel combustion equipment will be made until a guaranteed supply of suitable fuel is available. Conversely, production of specialized residue recovery machinery will not be forthcoming unless equipment for using the fuel is available. Many of these engineering problems are now receiving serious attention, and the development of integrated fuel supply and utilization systems is becoming a distinct possibility in the Northeast. In order to understand the potential and the problems of using forest residues as an alternate energy source certain questions must be addressed:

(1) How much material is available for the energy market?

(2) How can this material be harvested economically and ecologically?

(3) How best may it be utilized as an alternate energy source?

2. AVAILABILITY OF FOREST RESIDUES

In attempting to quantify the amounts of potential fuel wood available a problem of terminology is encountered: what is a forest residue? Different writers and authorities have different definitions, ranging from simply the slash (tops, branches, cull trees) left behind after logging operations to the more inclusive term of all presently unused wood fiber. The latter is the definition preferred by the writers and used in this paper; thus forest residues includes tops, limbs and branches, stumps and roots, fire, disease and insect damaged trees, pre-commercial thinnings and puckerbrush. Some of these terms themselves are misleading; 'pre-commercial' thinnings implies trees of small diameter with no commercial value. However, small trees which 5 years ago would have been left in the woods are now being chipped whole for pulp - one company, as reported later, is harvesting trees as small as 2" diameter. Thus it would probably be better to refer simply to 'thinnings'. Puckerbrush was originally a regional term referring to dense stands of young hardwoods, but Young uses it to apply simply to young stands (8). Biomass, material grown specifically for fuel, in 'energy plantations' is not included in this study. Certainly this may eventually provide substantial amounts of energy - one study performed for ERDA estimates 10 Q by 2000 AD, but this represents a long-term solution. In contrast, forest residues are available now and, perhaps more important, are available within the overall framework of existing timberland ownership and management systems. In the Northeast, for example, it is relatively easy to envision the major timber and paper companies harvesting an additional product, fuel wood, without this affecting the growth, harvesting and sale of trees for the so-called higher uses - paper, lumber, etc. It is on the other hand more difficult to foresee a major shift to biomass production, involving the commitment of extensive acreages to short rotation crops of fuel wood only.

Estimates of the quantities of residues available vary considerably. Arola puts a figure of 6 billion cubic meters on logging residues, fire insect and diseased trees and unused thinnings annually (1). Jamison estimates available unharvested residues in the U.S. at greater than 120 million dry tons per year (4). In the State of Maine alone, Young estimates approximately 13 million tons/year of presently unused material (9).

Traditional forest management throughout most of the world is based on the Merchantable Bole concept, with the merchantable portion of the tree harvested either by selective logging or clearcutting at intervals. The Complete Tree concept as proposed by Young in many publications not only involves using the entire tree 'from root tips to leaf tips', but also encourages improved management to increase sustainable yield while maintaining nutrient levels. In Maine, the bole of the tree contains approximately 65% of the fiber, the branches and tops 10%, the stump and roots 25%. Thus in harvesting a the residues, there is a potential for a total increase of 50% of that currently harvested. This does not include trees considered too small to harvest. Pucker-brush in Maine produces approximately 1.2 dry tons/acre/year above ground.

One often used argument against the use of residues for fuel is that this is competing with use for other things, presumably paper and made-up building materials. Certainly the value of wood for its structural and chemical properties will increase and the use of wood as fuel may set the minimum price. But that does not mitigate against its use. The market for pulp and lumber is not infinitely expandable; it must be remembered that an increase in production as small as 5% can make the difference between a shortage and a surplus. Construction of new paper mills and chip-board plants is a long-term proposition; capital costs are ever rising, and environmental considerations often slow down the process and increase costs.

While it is conceded that forest residues are not a permanent solution to even a local energy shortage, in the short and medium term a reasonable goal is to utilize this resource for fuel at least until it is needed for its structural/chemical properties rather than its energy content.

3. RESIDUE HARVESTING - GENERAL CONSIDERATIONS

Before considering actual residue harvesting systems it is appropriate to take account of the energetics of such harvesting, and also its biological or ecological effect. Approximate energy inputs for operations in various wood production systems have been determined (7). Table I uses these figures to illustrate the particular inputs required of some existing or proposed residue harvesting systems. All such systems have been shown to require less than 5% of the value of the wood harvested as fuel to run the system.

