THE ENERGY ANALYSIS OF WOOD PRODUCTION FOR FUEL APPLICATIONS

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Introduction

Wood was the prime fuel source for the United States during much of the 19th century. Consumption probably peaked around 1880 at 146 million cords* per year. Coal replaced wood for most applications. However, use of wood for residential heating continued to be important in some rural areas until after World War II. Residential use of waste wood and sawdust from wood utilizing industries persisted after the use of wood harvested directly for fuel has practically ceased. A number of industries continued to use their waste wood in boilers to produce steam for electricity generation and process heat. However the convenience and low cost of heavy oil fuels caused all but a very small number of operations to cease using their waste wood. The conical incinerator became a common sight at sawmills in the 1960s while wood drying kilns were being fired by oil in another part of the yard.

Salvage of waste wood from sawmills began anew a few years ago when some paper mills began to experience pulpwood shortages. Discarded pieces were chipped and sold for pulping. More recently there has been interest in using bark as boiler fuel partly because of the disposal problem and partly because of increased fuel prices. Since the Arab oil embargo of 1973 serious attention has been given to use of wood as a fuel on a large scale. For example, Szego and Kemp (8) have evaluated the possibility of energy farms on which woody plants would be produced for fuel use. The Maine Office of Energy Resources (9) has analyzed the possibility of methanol production from wood. Huff (4) has reported on the development of an automatically controlled furnace suitable for residences which can burn wood chips made from logging residues or puckerbrush. Smith (7) has examined conceptual designs for mechanized short rotation forestry, particularly the harvesting phase.

Methods of wood harvesting have been revolutionized recently as mechanization has come to forestry. A number of harvesting methods are now in use in which the basic operations of felling, transport to a landing, processing and loading for transport are approached in very different ways. This paper examines the energy inputs to each sub operation to allow estimation of total energy relationships for any complete system whether or not it is currently in use.

*A cord is a volume measure of 128 ft^3 of piled round wood, usually represented as a pile of 4 ft logs, 4 feet high and 8 feet long. Volume scaling is still much used in forestry as many operations are volume rather than weight sensitive. However a cord represents very different weights of dry matter depending on the species of wood. Weight per cord also varies greatly with moisture content. Green wood is around 50% moisture content. Dry matter per cord varies from about 1900 lbs for pine to 3500 lbs for hardwood such as birch and maple.

It should be stressed that for a large portion of U.S. forest lands the only significant operation involved in wood production is that of harvesting. Reforestation is often by natural means, very little fertilization or cultivation is carried out. Construction of a road network and actual harvesting of the trees at the end of the growing cycle is, by far, the greatest purchased energy input to wood production. The energy used in road building varies greatly with terrain and harvesting pattern. It is probably small in relation to other inputs and is neglected in this analysis.

Harvesting Equipment

For many years the axe and bucksaw were the sole means of felling and preparing wood for transport to the users' premises. Primary transport from the stump to the collection point at a roadside or on a riverbank, was by horse or ox team. Production rates for this system varied tremendously depending on size of trees, haul distances, terrain, etc. but it is generally reckonned that one man can fell, delimb, cut up and load one cord of wood per day while one horse will take about two hours to drag out that volume of wood.

Use of gasoline powered chainsaws has increased a worker's capacity about ten fold. Modern saws allow a man to fell, delimb and cut up about 1.3 cords per hour. Use of small tracked vehicles equipped with winches to skid out bunches of tree trunks displaced the horse and ox, but a multitude of new equipment is now displacing these devices.

Short descriptions of the main classes of equipment considered in this study follow:

Chain saw: A portable, gasoline engined, manually controlled machine with a toothed chain used to fell trees and remove limbs.

Feller-Buncher: A mobile machine designed to shear a tree at the stump, and hold it by means of a clamp and cutting head while it swings and deposits the tree onto a pile on the ground. The cutting head is usually composed of two hydraulically actuated shearing blades. Power requirements are from 80 - 130 horsepower.

Delimber Buncher: A mobile machine carrying a unit which strips the limbs and top off the bole of a previously felled tree and deposits the stripped bole in a pile on the ground ready for removal from the stump area to a roadside landing. Usually requires around 120 horsepower.

Wheeled Skidder: A tractor unit, usually with frame steering and four wheel drive, equipped with a winch or grapple which gathers and skids loads of full trees, tree length boles or logs behind itself from the stump area to a roadside landing. Power requirement usually exceeds 70 horsepower.

Wheeled Forwarder: A frame steered, self-loading vehicle equipped with hydraulically operated grapple and loading boom and a carrier or bunk to support its load of logs. Horsepower requirements vary from 40 to 100 horsepower depending on size.

