12 Oct 1978

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Abstract

The University of Kansas at Lawrence uses natural gas and oil to generate steam for heating and other campus needs. The projected price increase of these fuels has led to a study of burning solid waste and wood. This study discusses the technical and economic considerations of burning wood. Topics included are sources and availability, collection and transportation, preparation and burning, and environmental effects. It is concluded that sufficient wood is available; truck transport is the only feasible option; drying some wood is desirable; and that the burning can be done separately or directly with the solid waste.

1. INTRODUCTION

The University of Kansas at Lawrence operates a gas fired central steam system which supplies steam to heat 3.7 x 10^6 square feet of University buildings, cool 1.2 x 10^6 square feet of University buildings and supply steam for hot water service, cooking, laboratories and similar uses. Total average consumption for the system is approximately 390 x 10^6 pounds per year requiring a heat input of 500 to 600 billion BTUs per year.

The present cost of natural gas is $1.36 per 1000 SCFM or million BTUs. The gas is supplied at this price on a four hour notice for service interruption basis. When gas is not available the system is switched to oil which presently costs $0.35 per gallon or $2.36 per million BTUs. With this gas price there is little incentive to change to another fuel. Unfortunately this price is certainly going to increase by the year 2000. Obviously the price of natural gas and other fuels is the subject of much interest and speculation. The values shown in Figure 1, as compiled by Stone and Webster (1), are representative of the values forecast by various organizations. In addition to cost considerations, it is possible that natural gas and oil may become unavailable either from a lack of supply or by legislation which limits their use.

Given these considerations, there is clear incentive to look for alternate sources of energy. The sources for which commercial technology exist are burning coal, municipal solid waste and wood. Using the data in Figure 1 and projected steam demands, the cost of coal would exceed $2 x 10^6 by 1990 and would be approximately $4 x 10^6 by the year 2000. This fact alone makes solid waste a desirable alternative without even considering the cost of building a complete coal handling facility.

2. BURNING SOLID WASTE

Solid waste is readily available by diverting it from the Douglas County landfill. Unfortunately the quantity available is insufficient to meet the steam demand, as shown in Figure 2. The second problem, which becomes apparent from Figure 2, is the waste generation cycle and the steam demand cycle are out of phase with each other. An obvious alternative is to import solid waste from a nearby area such as Topeka or the greater Kansas City area. Investigation into this possibility indicates that several problems exist. First the distance involved neccessitates the use of packer trucks capable of holding approximately 20 tons of waste. Use of these trucks requires either the construction of a transfer station or the use of an existing facility. The quantities involved in this project make the construction of a new facility prohibitively expensive. The closest existing station is approximately 40 miles from Lawrence. The second problem is the fact that variable contracts for waste are difficult to obtain. It seems at best one would have to agree to take a fixed quantity per day and might be required to take a quantity which reflects the normal seasonal variation. This restriction comes from the fact that men and equipment must be available to move the waste even when not needed. Solid waste in the raw form is not a storable fuel and thus supplementing, even with a fixed quantity per day, to meet the winter demand is going to lead to excessive amounts during the summer. The waste can be processed into a refuse derived fuel (RDF) which is temporarily storable but the processing facility appears to be too expensive to build for the quantities being considered.

An answer for this problem is to use wood as the supplemental fuel. Wood has several advantages: it is locally available; it is easily stored; it has a low sulfur and ash content which make it clean burning. Most importantly - unlike coal - it can be burned in the same boiler as the solid waste.

3. SOURCES OF WOOD

There are three basic sources of wood: scrap from sawmills, cabinet factories and similar operations; urban tree removals; and growing wood in an energy forest.

3.1 SCRAP WOOD

Scrap is a desirable source of wood for at least two reasons. First, much of it is in a form which can be burned as received (chips, sawdust, small pieces). Secondly, the present supply appears to exceed demand; there is question as to how long this situation will last. A survey of sawmills, pallet manufacturers, modular and mobile home builders, and cabinet and furniture shops indicates that many of them have a scrap disposal problem. At the same time some of these operations use the wood scrap for their own heating needs or have found a market, e.g. selling the chips to paper box manufacturers. It seems likely that once the University becomes dependent on these suppliers the scrap will take on a market value. This value probably would not exceed the present value which is in the vicinity of $15 per ton plus loading and shipping.

The majority of scrap wood is available from sawmill operations. A survey of the large mills within 120 miles of Lawrence indicates an availability as shown in Figure 3. This figure also shows the relatively small amount available from manufacturing operations. As would be expected the quantity available is roughly proportional to the square of the distance from Lawrence; note there is a definite break in the supply at about 65 miles.

3.2 URBAN TREE REMOVALS

Urban tree removals are also a desirable source of wood because their cost is nothing or possibly negative, i.e. some communities may be willing to pay to have the waste removed. This advantage is offset by the fact that the urban trees must be chipped. The chipping cost is estimated by Gould (2) to be $7.14 per ton. To facilitate transportation, the chipping would be done at the source of supply.