There is some concern that residue removal adversely affects nutrients levels in the soil, and the soil's erodibility. If residues are left behind, they undergo bacterial decomposition, returning nutrients to the soil - there is no question that their removal reduces nutrient levels, but how much and for how long is a more complex matter depending upon site, climate, geology and other factors. Soil receives nutrients from several sources, not just from residues; weathering of bedrock, precipitation, and nutrient leaching from leaves are all involved. Thus the nutrients lost through residue removal will re-placed over time by geological and atmospheric inputs. Loss of residue nutrients may however be important where reserves of organic nitrogen are low to begin with. Young believes that nutrient depletion may be a problem with conventional systems, i.e., even where the residues are left behind (9). Intensive agriculture encountered this problem decades ago - the solution was fertilization, and there are many who believe forestry will follow the same course, in which case removal of the residues as well as the bole will affect only the mount of fertilizer needed, not the decision as to whether any fertilization is needed or not. There is much interest in the possibilities for using municipal garbage and sewage sludge for forest fertilization, as well as pelletized wood ash from various combustion processes.

Increased soil erosion has also been attributed to removal of residues, particularly stump/roots removal. Certainly more ground surface is left exposed to possible erosion but again the actual effects are site-specific. In New England and the

TABLE I

ENERGY USE IN HARVESTING FOREST RESIDUES FOR FUEL

		BTU/ton dry wood
(a)	Whole trees skidded, delimbed at landing	
	Additional energy cost of skidding	negligible
	Chipping	75,000
	Transport	190,000
	Unload	negligible
	Auxiliary activities	59,000
	Total	324,000
	(This system probably loses half the available material in skidding)	
(b)	Residues prebunched in stump area, forwarder used to transport to landing	
	Prebunching residues	71,000
	Forwarding	126,000
	Chipping	75,000
	Transport	190,000
	Unload	negligible
	Auxiliary activities	59,000
	Total	521,000
(c)	Thinnings cut, delimbed and bucked in woods; forwarded to landing	
	Felling and delimbing	33,000
	Bucking	31,000
	Forwarding	126,000
	Debarking	40,000
	Chipping	75,000
	Transport	190,000
	Unload	negligible
	Auxiliary activities	59,000
	Total	554,000

Energy value of residues = 16,000,000 BTU/ton dry matter

glaciated Great Lakes region erosion due to logging itself is simply not a problem - erosion due to poor road layout is the main culprit. In these regions the slopes are not great and the surface of the ground is so irregular that run-off is not a major problem. Removal of stump/root systems leaves a series of small depressions behind, not a condition to encourage erosion. In other regions, particularly the Pacific Northwest the climate and topography make for an entirely different situation where erosion can be a serious problem with or without removal of residues.

There are many other factors which warrant consideration if residue harvesting does become an accepted practice; for example, the effect on wildlife populations (logging slash provides shelter for a number of species), the effect of the increased logging traffic on road networks, the possible reduction of forest fires, sociological and economic benefits of an additional industry in a particular area, etc. The departure from traditional forest management concepts is a major step and is likely to lead to a great number of secondary considerations and difficult choices.

4. RESIDUES HARVESTING - EXISTING AND PROPOSED SYSTEMS

Conventional logging practice based on the merchantable bole concept involves the cutting of the tree and removal of tops and branches. The bole is taken from the woods and the other parts left on the ground. If the area is being selectively cut then trees unsuitable or too small may be left standing; if it is being clearcut these cull trees are left with the slash. Residue harvesting requires the removal of this presently left material; this can be done either by chipping the whole tree in the woods, trucking the whole tree to the mill and chipping there, or by chipping the residues left by conventional logging.

In 1969 Morbark Industries brought out a mobile version of their stationary chipper; since then whole tree chipping in the woods has been steadily increasing. The chips are blown into vans, transported to the mill and used for pulp or made-up building materials. Although highly successful there have been limitations, in that these large machines were uneconomical if used on small whole trees, and the ratio of bark/fiber reaches levels unacceptable for papermaking.

Recently, however, small mobile chippers and debarkers have been developed and imported, allowing the harvesting of trees as small as 2" diameter. One land management company in Maine is experimenting with a system based on these machines. Spindly trees from very dense 30-40 year old stands are felled, delimbed and bucked into 8 foot lengths by chainsaws. A specially adapted forwarder removes the 8 foot material which is debarked and chipped at a landing. Twenty tons of dry matter per acre are being removed in the operation, which because of its labor intensity barely breaks even at present. However, the trees thus harvested and marketed would be dead and rotted away before the main crop was ready for harvest so the yield from the land is greatly increased. In addition it appears that subsequent growth of desirable trees in the thinned area is considerably improved over adjacent control areas. Availability of equipment to mechanize the selective thinning and processing of the cull material might well make such operations highly profitable and add many millions of tons per year of wood fuel to the national energy product. A figure of $25-30 per dry ton delivered within 30 miles has been estimated for the fuel wood from this operation. Most authorities agree that residue harvesting costs will decrease as the technology improves.

