WOOD AS A SUPPLEMENTAL FUEL FOR STEAM GENERATION

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ABSTRACT

The central steam plant at the Lawrence campus of The University of Kansas is fired with natural gas and oil. A new plant is needed to burn fuels other than those presently being used. One alternative is urban solid waste procured from the immediate area surrounding Lawrence, plus wood to supplement the refuse. In 1976, a 4 year study was begun to identify wood-supply alternatives such as residues from local forest industries, urban waste-wood trimmings, thinnings from nearby woodlands, and biomass plantations specifically managed as an "Energy forest". Early evaluations indicate three of the four alternatives appear to be feasible sources of wood for the Lawrence steam plant.

This is an interim report which summarizes the findings of the first three years of a four year study.

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WOOD AS A SUPPLEMENTAL FUEL TO GENERATE STEAM 1/

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Background

Wood for energy not only may help alleviate the nation's energy crisis, but also may provide practicing foresters with a new and highly marketable forest product. In a few years, harvesting "energy" wood may be as common as harvesting corn.

Burning wood as a fuel peaked in the United States about a century ago, when it provided 3 of the 4 qualdrillion BTUs of energy consumed annually by the nation. Today, annual energy consumption has risen to 75 quads, but the contribution of wood has decreased to 1.1 quads.

A few technological events contributed to the reduced use of wood. In this country, the discovery of vast coal and oil deposits was the beginning of a major switch from wood to the more convenient fossil fuels. Later, regulation of the price of natural gas induced many industries to switch to this cheap, clean, and highly efficient fuel. Still later, air-quality regulations accelerated the switch from high-sulfur coal to oil and gas.

These events were accompanied by sociological changes. We became a highly mobile society, dependent upon petroleum-fired individual transportation systems. We became affluent and, in our affluence, we demanded a higher standard of living and more leisure time. Wood, as a source of home heat, was quickly replaced by the oil and gas-fired central heating systems when we discovered the convenience of turning the dial on the thermostat as opposed to carrying in an armload of wood. Almost simultaneously, wood as a fuel was replaced by wood as an aesthetic device; millions of our homes were outfitted with outrageously inefficient fireplaces so that we might pacify our prehistoric fascination for watching a blazing fire.

The Study

In 1976, a project team of foresters from Kansas State University and engineers from the University of Kansas began to examine the feasibility of using wood fuels to provide "top-off" for a proposed solid waste-fired generating plant on the University of Kansas campus.

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A preliminary investigation by the School of Engineering at the University of Kansas had established that: (1) Technology existed to construct a solid waste-fired generating facility, (2) the existing generating plant was becoming obsolete and needed to be replaced; and (3) there was available, within an economical hauling distance, almost enough solid waste to provide the fuel needed to operate a new plant.

From the preliminary investigation, it was found that, during the three coldest months of winter, there would be a potential 15% shortage in BTUs of fuel from the solid waste available. Because the nominal heat yield from solid waste is low (4,500 BTU/lb), using coal (at 11,000 BTU/lb) in the fuel mixture would create technical problems. But wood (averaging 6,000 BTU/lb, as fired) is compatible for combustion in systems designed primarily to use solid waste. (Thus, we decided to test the feasibility of wood as a "top-off" fuel.)

The engineering investigation showed that the fuel "deficit" from solid waste alone would range from about 32 billion BTUs in a mild winter to 79 billion BTUs in a severe winter. Translated into tons, that represents a range of from 2,700 tons to 6,600 tons of air-dried wood (20% moisture content) per year.

Meanwhile, the desirability of making the new power plant basically a coal-fired unit had been investigated. The initial cost of a coal-fired plant would be lower than that of a wood-fired unit, but high fuel costs would rapidly offset any savings. Likewise, the problems of meeting rigid air-pollution control standards would greatly complicate a coal-fired system.

Here we are reporting on findings during three years of a 4-year project. The project was divided into three areas of investigation:

1. Supply analysis, to evaluate existing sources of waste wood suitable for fuel and to determine production problems.
2. Plantation tests, to evaluate the production potential from trees grown specifically for fuel purposes.
3. Economic analysis, to determine net cost per million BTU by source of supply.