An estimate of the quantity of wood available from urban trees is included in Figure 3. These quantities are predicted from landfill data and have been corrected for an expected decrease due to better control of Dutch Elm Disease. It seems likely that some privately cut trimmings are being deposited on private land. Presumably, if these cuttings were accepted free of charge they would be delivered and the total supply from the local area for this source could increase, perhaps by as much as 50%. The amount of wood available in the 120 mile radius of Lawrence is sufficient supplemental fuel even if the only source of solid waste is Douglas County. The economics of purchasing and transporting this wood will be examined later in this report.

3.3 ENERGY FOREST

An energy forest is the most costly source of supply. This is reflective of the fact that this wood has the chipping costs of the urban trees plus the costs for land, planting, cultivating, and harvesting.

In order to evaluate the practicality of an energy forest the University of Kansas has entered into a joint project with Kansas State University to plant experimental forest plots at three locations. The main purpose of these experiments are to evaluate yield as a function of tree spacing, species and site location. The preliminary results shown in Figure 4 (3) are reported here to indicate the potential of an energy forest. While the higher concentrations give higher yields in the early growth years the curves tend to level out as the trees mature. Obviously this is a result of interference between trees in the more concentrated areas. It is estimated that a five year growing cycle will produce about 40 green tons per acre of Cottenwood or Black Locust. Thus a yield of 8 ton per acre per year is possible. Assuming a heating value of 5000 BTUs per pound the heat value yield is 80 x 10^6 BTUs per acre per year.

The trees are cloned from existing trees by planting cuttings; the cost is $0.10 per seedling. These seedlings can be planted by automated machinery once the land has been properly prepared. Weed control during the early growth is a serious problem and requires careful attention.

At this time none of the test trees have reached sufficient size to harvest. An investigation into harvesting techniques indicates that mechanized harvesting equipment does exist; however, it seems likely that the investment would be too great for the size forest being considered. The general plan for harvesting would be to enter the rows from one end and cut the trees with a chain saw or hydraulic cutter and stack each tree on the one previously cut. The second step would be to enter the row from the opposite end and feed the trees, cut end first, into a chipper. The chips would be blown into a truck or wagon behind the chipper. This type of operation could be done with a small capital investment. Both the harvesting and planting operations could be done using student help thus providing and added benefit to the University. The trees would be harvested in the fall and winter when the leaves are off the trees; allowing the leaves to compost on the ground maintains the soil nutrient balance.

The total cost of wood from an energy forest is a complex combination of several variables including cutting cycle, tree spacing, tree species and land cost. Using preliminary studies by the Forestry Department, Kansas State University (4) these costs are estimated as follow:

	$/$10^6$BTUs	$/ton
Production costs (includes $18/ac land preparation, $47/ac weed control, $68/ac seedlings, $20/ac planting)	$1.10	$11.00
Harvesting costs ($7.14/ton chipping cost, $2.86/ton cutting)	1.00	10.00
Land cost ($350/ac to be sold at the end of 20 years for the same price and a 6.8% interest rate)	.61	6.10
Total Cost	$2.76	$27.60

4. COLLECTION AND TRANSPORTATION

Any consideration of the problem of transporting wood to the proposed plant quickly leads to the conclusion that trucks are the only feasible means of transportation. The plant site is approximately five miles from the nearest rail line. The quantity of materials and the distances involved preclude consideration of building a rail link.

It also quickly becomes apparent that handling costs are large compared to the hauling costs for the distances involved. For example, typical loading costs are $2.00 per ton, typical hauling costs are $0.05 per ton per mile (2); the loading cost is equal to 40 miles of hauling costs. From this consideration it is almost mandatory that the wood be loaded once and delivered without rehandling.

If the wood is not in small pieces prior to shipping it will be best to chip it prior to shipping. Chipped material is more easily loaded and will better utilize the weight and volume limitations of the trucks. These advantages appear to offset the probable higher costs of operating a mobile chipper.

Using typical transportation and chipping costs (2) it is possible to summarize costs for fuel delivered to the plant, in dollars per ton; as follow:

Type of Cost	Wood Source		
	Scrap	Urban trees	Energy forest
Payment to the supplier	5.00	0.00	21.00
Chipping	3.57	7.14	7.14
Loading	2.00	2.00	2.00
Hauling an average distance @ $0.05 per ton per mile	2.50	1.25	1.00
Totals	$13.07	10.39	31.14

The $5.00 payment to supplier for scrap is based on present prices for chips used for paper making, present supply exceeding demand and the fact that scrap for combustion can include saw dust and bark. The chipping cost for scrap is based on chipping one half of the scrap, i. e. the large pieces. It seems possible that the payment for scrap may become dependent on the differential between chipping costs for scrap and urban trees.