Experiments carried out some years ago in Georgia on planted sycamore harvested after 5 years showed dry matter yields of over 50 tons/acre, and growth rates of up to 16 tons/acre year. As a "residue" this type of young stand or puckerbrush is most definitely worth harvesting. A West German company now markets a self-propelled puckerbrush harvester, and it appears that there is considerable interest in the concept in this country. Short rotation forestry involving growing and harvesting of puckerbrush type material on a regular basis has been suggested as a potentially large source of fuel wood. One objection, however, is that the entire production is of low unit value, losing the higher value of sawlogs, veneer logs, etc., which might result from longer rotations. The complicated molecules in wood and the consequent useful structural characteristics of wood are wasted if the entire growth is used for fuel. With the diversity of products into which wood can be formed, a pattern of culture might be developed which would allow the maximization of production gained by short rotations, while not eliminating select trees which have the potential for producing high quality veneer and sawlogs. The system should allow more frequent partial harvesting to increase total yields and ensure that minimal quantities of photosynthetic products are lost. Even small, non-competitive, dying trees could produce significant fuel wood while their removal, along with thinning of still growing stems could provide better conditions and stands for maximum growth. The pattern might be based on a series of narrow East-West lanes for use by machinery which could reach into the forest swaths between lanes, pruning to the correct stand and processing the removed material for fuel, chips, made-up building material, pulp logs, etc. Harvest of the mature trees would take place when their shade had protected the next generations of desirable species and eliminated the scrub phase associated with clear cutting. It appears that as much as 3-4 tons of woody material per acre per year could be produced by methods like this on land which currently yields only 1 ton per acre per year. This additional production is available now for the effort of gathering. Development of an economical method for obtaining it would also increase future wood supplies.

A research project to test such production intensification/residue harvesting concepts is just beginning at the University of Maine. Three distinct types of harvesting will be studied:

(1) Cutting of permanent East-West lanes in young stands to permit equipment movement.
(2) Thinning, initially at approximately 5 year intervals, of dead and small trees up to 1.5 inches diameter.
(3) Removal of part grown trees, up to 4 or 5 inches diameter to leave as near an ideal stand as possible.

The first of these operations involves the use of a "puckerbrush harvester" as proposed by Smith and similar to the machine recently developed in Europe (6). This machine would operate in a similar manner to a combine harvester, cutting and blowing the chipped material into a trailer behind or parallel to the machine.

The second operation requires selective cutting and chipping and for this no single machine presently exists. We have proposed the development of such a device. It would consist of a skidder-mounted boom capable of reaching 20' or so into the stand between lanes. At the end of the boom would be a cutting device (probably continuously operating saw type rather than an intermittent shear type) and small chipper. After chipping, the material would be conveyed pneumatically back to the machine and into a towed or self-propelled container. Initial analysis has indicated that such a machine should cost approximately $25,000 and have a production rate of 2-3 tons/hr in order to be economically viable. Preliminary tests on a prototype combination cutter/chipper mechanism are very encouraging.

For the third operation it is envisioned that a conventional feller-buncher would be used with the trees left in the lanes to be chipped by a towed conventional chipper. Table II gives an indication of estimated energy requirements for these operations. Since the energy value in the fuel harvested is 14-16 million BTU/ton, the energy conversion ratio is substantial.

Another development is use of the stump-root system as proposed by Young and evaluated practically in Finland by Hakkila (2). To date the base machine for stump harvesting has been an excavator or a modified feller-buncher. A commercial machine is now in use which uproots, cleans, splits and bunches stumpwood. Primary transport of the product is done by a forwarder which is equipped with a

TABLE II

PROBABLE ENERGY REQUIREMENTS FOR FUEL PRODUCED FROM INTENSIVE "STRIP" FORESTRY

		BTU/ton dry wood
(a) Lane thinning		
Assumptions	Energy requirements similar to a short rotation system other than planting and fertilizing	470,000
(b) Selective thinning of material up to 1.5 inches diameter		
Assumptions	Energy consumption for chipping increased by approximately 3 times due to idle time in reaching and for part loading of chipper. Work rate of 3 tons per hour estimated	620,000
(c) Thinning trees up to 5 inches diameter		
Assumptions	Use of normal feller buncher followed by mobile chipper running in lanes. Production rate of feller buncher assumed to be only 33% of normal work rate due to small trees and extra difficulty of removal	685,000

stump grapple, enlarged loading space and a tipping body. A pulping plant presently utilizes the green stump wood as a supplementary raw material for sulphate pulp. The stump processing unit of the mill can produce 20,000 dry tons per year of chips from the stumps with a sand content less than 0.2%.