Our final report is due in September 1979, and the power plant is scheduled to be operating in the fall of 1981. This project was funded by two special grants from the Ozarks Regional Commission (total, $106,137.00) and matching funds from the University of Kansas ($32,170.00) and Kansas State University ($29,437.00), for a grand total for the 4 years of $167,794.00.

Engineering Considerations

The price and the unreliable supply of fuel oil and natural gas have caused serious problems for operating institutional heating systems. Likewise, the capital costs of solar heating systems and the safety restrictions on nuclear fuels have substantially narrowed the options available.

Currently coal is looked upon as the savior of the energy crisis for many situations in which large amounts of fuel are consumed at centralized points to produce industrial power, institutional heat, and energy for other purposes. But coal has problems too, as evidenced by the 1977 coal miners' strike, which approached disastrous proportions. In the future, it might be feasible for a university, state prison, hospital, or other public institution to manage forests for the production of fuel wood; it is less likely that those organizations would be able to operate their own coal mines.

Coal is not just coal -- extremely important variations in heat yield, sulphur content, and foreign material must be taken into account. For example, "western" coal from Wyoming and Montana is generally either sub-bituminous or lignite grade. Although classified as "low sulphur" and thus more readily adapted to current air-pollution control standards, the run-of-the-mine yield is only 6,000 or 7,000 BTUs per pound (less than dry wood). This coal is also high in foreign material, leading one observer to call it "good, burnable dirt."

Coal from the Western Interior Province of the U.S. is predominantly bituminous grade and is classified as high sulphur. Although it yields better (10,000 - 11,000 BTU/lb.), it is "dirty" from the standpoint of air pollution control standards and plants using it require elaborate stack scrubbers to prevent sulphites from entering the atmosphere.

If we should design a plant for use of anthracite or bituminous coal, we would get high efficiency in energy, many air pollution but few transportation problems, great sensitivity to labor strikes; and we could get by with the little yard storage. Plants designed to use sub bituminous or lignite coal would give us the reverse considerations.

Buring urban solid waste presents some particular problems. The available supply of trash tends to peak in late spring, when demand for fuel is the lowest. Conversely, people apparently don't throw away as much trash in the dead of winter, when the demand for fuel is the greatest.

Although the average daily availability of solid waste in the vicinity of the KU power plant is 200 tons, the amount varies as much as 10% seasonally. Thus, availability must be considered simultaneously with the problem of stockpiling surpluses. Coal, wood, and oil are relatively easy to stockpile in times of surplus supply for later use during periods of peak demand. Stockpiling garbage is more difficult.

The plan concept is that a storage silo capable of accommodating about 1,500 tons of solid waste (7-day supply) will be constructed so that is can be loaded from the top and unloaded from the bottom. Thus, theoretically none of the solid waste will "cure" for more than 7 days as it is cycled through.

Separating waste and preparing it for firing are also critical considerations. The cost of separating waste before it is burned can only be justified when (1) there is a market for reclaimed noncombustibles or (2) the cost of over-designing the system to accept straight-run waste is prohibitive, compared with the cost of front-end separation. Our plans at present call for straight-run feeding of the waste fuel, through a shredding device, directly to the combustion chamber.

The potential heat yield of straight-run waste is 4,500 BTU/lb., which is closely compatible with the 6,000 BTU/lb. for field dried wood (20% moisture content, O.D. Basis). That simplifies the designing of a combustion chamber at acceptable levels of efficiency for mixed fuels.

To facilitate even and efficient combustion and fuel mixing, all wood material should be shredded, hogged, or chipped to a nominal standard 2-inch cube to make it compatible with the system.

Findings

Fuel from native forests: Initially we assumed that the 115,000 acres of native forest within the adjacent three-county area would be an important potential source of fuel for the power plant. Most of this acreage contains substantial volumes of unused dead, low-grade timber (more than 700,000 tons by our estimate) that is surplus to the needs of the forest. Indeed, the systematic removal of this surplus material could enhance the economic productivity and value of this forest land. Timber-harvesting practices during the past three decades generally have been done on low-utilization standards; that has left large volumes of tops, limbs, and low-grade logs in the woods to rot.