5. PREPARATION AND COMBUSTION

The handling of the wood once it arrives at the plant falls into three categories, chipping, drying and storing.

5.1 CHIPPING

As indicated much of the wood will be chipped prior to arrival, some however will not be chipped, e.g. trees from private trimmers and industrial scrap delivered by the producers. The following comments on chipping devices and their cost apply to chipping at the plant or at the source of supply. While many devices in varying sizes are marketed to chip wood the principle of operation in most is using rotating knives or hammers to shear the wood into small chips. The largest mobile devices can accomodate logs up to nine inches in diameter and any length. A typical cross section is shown in Figure 5.

Chipping costs are given by Gould (2) as follow:

Type of Cost	Dollars per ton
Equipment, $50,000	1.86*
Labor and maintenance, 3 men @ $12.00 total per hour	3.43
Fuel, lubricants, etc.	1.65
Administration, insurance,	.20
Total	$7.14

*Based on a 5 year life

These figures are based on chipping seven hours per day at 3.5 tons per hour.

These figures are for a mobile chipper; an in plant chipper operated by a turbine using waste steam would probably have a lower cost per ton. Present studies indicate that chipping in the field to facilitate shipping more than offsets this cost saving.

5.2 DRYING

The majority of wood sources being considered produce green wood which has a moisture content of approximately 40 to 50 percent of the total weight. This has two detrimental effects on the combustion of the wood. First, the weight of moisture must be included in handling the material. Dry wood heating value is 8500 BTUS/pound, green wood is about 5000 BTUS per pound. Secondly, the moisture must be vaporized thus reducing the boiler efficiency. Given these considerations some form of drying is desirable. The most obvious system is to use excess steam, generated during the non-heating season, as a source of heat. While the exact details could take on many forms, the general plan would be to heat air with a steam coil, blow it through the chips and vent it to the atmosphere. A perfectly efficient system would drive off roughly one pound of moisture for each pound of steam used. A first approximation of an actual system indicated that 1.6 pounds of steam would be required to drive off a pound of moisture.

5.3 STORAGE

The big advantage of burning wood instead of additional solid waste is the fact that it is a storable fuel. Wood chips can be stored outside with less than one percent per month deterioration if the pile depth is less than 20 feet (2). This would be the best method for storing the chips prior to drying; after drying additional protection will be required. The simplest approach would be an open sided 'hay shed' type structure. The chips could be moved in and out using a front end loader, portable conveyor belts or a pneumatic conveyor. A more elaborate approach would be to use closed bins as shown in Figure 6.

The system being proposed would store large quantities of green chips outside; the quantity would be 20,000 to 30,000 tons, approximately one year's supply. These would be dried when excess steam is available and then would be moved into closed storage. Enclosed storage for all the wood used during the winter will probably be excessively expensive. Therefore dried chips would be used during wet weather when the solid waste has a high moisture content and when maximum steam output is required. The remainder of the time green chips would be burned directly.

6. BURNING WOOD

There two basic options for burning wood. The first is to burn it with the solid waste, the second is to burn it separately in a boiler specifically designed for wood. If only small quantities of wood are being used, burning directly with the solid waste is the obvious choice. If substantial quantities of wood are being considered, as is the case at the University of Kansas, using separate wood burning boilers should be considered. There is a trade off between the versatility and convenience of using all solid waste type boilers and slightly better boiler efficiency in wood burning boilers. As indicated earlier, an additional advantage of burning wood directly with the solid waste is an ability to even out the BTU content of the fuel when the waste is wet.

Many incinerators for burning raw solid waste are available. Typically, as shown in Figure 7, these units have a moving grate which slopes in the direction of travel. The solid waste is burned as it is moved across the grate by a combination of mechanical action and gravity. Commonly these units will introduce additional combustion air above the grate. Wood will burn well in these devices if the pieces are not too large. Indeed sections of railroad ties are being burned in this type of unit.

Units which burn wood only are more closely related to coal fired boilers. The most common types employ some type of moving belt grate as shown in Figure 8. While not as numerous, suspension and fluidized bed boilers are also being used to fire wood. Being designed for a more consistent fuel, these units have better efficiencies; typically 70 to 80 percent versus 60 to 70 percent for waste burning units. The boiler efficiencies quoted for wood boilers (5) are variable, and possibly misleading, because the heat required to vaporize the moisture in the wood is often charged against the boiler efficiency, not the fuel BTU content. Finally wood has a low ash content and thus wood boilers do not have the large ash handling capacities found in units designed to burn solid waste.

Burning wood has a distinct advantage in terms of pollution control. First, wood is low in sulfur content, typically less than 0.1%; likewise the ash content is low, in the range of 0.5 to 5 percent (5). The main problem with burning wood is production of oxides of nitrogen, particulates and hydrocarbons in the stack gases. Typical values are 25 to 30 pounds of particulates and 10 pounds of nitrous oxides per ton of wood burned (5). The amount of hydrocarbons released is somewhat variable with the highest levels occuring during poor combustion. Multiple cyclone separators, electrostatic percipitators, wet scrubbers or bag houses will effectively control the particulates. Little information is available on nitrous oxide and hydrocarbon emission control; it would appear that good combustion control can keep these pollutants within acceptable levels.