Loader: A hydraulically operated boom and grapple which can be mounted on a truck chassis. It is used to gather logs or tree lengths from a pile and build a load on a truck body.

Chipper: A machine which reduces logs and tree length wood to small chips by means of a rapidly rotating drum or disc, carrying a series of blades. The chips usually leave the cutting device in an air-stream induced by the fan effect of the chipping mechanism and are thus automatically conveyed into transport vehicles or stock-piles.

Power requirements are around 300 horsepower for a machine capable of chipping around 25 tons per hour.

Energetics of Mechanized Harvesting Systems

Table I shows typical production rates and fuel consumption figures for the various pieces of equipment previously described. The writers were fortunate in that the American Pulpwood Association published the results of a 1974 survey of members' operations (1) while this paper was being written. Whenever possible the data from that survey was used in preparing the table. The data sources from which other figures were calculated are indicated in the footnotes. Figures for the energy subsidy represented by the energy used in manufacturing the equipment are very approximate and were derived by assuming an average figure of 25,000 BTU per lb consumed in the manfacturing process (most of the equipment weight is in the form of steel which requires around 21,000 BTU per lb in the transformation from ore in the ground to steel plate (2)). The energy used in manufacture was divided by the approximate lifetime production of the equipment to arrive at a figure of BTU/ton of dry wood.

The approximate energy cost of practically any system of production using present equipment can be calculated from the table. For example, a very common system uses chain saw felling and delimbing, tree length skidding to a forest landing, loading the tree length material onto large trucks for transport to a mill yard, unloading by the same type of loader used in the woods, followed by chipping.

Many operators are now moving toward chipping whole trees in the woods with a fully mechanized system. The steps might be as follows: -Felling with a feller-buncher; grapple skidding to a landing; chipping, with pneumatic conveying into trucks as an integral part of the operation; transport; unloading by tipping the whole truck body backwards to dump the chips by gravity.

Table II illustrates the breakdown of energy use in these two systems, including a 50 mile haul to the utilization site, which appears to be a fair average for much of the U.S.

Several interesting facts appear from the comparison:

1. Both methods, though very different in procedure, have approximately the same unit energy consumption. In fact this is so for most of the mechanized systems for producing wood from the tree trunk. Perhaps this is not surprising as most of the same operations appear in each system though they may be performed in a different order.

2. Transportation, even if only to a user 50 miles from the growing site can represent almost 50% of the total energy input to present the product to the consumer. It may seem that substantial savings could be made by consuming the wood closer to the growth site. However, economics rather than energetics will decide whether this will be done.

3. Reduction of the wood from tree length to the convenient form of wood chips takes only about 20% of the energy used in production. Even though the bulk of the wood is considerably increased by chipping, weight,not volume,remains the limit on load size for transportation. The bonus of self loading from the chipper and easy unloading of chips make in-forest chipping very attractive.

4. Comparing the energy consumption in these systems with the man-axe-horse combination of the past, where about 8 man hours and two horse-power hours produced one cord of wood ready for transport, shows one of the problems of mechanization. If an overall efficiency of 20% is assumed for the animal power units involved, the energy required to prepare the wood for transport to the user would be less than 30,000 BTU per ton of dry material. This compares with about 200,000 BTU/ton for the same operations in mechanized systems. The same order of increase in energy consumption per unit of production can be found in mechanized agriculture (6). However, the comparison of energy use to energy yield is still very favorable. A ton of dry material has a gross energy content of about 16 million BTU. Even allowing for the fact that each ton of dry matter is delivered in the form of green wood containing, for example, 50% moisture, ie with a ton of water to be evaporated per ton of dry material,the net energy available will exceed 14 x 10^6 BTU/ton of dry material.

   On this basis the energy used in processing the wood represents less than 4% of the energy available from the wood.

5. The energy input to wood production in the form of equipment manufacture is fairly small in relation to energy for operating the equipment. Manufacturing energy subsidy is less than 20% of the total energy input per ton of wood for all of the equipment in Table I and averages around 10%.

It would certainly appear that fuel used to manufacture and operate machinery to produce wood for fuel would be energy well used. However it must be remembered that use of wood, as currently harvested, for fuel would compete with other wood uses, such as for paper and lumber. In all probability any large scale use of wood for fuel will need to come from an increase in production over and above current needs.

The most obvious source of additional wood is in the parts of the tree now discarded - the branches and tops, along with undersized and other undesirable trees. This material probably represent around 20% of the growth on land now harvested, i.e. on land which has a road system already developed and paid for by other forest products. The branch material and small trees will probably need to be chipped as early in the harvesting process as possible to reduce bulk and provide an easily handled product.