A prototype device which can harvest the stump and root system directly has been developed in the U.S. and was tested in Maine during the summer of 1977. Very little soil disturbance results from the extraction of the stump which is vibrated while being pulled out of the ground. Fifteen tons of dry matter per acre were removed by the stump extraction process.

Much of the material resulting from an intensified production/residue removal system will certainly be used as a raw material rather than as fuel, especially if upgrading of barky woodchips becomes commercially accepted. Nevertheless, the demand for wood products is not inexhaustible and rising energy costs make the utilization of substantial amounts of these harvested residues as fuel an economically sound proposition.

5. ENERGY RECOVERY FROM RESIDUES

The chipped material from forest residues is an essentially homogeneous material with a higher bark/fiber ratio than that obtained by chipping fully grown trees. Moisture content of the green material is between 40 and 50%, and the energy content between 8000-9000 BTU/dry pound depending on species and bark content. It can be converted to usable energy by many different processes, including bioconversion techniques such as anaerobic digestion or fermentation, and thermochemical processes, pyrolysis, gasification and direct combustion.

Although considerable effort is being directed towards the development and improvement of many of these processes, it is felt that the most promising, most advanced and most feasible technology is simple direct combustion of wood fuel. Conversion of wood to other fuels, for example, low BTU gas, substitute natural gas, synthetic oils and methanol give portability and multiple use, but generally at the expense of capital cost and conversion efficiency.

Potential applications for wood combustion systems range from large electricity generating stations to small comfort heat-, ing systems for residential and commercial use. Several utilities have studied the potential for power generation using wood fuels. The possibilities depend greatly on location, fuel availability, projected demands, etc. One major problem is that of balancing fuel transportation distances against size of proposed plant. Cost per megawatt decreases with the size of the plant because of the economies of scale, and the trend is to build bigger and bigger stations. However, to supply fuel to generate, for example, 800 MW of power necessitates drawing wood supplies from a 30,000 square mile area, with trucking distances up to 100 miles. Present costs make this entirely uneconomical.

Stations of approximately 50 MW output, drawing fuel from within a 20 mile radius have been proposed for several areas in New England. A recent ERDA grant of $2.5 million provides for planning and start-up assistance for such a plant in northern Maine. The feasibility study will include investigations into the merits of using biomass, residues, and other resources.

Power generation using manufacturing wood residues e.g. stud mill wastes, is already an accepted concept, and the technologies of handling and combustion are basically the same as for logging residues. Manufacturing wastes are available at a fraction of the cost, however, since their cost is absorbed by the primary timber products and they are utilized at, or very close to the site of production. One waste wood boiler at a Maine stud mill operates a generator supplying 7.5 MW, and burning 33 truckloads of hogged fuel per day. The possibilities of using other types of residue is under investigation. Another Maine company plans to construct a similar, larger generating station in the near future.

Recent developments in magnetohydrodynamics (MHD) may change the economics of wood fired stations considerably. MHD generators, in combination with conventional steam turbines are capable of efficiences (predicted) of approximately 50%—a 50% increase over existing systems, and are adaptable to wood fuels. The smaller 50 MW stations may thus be made efficient enough to be economically feasible using trucked-in logging residues.

Large-scale wood combustion competes with No. 6 fuel oil presently costing approximately 35 cents/gal. Competition with No. 2 oil (50 cents/gal) used in smaller, comfort and process heat systems allows the high cost of wood fuel transportation ($5/cord - 10 cord load, 50 mile radius) to be more readily absorbed.

Residential space heating accounts for something over 10% of all U.S. energy consumption. While it is recognized that on a national basis wood has the potential for supplying only a part of this, in certain areas, notably New England, the Northwest and the Great Lakes Region wood fuels can make a major contribution.

Since 1973 there has been a tremendous increase in the use of wood as a home heating fuel. Sales of woodstoves have multiplied enormously over this period and many homes have completely replaced oil by wood. However, the overall effect of all this woodburning is relatively small; there are many reasons for this. It is doubtful that wood will become widely accepted as a home heating fuel until it can offer levels of convenience, safety and reliability comparable with conventional fuels; not everyone is willing to expend the time and energy needed for cutting, splitting, drying, carrying and hand-feeding of stickwood. Many woodburners are realizing that paying $75 per cord for firewood is a rather poor investment, even at today's oil prices. Conventional woodstoves are efficient and safe only over a limited operating range. Since they rely on draft control for regulating heat output, the wood fuel receives less than stoichiometric oxygen except when run flat out. This leads to incomplete combustion, low efficiency and the generation of intermediate combustion products which can condense in chimneys to form creosote, one cause of the tragic increase in residential fires attributed to woodstoves.