The low ash content of wood makes disposal a small problem. One possibility for wood burning only units is to return the ash to the energy forest and spread it on the soil; this will help maintain the chemical balance of the soil.

7. CONCLUSIONS

Wood, being a relatively inexpensive, clean burning fuel, is a desirable supplement to be used with solid waste. Its storability and compatibility in burning with solid waste further enhance its desirability.

The principle sources of wood are sawmill scrap, urban tree removals, and an energy forest. Depending on the market value for scrap, urban trees or scrap wood may be the most economical source. In fact it is possible that the market value for scrap may come to depend on its saving over chipping urban tree removals. Wood from an energy forest is more expensive than either scrap or urban trees; however the energy forest is a necessary component in that it is a controlled supply. These three sources could provide adequate supplemental fuel for the proposed University of Kansas power plant.

Trucks are the only form of transportation which is feasible. Handling costs are such a significant fraction of the total hauling costs that rehandling is not acceptable, i. e. the wood must be loaded at the source and delivered directly to the plant. With transportation costs being a significant portion of the overall cost, the feasible distance to haul wood is limited probably to no more than 100 miles, perhaps no more than 60 to 70 miles. In most cases chipping prior to shipping will be desirable and will offset the added cost of field chipping.

The storage system should have a large volume, enough for one severe winter season. The majority of this could be outdoor storage but there should be protected storage for at least several thousand tons of chips. These chips would be dried by using excess steam generated during warm weather.

In small quantity the wood can be burned directly with the solid waste. If a large amount of wood is being burned, separate wood burning boilers will give better combustion efficiency. Wood in relatively large amounts can be burned in some of the available solid waste units with some penalty in the heat recovered.

ACKNOWLEDGMENT

This work is being supported by Franklin Associates Ltd. of Prairie Village, Kansas and is part of their feasibility study of a new steam system for the Lawrence campus.

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BIOGRAPHIES

Mr. Banta holds a Bachelor of Science in Mechanical Engineering and a Master of Engineering in General Engineering, both from Penn State University. He is currently working on a Doctor of Engineering at the University of Kansas. He has worked for the Water Department, City of Philadelphia, Pennsylvania and Ingersoll Rand Company, Phillipsburg, New Jersey. While employed by Ingersoll Rand he worked on development of new designs for steam

surface condensers and related equipment. He is presently on an educational leave from Northampton County Area Community College where he is an Associate Professor of Engineering.

William P. Smith was born in Superior, Wisconsin on January 5, 1915. He received the BEE and MS in EE degrees from the University of Minnesota, Minneapolis in 1936 and 1937 respectively and the Ph.D. degree from the University of Texas, Austin, in 1950. After graduation he was with the Commonwealth Edison Company, Chicago. He was called to active duty in the United States Naval Reserve in 1941 and served all of World War II at the Inspector of Naval Material Office, Schenectady, New York. From 1946 to 1948, he was Dean of Engineering at Sampson College, Associated College of Upper New York. Since 1950 he has been at the University of Kansas serving as Chairman of Electrical Engineering 1955-1965 and Dean of the School of Engineering since 1965. He is a member of Tau Beta Pi, Sigma Xi and served as National President of Eta Kappa Nu 1968-69. He is a registered professional engineer in the State of Kansas and has served as a member of the Kansas State Board of Engineering Examiners.