The recent energy crisis, coupled with the threat of fuel shortages and rapidly rising fuel costs for home heating, has created an upsurge in the market demand for fireplace wood. Because they are close to the Kansas City metropolitan area, these natural forest stands are a source of wood for the area's household market. Competitive pressures for the available supply are magnified by the high unit price being received for this wood -- $60.00 per delivered cord being approximately the equivalent of $2.50 per MCF of natural gas. In that currently natural gas used by the KU power plant costs about $1.40 per MCF, it would not be economical to obtain fuel from natural forest stands for the plant's "top-off" requirements. But if the price of natural gas were to be de-regulated, this source of wood fuel would then be marginally equivalent in price to that natural gas.

The break-even cost for wood compared to natural gas, delivered to the plant, is $16.80 per ton (ready to burn). The cost of chipping or hogging the wood is calculated currently at $7.14 per ton; that gives a break-even price of $16.80 - $7.14 = $9.66 per ton, FOB the plant (approximately $20.00 per cord).

Industrial waste wood: The two major sources of industrial waste wood in the Lawrence area are sawmills and wood finishers, where already market value of some waste products is low, mostly "giveaway." The accumulation of waste at wood-manufacturing plants of all echelons is a fire hazard as well as a disposal-cost problem. The fuel quality from the two sources (sawmills and wood finishers) is distinctly different. Sawmill waste tends to have a high percentage of bark; commonly is high in grit, dirt, and similar foreign material; and usually is high in moisture content (40% - 60%), so that it yields a low heat per pound. Waste from wood finishers' manufacturing processes generally is smaller in dimension, is relatively free of foreign material, and is typically high in unit heat yield (up to 8,000 BTU/lb) because it has been kiln-dried to 6% moisture content prior to processing for the finished product.

By the end of 1977, we had located within a reasonable hauling distance of the KU plant, two cabinet manufacturers and one sawmill from which annually 73 billion BTU of waste wood would be available for the cost of loading and hauling.

Delivering this fuel to the plant (using $1.00 per loaded mile, 20 tons per load, $3.50 per ton loading cost) would cost $57,100.00 annually (at 78.3 cents/million BTU). Compared with natural gas (at $1.40 per MCF), this waste wood fuel is currently available at a savings of 44%.

It must be emphasized, however, that because disposing of surplus waste currently is a problem for these wood operators, they are actively seeking market outlets for this material. At any time markets may open up and create demand competition--and thus price increases. Transportation costs are also increasing, but at a rate nearly parallel to the increase in natural gas prices.

Urban waste wood: Since Dutch elem disease became common in northeastern Kansas in the mid-1960's, huge numbers of shade trees have died and have created problems of safety, removal, and disposal. Costs borne by homeowners and city governments for removing and disposing of the dead trees have been correspondingly high. Disposal of the material has been further complicated by air pollution control regulations, which prohibit the open burning of large volumes of waste. The alternative used in most cases is either to stockpile the material or to bury it. Neither solution is efficient in terms of utilization of landfill sites, and disposal costs are high.

Because currently most shade-tree waste is being disposed of at landfill sites, we surveyed three sites to determine the potential fuel volume. Within a 35-mile radius of the new plant, we found disposal potential to be 114 billion BTU annually (1976 and 1977 data averaged).

This "fuel" would be available at $1.11/million BTU, based on the following assumptions:

1. Yield in heat is 5,500 BTU/lb (average field condition)
2. Chipping costs $7.14/ton; loading, $3.50/ton.
3. Hauling by twenty ton trucks costs $1.00/loaded mile.

After surveying current availability of shade-tree waste, we made an inventory of street-side trees in Topeka to determine age, species distribution, condition, and rate of mortality. If all 1976-77 street-tree removals from Topeka had been available to the KU power plant, that single source could have supplied 134% of the estimated requirement for supplemental wood fuel.