The use of forest residues for fuel represents an entirely different situation. The material is in the form of chips, which allow the use of mechanical feeding and automatic operation similar to residential coal stokers of the past. With mechanical feeding of the fuel, the rate of burning can be controlled by rate of fuel input rather than by restricting air supply. Thus, there is always complete combustion, no dangerous or unpleasant intermediate products, and a higher thermal efficiency. Chips can be dried much faster than stickwood because of their higher surface area/volume ratio; they ignite easily and burn well, and can be stored, conveyed and handled more easily than logs. Regular delivery of chips for fuel, from a central stockpile, would be similar to coal delivery systems; outdoor silos or basement hoppers would store a 3-4 week supply, eliminating the need for large woodpiles.

The Agricultural Engineering Department of the University of Maine has been studying this concept since 1973, and has developed many of the components required for the system. Small scale (less than 1 million BTU/hr) automatic woodchip burners have been designed, constructed, and satisfactorily tested. This work is described in other papers (3, 5). The latest system developed under this program is a 200,000 BTU/hr fully automatic system capable of burning chipped puckerbrush, residues or hogged fuels at moisture contents up to 45%. A second prototype, of 500,000 BTU/hr capacity has been installed in a factory in Southern Maine and will be tested this winter. A third unit, of 450,000 BTU/hr is being designed to fire a hot water heating system for a new vocational center in Ellsworth, Maine. Additional installations have been proposed for a greenhouse complex in North Carolina, a senior citizens housing project in Maine, a hotel in New Brunswick and several other applications. At this point the concept looks extremely attractive. Capital costs for these systems are running 3 to 4 times that of equivalent sized oil-fired units, but these higher costs can be recovered in 4 to 8 years depending on the source of chips.

At present there is no commercial network of storage and delivery of chipped wood fuels for small scale users. All the systems so far built or proposed either have a private source of wood wastes, or plan to purchase a woodlot and a chipper and supply initially themselves and later other similar systems. It will certainly take many years to set up a widespread wood fuel supply network, but if the demand exists then it will only be a matter of time. It must be remembered that the present fuel-oil delivery network was not set up overnight.

6. CONCLUSIONS

Use of forest residues, combined with intensification of present wood production undoubtedly has great potential as an alternate energy source.

The forest industry is justifiably, but perhaps overly, cautious about entering the wood fuel market. Uncertainty about continuing supply of fuel, and the fact that even if the most optimistic projections are correct wood residue fuel will supply the annual equivalent of only about a 40 day oil supply, explain national inattention to this resource. However, with intensified production and efficient fuel utilization it seems that even the most optimistic projections may be too conservative.

Current development work on utilization has two directions, the large-scale generation of electrical power and small-scale production of comfort heat. Both schemes have merit, and are certainly not mutually exclusive. Growing around us we have a large supply of potentially clean-burning renewable fuel, and there is little doubt that the next decade will see major development in its harvesting and use.

References

(1) Arola, R. A., 1975. Logging Residue: Fuel, Fiber, or Both? Trans. ASAE. 18(6).

(2) Hakkila, P., 1976. Stumpwood as Industrial Raw Material. Folia Forestalia. 292.

(3) Huff, E., J. G. Riley and D. Smyth, 1976. Modern Residential Heating with Woodchips. Amer. Soc. Agr. Engrs. Paper No. 76-4555.

(4) Jamison, R. L., 1977. Trees as a Renewable Energy Resource. Proc. Symp. on Clean Fuels from Biomass and Wastes. Inst. of Gas Technology, Chicago.

(5) Riley, J. G., 1976. Development of a Small Institutional Heating Plant to Use Forest Residue Fuels. Amer. Soc. Agr. Engrs. Paper No. NA76-101.

(6) Smith, N., 1974. Concepts for Mechanized Production of Wood Fiber. Canadian Agricultural Engineering. 16(1).

(7) ________, and T. Corcoran, 1976. The Energy Analysis of Wood Production for Fuel Applications. Proc. Fuel Div., Amer. Chem. Soc.

(8) Young, H. E., 1974. Biomass, Nutrient Elements, Harvesting and Chipping in the Complete Tree Concept. Journ. Assoc. Consulting Foresters. 19(4).

(9) Young, H. E., 1977. Personal Communication.

Biographies

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