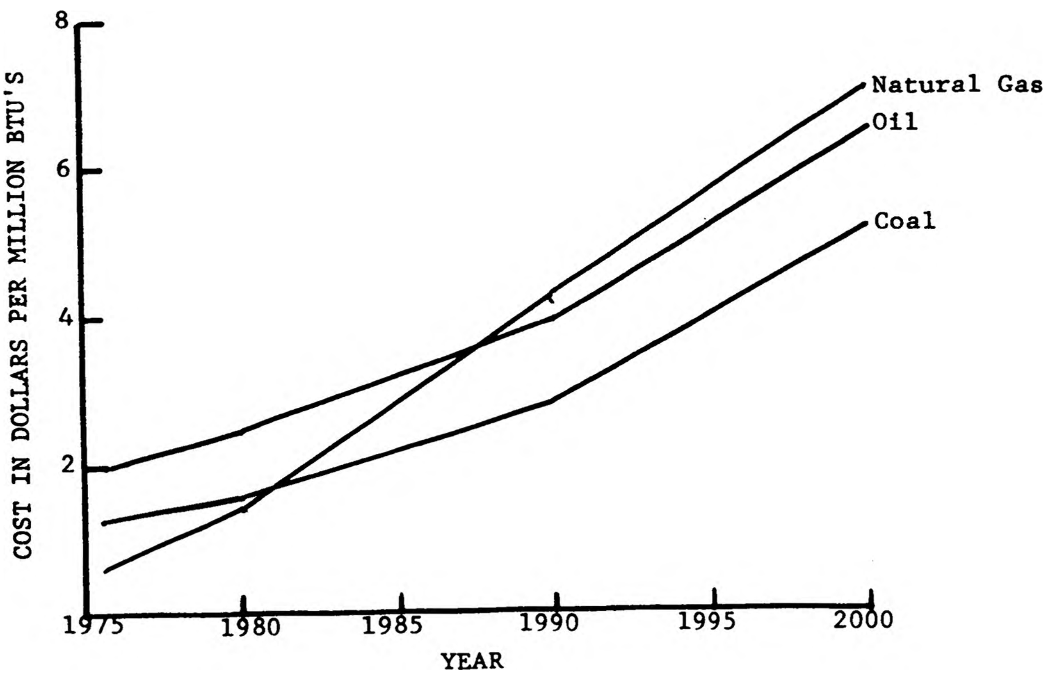

Figure 1. Projected Prices For Natural Gas, Oil and Coal From The Present To The Year 2000.

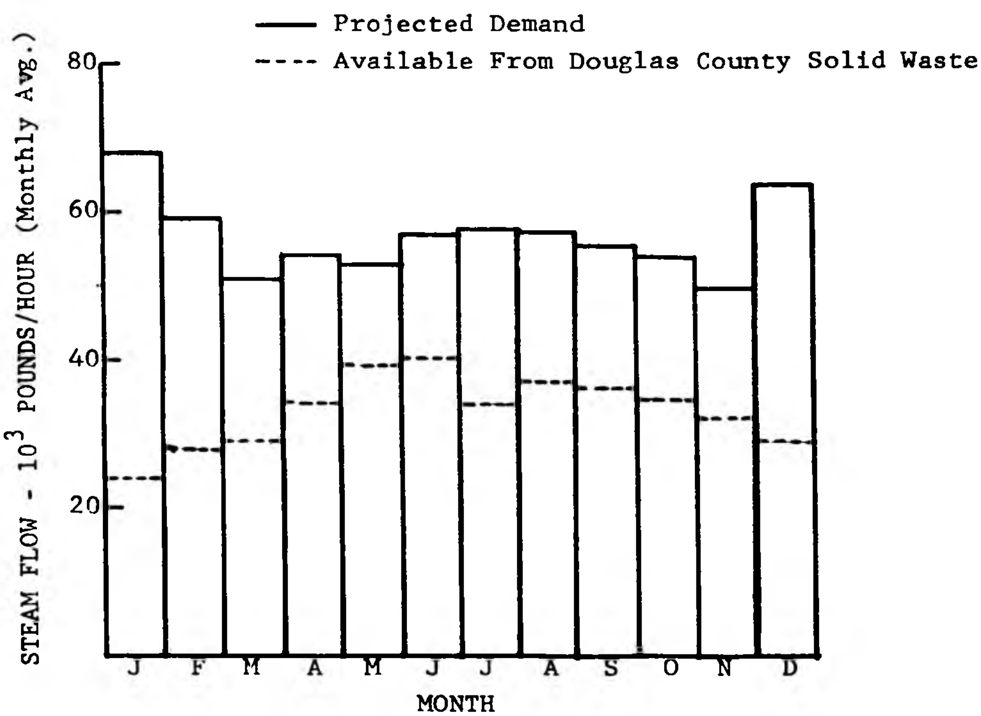

Figure 2. Comparison of Monthly Average Projected Steam Demand And Amount Which Could Be Generated Using Douglas County Solid Waste.