The trend in species composition, age, and condition of the Topeka shade trees indicates that there will be a significant reduction in the rate of tree removals through 1985, by which time the crisis induced by Dutch elm disease should be neutralized; at that time removals should reach a reasonable constant 30 billion BTU per year -- a 325% decrease in 7 years. We anticipate that the annual removals through the remainder of this century will range from 25 to 30 billion BTU.

Topeka's shade trees provide an excellent short-term source of fuel wood at reasonable cost. But 1985 the decline in supply and the inevitable increase in competing markets for this material will make it unlikely that more than 25% of the "top-off" demand can be obtained there.

It should be pointed out that at the present it costs an estimated $1.50/ton to dispose of tree waste at the Shawnee County (Topeka) landfill, whereas the estimated cost of hauling this material to Lawrence for fuel purposes would be $1.75/ton. If the savings of $1.50 per ton could be claimed against the fuel cost, that would yield a net savings of 13 cents per million BTU, giving a cost at the KU power plant of $.99 per million BTU. Although a savings would occur, it might not be realized by the power plant; it would more likely be passed back to the residents of Topeka.

Railroad ties: Another possibility for fuel from industrial waste is old rail ties. Both the Santa Fe and the Union Pacific railroads have active tie-replacement programs. The Union Pacific has 150 miles of trackage between Kansas City and Topeka; on that section, about 30,000 ties are replaced per year. Old ties, made of hardwood and creosote treated, have a heat value of 10,000 BTU/lb (equivalent to that of soft coal). This source of fuel would yield 80 billion BTU/year. Currently ties are cut into three pieces when removed and are stacked and burned on the right-of-way. Officials of both railroads have indicated they would be glad to give us the old ties; but we haven't yet devised an efficient means of collecting and hauling them.

Impact on the Lawrence landfill: If the solid waste-fired steam plant goes into operation, slag and furnace residue will require disposal. Preliminary information indicates that it would not be profitable to recover ferrous metals for recycling because of the small quantities involved.

Hauling the residue to the Lawrence landfill site (the one nearest the University) would reduce the annual requirement for space there by 80%. Thus, the landfill would require only three acres per year instead of the present fifteen.

Other proportionate cost savings would be realized by the City--a net annual savings of $45,521.00, according to a recent estimate by the Director of Public Works. His report also shows an item of $20,720.00 annually for "landfill receipts" paid to the city by the public for dumping privileges. Although that amount would be debited against the gross savings to the city, it would represent a savings to the public, bringing the total "theoretical" savings to the people of Lawrence to $66,241.00 annually.

What would actually happen to this "money saved" is academic--it would be available to be spent by the people for other goods and services through either the public or the private sector. This sum, for example, would be adequate to pay the land rent for more than 700 acres of land of the quality owned by the City along the Kaw River north of Lawrence--more than the estimated 500 acres of energy forest plantations needed to "top-off" the solid-waste power plant.

There would be, of course, other trade-offs, many not immediately evident . For example, the long-range plans of the City call for constructing a public park on the landfill site after it has been filled. An 80% reduction in the rate of filling would postpone the building of the park by several years.

A large share of the savings--$37,414.00--would be for salaries of three landfill employees, who--assuming changing and growing city work force--probably could be internally transferred to other work. For example, one equipment operator for the landfill would still be needed on a 20% basis.

With all material incinerated before being taken to the landfill, there would be no need to cover the residue to control rodents, fire, blowing paper, or offensive odors.

Fuelwood plantations: Although in this study we concentrated initially on the availability, cost, and quality of wood wastes for fuel, a collateral part of the project has been evaluating specialized forest plantations for direct production of fuel. By doing that, we have one of the first operational tests of the "silvicultural biomass farm" in the United States.

A major problem in converting waste to usable products is that marketing ingenuity and technology rapidly develop to create a price structure on the basis of the economic utility of the product. Thus, even though costs of waste wood materials might be zero or even negative initially, that situation will change. In some cases, the developing price structure is strictly opportunistic; in others, it is the result of bona fide creation of new demand as technology develops to "prove" the economic value of the product (waste wood in this case). Plantations operated by the University of Kansas to supply wood fuel for the power plant would be kept effectively free of competitive markets; but all other sources now available would be subject to competitive pricing in the market at some future time.