Two basic methods of handling the branch material are possible. One would be to skid whole trees to the landing, use a delimber in a stationary position and chip anything stripped off the boles. Skidding whole trees would be very little different from skidding delimbed material, but experience has shown that up to half of the branches are broken off as the trees are skidded out. Feeding the stripped branches into a chipper need be no more energy consuming than feeding tree length logs. The second system might use a delimber at the stump and leave the branches and undesirable wood at the growth site. Some work has been reported from Finland (3) on this possibility. Small bulldozers or wheeled loaders were used to pile up the branch material which was then brought out by a skidder/forwarder for processing at the landing or a later stage. Performance figures from this experimental operation are included in Table I.

Table III compares the additional energy inputs needed to obtain these harvesting residues. Once again it is apparent that the wood fuel can be delivered to a consumer for less than 5% of its energy content. The more economical method unfortunately loses a good percentage of the branch material. This leads to the consideration of increasing production of wood specifically for fuel. It is generally accepted that in Northern areas growth to maturity averages about 1 ton of dry matter per acre per year. However Ribe (5) has shown that more than two times the wood present at harvest of a mature stand has grown and died in the competition for sunlight and rotted away during the growth of the stand. This indicates that visiting each site perhaps twice during the growing cycle to remove dead wood and thin too-dense areas could increase total yields of wood by perhaps 100%. Much of the material obtained would probably be "fuel grade". However the economics of such a practice are unknown and the question of what effect removal of such quantities of material might have on the available nutrient pool in the soil is certainly important.

A further possibility for wood fuel production is for intensive short rotation forestry where small trees might be harvested every five or ten years with a mobile mower/chipper laid out similarly to a grain combine. There are distinct engineering economies to this type of machine where each component performs its function the whole time, for example, the mowing mechanism mows continuously and the chipper is continuously loaded. Equipment for full size tree handling operates intermittently e.g. the shear on a feller buncher shears the tree and then is out of use until the tree has been lifted and bunched by the other parts of the machine. Such a machine might be expected to cover one acre per hour for a throughput of about 20 tons of wood.

Fertilization of fast growing species in a short rotation system could produce annual yields of around 5 or 6 tons of dry matter. The use of species which would grow up from existing root systems could provide very fast regeneration after harvest, though wood from such species might be of too low quality for use other than as fuel. Replanting might be necessary only after four or five harvesting cycles - perhaps only every 20 years. Assumptions and energy cost estimates for such a system are given in Table IV.

The intensified production, as in agriculture, results in a greater energy cost per unit of production, with approximately half the energy input accounted for by fertilizer. Omission of the fertilizer would probably reduce the annual yield to around 2-3 tons per acre, but would bring the energy cost per unit in line with long rotation systems. It is interesting to speculate what might be done to fertilize intensive energy farms with garbage and sewage sludge. Actual field experiments would be well worthwhile. However, even with full fertilization, wood fuel from short rotation systems can probably be produced at an energy cost not exceeding 7% of its energy content.

In summary it can be said that the energetics of wood fuel are very attractive. The fuel itself has many desirable qualities - it contains practically no sulphur, only about 1% ash, can be burned cleanly, is reasonably compact (about 100,000 BTU/ft^3 in chip form) and represents a renewable energy source. Nevertheless economics will decide the acceptability of wood fuel. A material as versatile as wood will be competed for by many different uses.

REFERENCES

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TABLE I

APPROXIMATE ENERGY USE IN WOOD PRODUCTION OPERATIONS

A. Energy Subsidy due to Equipment Manufacture

Machine Type or Operation	Typical Machine Weight (lb)	Production Rate	Life	Manufacturing Energy Subsidy (BTU/ton dry wood)[b]
Felling:				
Chain saw: (Felling and delimbing)	10	2.6 cords/hr [c]	2,000 hrs	32.0
Feller-Buncher	52,000	8.38 cords/hr[c]	10,000 hrs[d]	10,350
Delimbing:				
Limber Buncher	45,000	9 cords/hr[e]	10,000 hrs[d]	8,350
Trans. to Landing:				
Wheeled Skidder				
whole trees	25,000	3.08 cords/hr	13,000 hrs[d]	10,400
Forwarder				
residues	27,000	9.2 green/tons[f]	13,000 hrs[d]	11,300
Wheel loader:				
prebunch residues	4,000	4.5 green/tons[f] hr	13,000 hrs[d]	3,400
Yard Operations				
Chain saw:				
Bucking to short lengths	10	3.65 cords/hr[c]	2,000 hrs	23.0
Loading:				
tree length	25,000	10.78 cords/hr[c]	10,000 hrs	3,900
Trucking:				
small truck	12,000		300,000 mi[d]	6,700[i]
large truck	25,000		500,000 mi[d]	3,300[j]
Chipping				
whole tree chipper	57,000	10 cords/hr	10,000 hrs[d]	9,500
Auxiliary				
management vehicles etc.	4,000		100,000 mi	1,000[k]