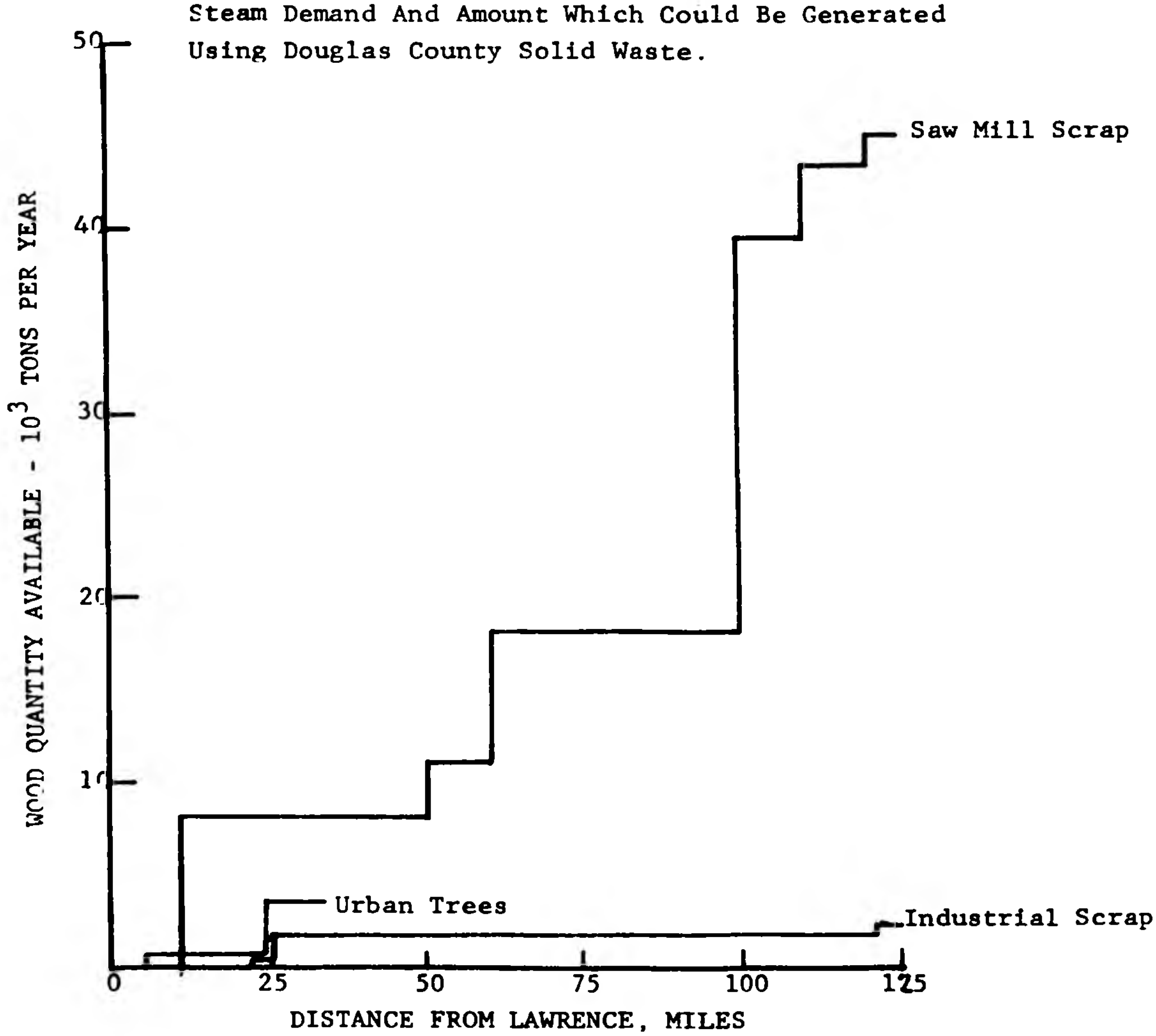

Figure 3. Cumulative Wood Supply Available From Various Sources As A Function of Distance.