The most urgent problem regarding plantation fuelwood production is to find a management system that would insure the production of enough fuel at or below the break-even cost of alternative fuels. Selecting the "best" management system involves manipulating such variables as species selection, trees per acre, cultural practices, timing of harvest, method of harvest, land cost, and cost of alternative fuels.

Experimental tree plantings have been established on fifteen acres: six different species were planted on four different soils and at eight different spacings. About half the trees were planted in the spring of 1976, the remainder, in the spring of 1977.

Survival, growth, and development have been excellent in most cases. We initially selected cottonwood, silver maple, European alder, Siberian elm, and black locust for testing. At the end of the 1976 growing season, we discontinued consideration of the alder because of its poor survival rate. In 1977 we added catalpa to the tests.

Each species of tree has a different biological potential; fast-growing trees usually have low wood density and thus yield less fuel per cubic foot than so slow-growing trees. Likewise, some species perform better on one soil than on another. In terms of costs, however, all trees are about equal in price per seedling, cost for planting, and cost of cultivation and management.

Initial data in 1977 indicated that cottonwood (at 199,000 BTU per cubic foot) and black locust (at 354,000 BTU per cubic foot) were the most likely species to produce substantial quantities of fuel economically. These species have remarkably different heat values, but because of natural differences in growth patterns, they could yield about the same quantities of fuel (BTU) per acre under intensive management.

By 1978, however, black locust had substantially out-produced cottonwood, and productions of the silver maple nearly equalled that of the cottonwood. It is still premature to make further conclusions (Figure 1).

To analyze plantation-management alternatives, we developed a systems matrix that uses information assimilated from published research reports (Ek and Dawson, 1976) but it is not specific to our experience and growing conditions. It therefore can be used only as a directional guide at this time.

As soon as our plantations have developed adequately to show their actual growth patterns (4 years), we shall use the matrix to present measured field data in a decision format.

Silviculturally speaking, our challenge is to (1) select the best species by site for rapid juvenile growth; (2) determine the best spacing for desired tree size, vigor, and biomass yield; (3) establish plantations; (4) develop practical weed-control techniques," (5) select the best rotation age; and (6) reproduce the stand with many fast-growing, healthy coppice cycles. We then must select the treatments and techniques that will give us the least cost per million BTU.