a. Assumes 25,000 BTU/lb consumed in equipment manufacture.
b. Assumes 3,000 lb dry wood per average cord.
c. Source - "Fuel Requirements for Harvesting Pulpwood" - APA Survey
d. Source - Estimate of Woodlands Manager.
e. Source - Average of two company operations.
f. Source - Folia Forestalia 237 - Finnish Forest Institute
g. Estimate based on engine size and research reports.
h. Average figures for 100 mile round trip.
i. 10 cord loads, handles 45,000 tons in useful life
j. 25 cords, loads handles 187,500 tons during useful life.
k. Assumes 1 vehicle per fully mechanized harvesting crew.

TABLE I

APPROXIMATE ENERGY USE IN WOOD PRODUCTION OPERATIONS

B. Equipment Operation and Overall Energy Requirements

Machine Type or Operation	Fuel Consumption	Energy Use[b] (BTU ton dry) wood	Total Energy Requirements (BTU/ton dry wood) to nearest 1000 BTU
Felling:			
Chain saw: (felling and delimbing)	0.41 gal/cord[c]	33,000	33,000
Feller-Buncher	0.64 gals/cd[c]	59,700	70,000
Delimbing:			
Limber Buncher	0.62 gals/cd[d]	57,900	66,000
Trans. to Landing			
Wheeled Skidder			
whole trees	0.95 gals/cd	88,500	99,000
Forwarder			
residues	0.41 gals/green ton[g]	115,00	126,000
Wheel loader:			
prebunch residues	0.24 gals/green ton[g]	67,200	71,000
Yard Operations			
Chain saw:			
Bucking to short lengths	0.39 gals/cd[c]	31,200	31,000
Loading:			
tree length	0.47 gals/cd[c]	43,500	47,000
Trucking:			
small truck	.04 gals/cd mi[c]	373,000	380,000
large truck	.02 gals/cd mi[c]	187,000	190,000
Chipping			
whole tree chipper	.7 gals/cord[d]	65,500	75,000
Auxiliary			
management vehicles etc.	0.72 gals/cd	57,600	59,000

a. Assumes 25,000 BTU/lb consumed in equipment manufacture.
b. Assumes 3,000 lb dry wood per average cord.
c. Source - "Fuel Requirements for Harvesting Pulpwood" - APA Survey.
d. Source - Estimate of Woodlands Manager.
e. Source - Average of two company operations.
f. Source - Folia Forestalia 237 - Finnish Forest Insitute.
g. Estimate based on engine size and research reports.
h. Average figures for 100 mile round trip.
i. 10 cord loads, handles 45,000 tons in useful life.
j. 25 cords, loads handles 187,500 tons during useful life.
k. Assumes 1 vehicle per fully mechanized harvesting crew.

TABLE II

ENERGY USE IN TWO WOOD PRODUCTION SYSTEMS

(a) Tree length System	BTU/Ton dry wood
Felling and Delimbing (Chain saw)	33,000
Skidding	99,000
Loading (tree length)	47,000
Transport (50 miles one way)	190,000
Unloading	47,000
Chipping	75,000
Auxiliary	59,000
Total	550,000

(b) Whole tree chip system	
Felling and Bunching	70,000
Skidding	99,000
Chipping	75,000
Transport	190,000
Unload	negligible
Auxiliary	59,000
Total	493,000

TABLE III

ENERGY USE IN HARVESTING FOREST RESIDUES FOR FUEL

(a) Whole trees skidded, delimbed at landing		BTU/ton dry wood
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

TABLE IV

PROBABLE ENERGY REQUIREMENTS FOR A SHORT ROTATION WOOD FUEL CROP

Assumptions

Cultivate and plant at 20 year intervals - 6 gallons fuel/acre/planting
Growth rate - 5 tons/acre/year
Fertilizer - 200 lb nitrogen/acre/year @ 13,000 BTU/lb mfg. and application cost
Harvesting - equivalent to present chipping in energy cost
Transport to truck or stockpile - equivalent to skidding
Loading trucks from stock pile or primary transport - equivalent to tree length loading

Energy Use Estimates		BTU/ton dry wood
Cultivation and Planting		8,000
Fertilization		520,000
Harvesting		75,000
Transport to stockpile		99,000
Load trucks		47,000
Transport to User		190,000
Unload		negligible
Auxiliary operations		59,000
	Total	998,000