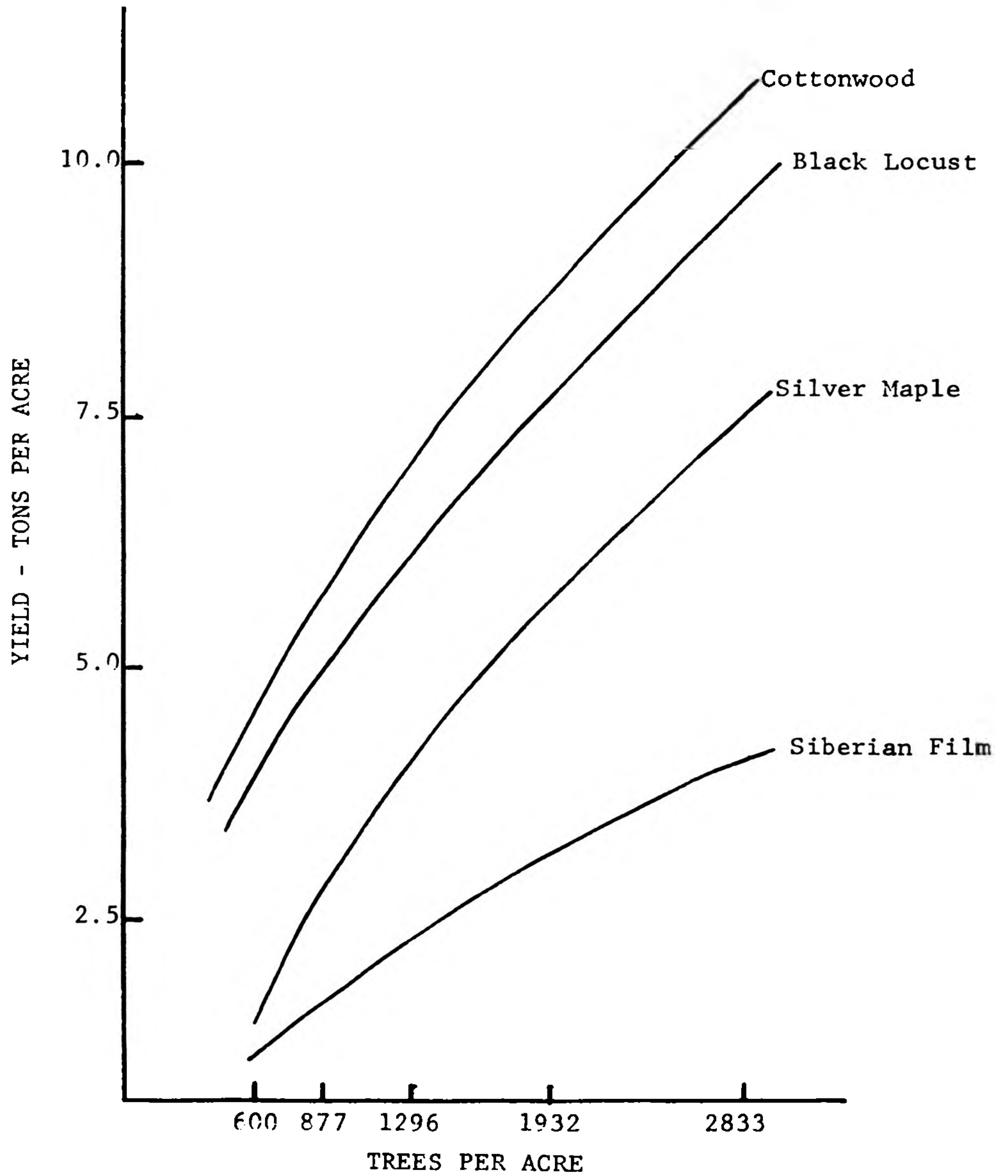

Figure 4. Average Yield For Various Tree Species And Planting Densities After Two Years of Growth.

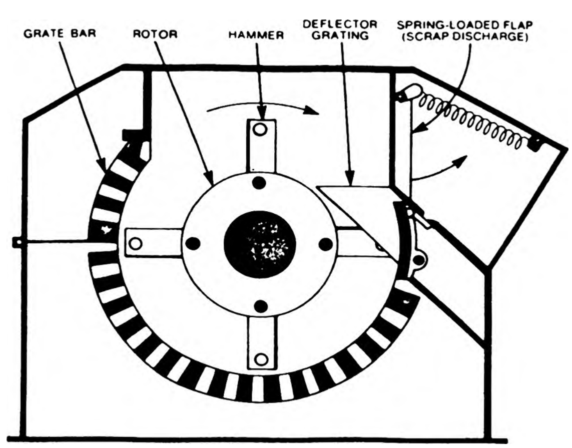

Figure 5. Typical Hammer Mill Used To Chip Wood. (Courtesy of Allis-Chalmers, Appleton, Wisconsin).

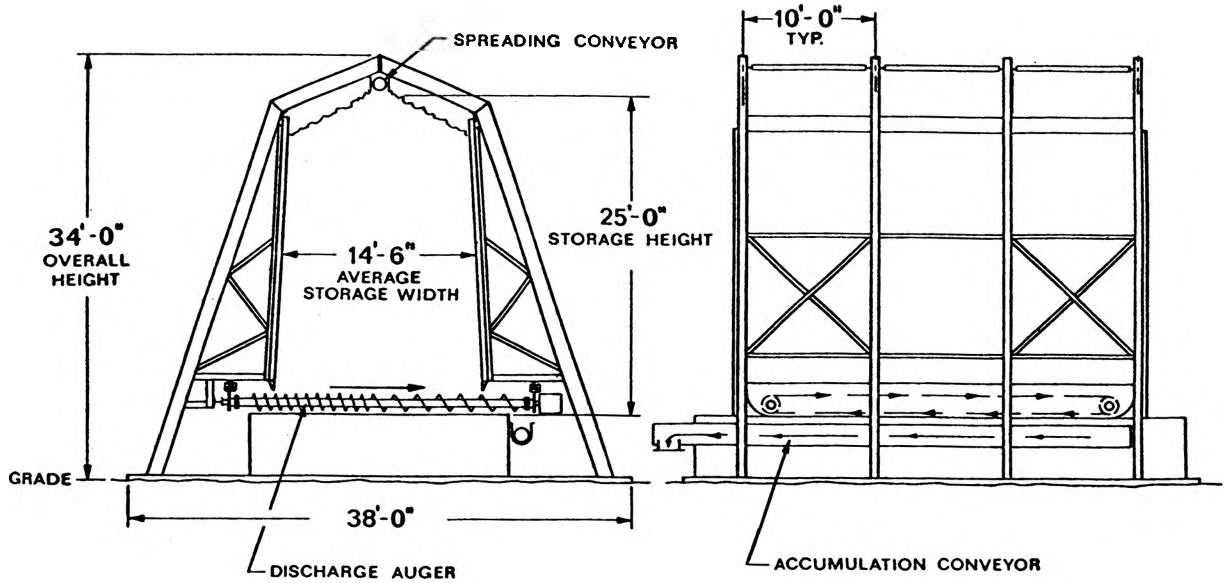

Figure 6. Typical Closed Storage Bin For Chips
(Courtesy of Clarke's Sheet Metal, Inc., Eugene, Oregon).