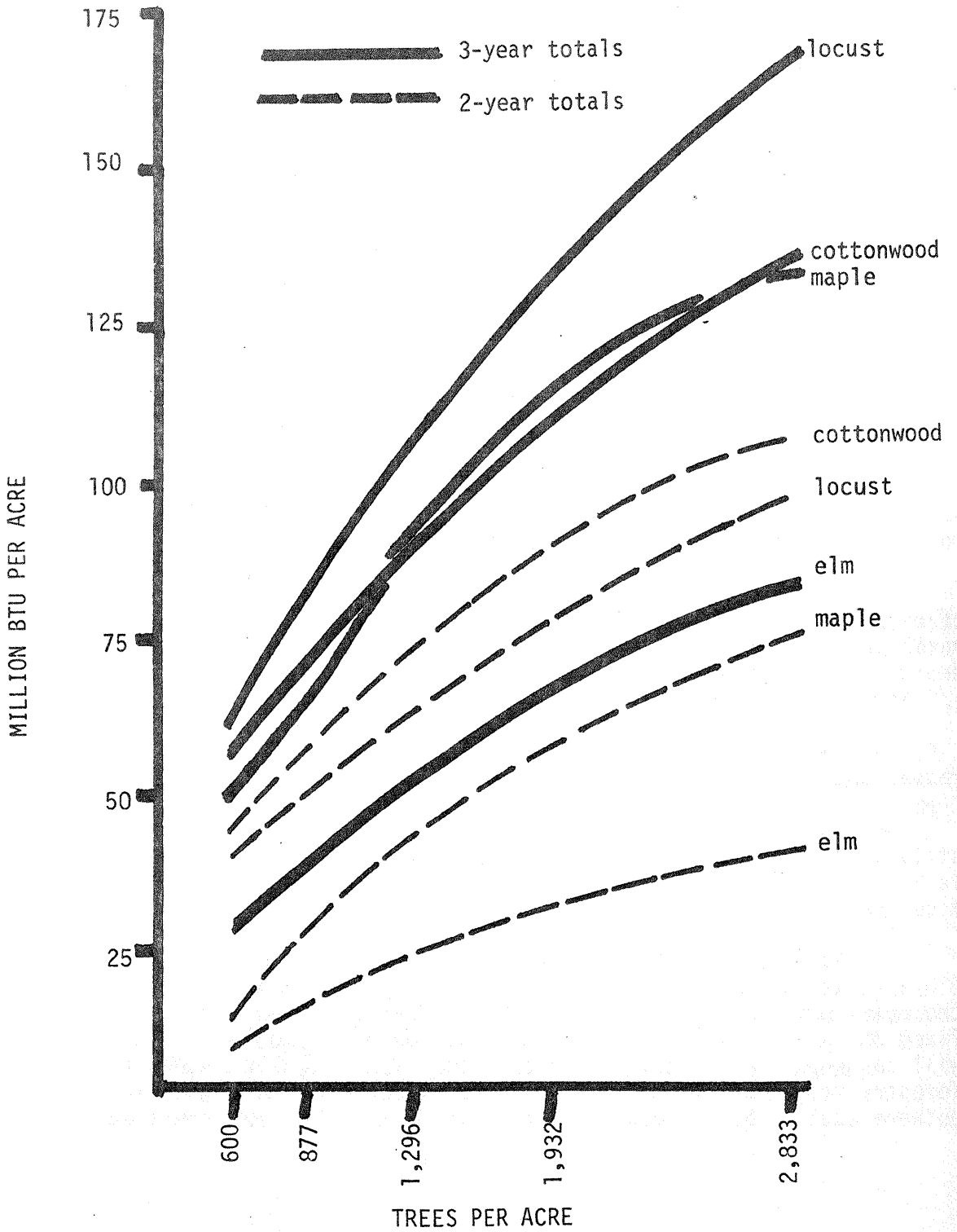

FIGURE 1. Forest Plantation Biomass - 3 sites averaged.

We had four sites available for testing, two prairie and two bottonland:

Site no.	Soil type	Description
1	silt loam	bluegrass prairie, shallow (8-10"), 5-8% slope, pH 5.6, N=17ppm, P=22#/Ac, K=427#/Ac.
2	silt loam	bluegrass priarie, shallow (10-16"), 3-5% slope, pH 5.6, N=15ppm, P=8#/Ac, K=378#/Ac.
3	sandy loam	river bottom, deep (40"+), flat, pH 7.5, N=6ppm, P=79#/Ac, K=342#/Ac.
4	silty clay loam	river bottom, deep (40"+), flat, pH 7.6, N=10ppm, P=176#/Ac, K=552#/Ac.

We expected tree growth to be the best on Site 4, with the richest soil; and to be the least on Site 1, with the poorest soil.

After 3 years of growth, trees in the test plots did not conform to our expectations---and perhaps never would in a "short rotation" system. The "best" soil so far has proved to be the most difficult to handle in terms of weed control, and to date the growth of trees has been poorest on that site. The traditional concept of site quality used by foresters may need some new interpretations for "short rotation" forestry. That needs to be continually evaluated.

To test the spacing variable--perhaps the most critical in terms of cost control and site efficiency--we used a modification of Nelder's variable plot design: a circular plot in a "cartwheel" design. Our design has 30 "spokes," seven trees per spoke, and covers approximately 1/5 acre. There is one wheel for each species at each site.

We can approximate five different test specings using average radial and chord distances and excluding trees No. 1 and 7 as buffers.

At the end of the second growing season, trees on all plots were still expressing accelerated growth characteristics, but by the third year cottonwood was decelerating while the others were continuing to accelerate some.

Our target for harvesting is to get as close to 400 million BTU/acre as possible. We expect that to be a good compromise between the optimum <u>time</u> between cuts and the optimum <u>yield</u> per cut. Because fixed costs of harvesting are expected to be high, harvesting too soon will cause excessive costs per BTU. Time is always a big expense in forestry programs; so realistically, we expect seven or eight years between cuts to be the maximum time that we can consider economical.

In a preliminary analysis, using data from Ek and Dawson (1976), we calculated that theoretically yields of cottonwood trees at age 6 would produce 72 billion BTU per year for the campus power plant (Table 1). These theoretical data will be recalculated from empirical information for all test species at the end of the trees' fourth growing season.

If we now know that the expected production cost of cottonwood trees is 60 cents/million BTU (8x8 spacing at 6 years), then (for cottonwood) we can predict a delivered cost of fuel at $1.12, based on previous calculations of 52¢ for expected harvesting, chipping, and hauling costs. That would be only 80% of the cost of natural gas at the existing power plant!

We hasten to point out that these costs have not yet been confirmed in practice, but we are inching our way toward doing that. It is also important to point out that the species used affects the cost per BTU in hauling, because of inherent variations in the potential yield of a cubic foot of fresh wood. For example:

	BTU/green cu. ft.	Load and haul cost/million BTU
Cottonwood	199,000	52 cents
Catalpa	204,000	50 cents
Silver maple	236,000	44 cents
Siberian elm	247,000	42 cents
Black locust	354,000	30 cents

The variations are due to the bulkiness of the cargo and the limitation on the standard gondola trailer at 800 cubic feet per load. Exceeding weight limitations on chip vans is not so likely as is exceeding overall dimension restrictions for highway vehicles. Another way of looking at the problem is that the high water content in fresh cottonwood and its low specific gravity make it more expensive to haul than other trees. It is less efficient to harvest, chip, and haul cottonwood in separate operations (to allow for some air drying of the chips prior to transport) than to haul green chips because the added handling costs would exceed the savings on short hauls (under 60-80 miles).

Final note

Because this is an active project, many unsolved problems remain. At every turn we uncover in the concept new complexities, many of which must be resolved before a management plan can be completed.

TABLE 1 - Theoretical Variation of Cottonwood Fuelwood Plantations at Age 6

Tree spacing	Yield million BTU/Ac.	Establishment cost per ac.	Production cost/MM BTU	Acres of plantation required for 72 billion BTU/year	Initial capital investment
1x1	610	5,700	$14.00	700	$6,050,000
2x2	510	1,500	4.50	850	1,900,000
4x4	505	450	1.30	850	570,000
8x8	375	150	.60	1,150	260,000
12x12	215	100	.65	2,000	270,000

If waste wood is to be used, the dynamics of supply/demand will establish a price structure that must be considered in the planning process.

If plantation biomass is to be used for fuel, the following considerations are important:

1.) Trees are more suitable as fuel than nonwoody biomass because of their "storability" on the stump and the slower rate of deterioration of wood chips in storage.

2.) Species selection should be geared toward those that coppice readily and grow rapidly in the juvenile stages -- "weedy," early succession species.

3.) We must think in terms of "high" plant populations - 1,000 to 2,000 trees per acre.

4.) Harvesting should be done during the dormant season -- to allow the nutrient capital in leaves to remain on the site and to insure maximum food reserves in the root systems for rapid coppice recovery.

5.) Where seedling costs are high and/or supplies are limited, consideration should be given to direct seeding for plantation establishment.

6.) Mechanized harvesting is essential for cost control; apparently direct chipping in the field is cheaper than hauling total trees to an off-site facility.

7.) Chipping at time of harvest diversifies the use of the biomass for other potential markets, such as for pulp fibre and livestock feed (especially cottonwood) in addition to fuel.

8.) Thorough weed control during the first and second year is essential to rapid biomass production. The plantation should attain maximum potential solar interception by the third year.

9.) The "target" yield for economical harvesting of biomass is about 400 million BTU per acre. In the case reported here, the first harvest will be when the plantation trees are 7 or 8 years old. In the later cycles, we can expect to take coppice material every 5 or 6 years.

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