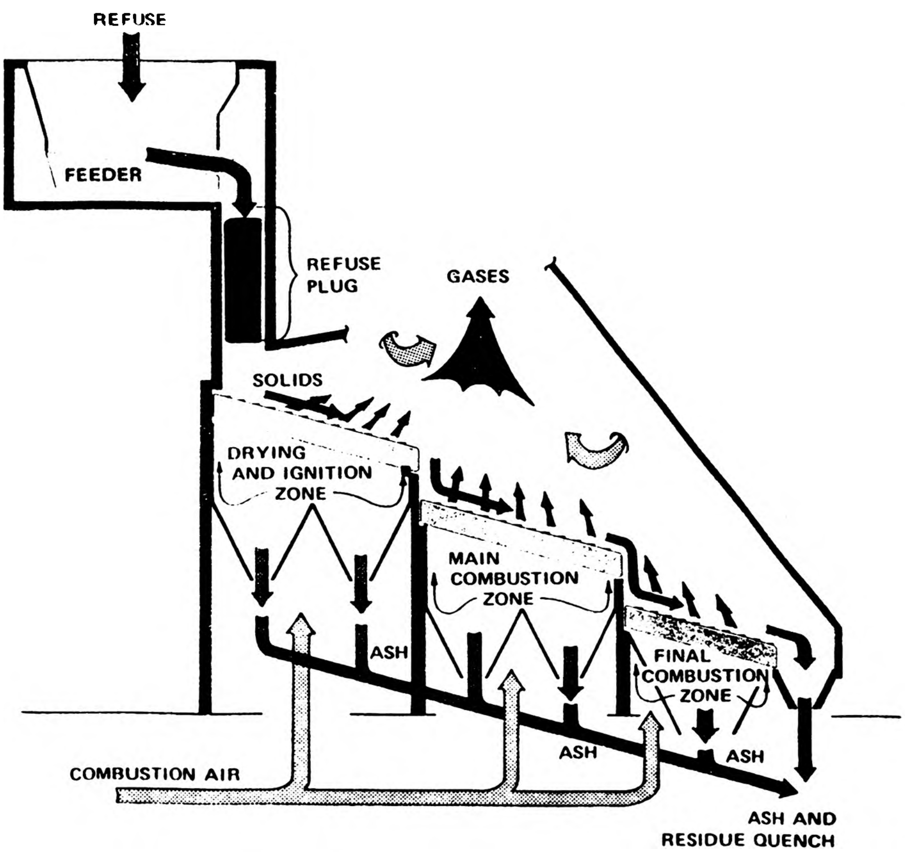

Figure 7. Typical Solid Waste Grate System (Courtesy of Andco, Inc., Buffalo, N.Y.).

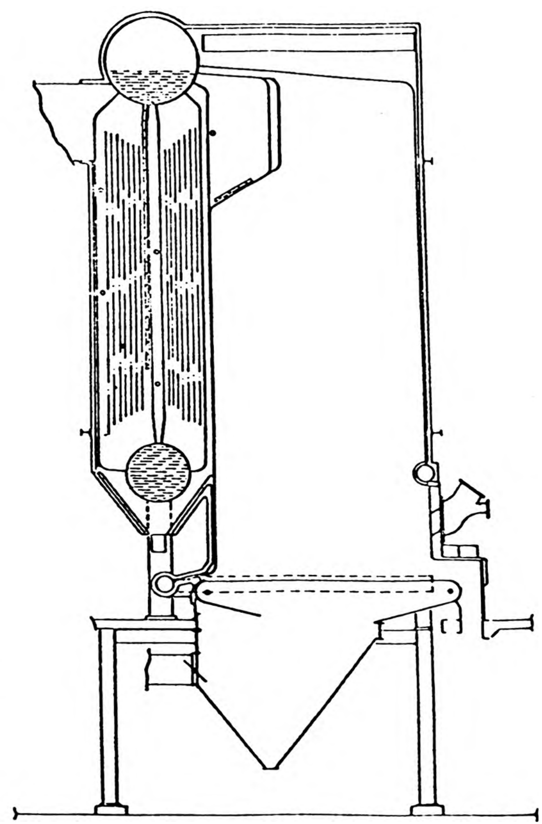

Figure 8. Typical Spreader Grate Boiler For Burning Wood Chip (Courtesy of Foster Wheeler Limited, St. Catharines, Ontario).