THE FEASIBILITY OF UTILIZING FOREST RESIDUES FOR ENERGY & CHEMICALS

A Report to the
NATIONAL SCIENCE FOUNDATION
AND FEDERAL ENERGY ADMINISTRATION
RANN/Research Applied to National Needs
Washington, D.C. 20550

USDA - FOREST SERVICE

MARCH 1976

NSF-RA-760013

Final Report on the Feasibility of Utilizing Forest Residues for Energy and Chemicals

A Report to the
NATIONAL SCIENCE FOUNDATION
AND FEDERAL ENERGY ADMINISTRATION
RANN/Research Applied to National Needs
Washington, D. C. 20550

by
Forest Service, USDA

Contract No. NSF AER-75-19464
March 1976

The Forest Industry Energy Program, under the direction of the Forest Service of the U. S. Department of Agriculture, is a part of an effort funded by the National Science Foundation under a program of Research Applied to National Needs (RANN) entitled "Utilization of Agricultural and Forest Residues for Production of Energy" and by the Federal Energy Administration. USDA agencies charged with the initial responsibility were the Agricultural Research Service (ARS) and the Forest Service (FS). The Forest Service portion is concerned with the conversion of forest industry residues into energy either through direct combustion or conversion into petrochemical substitutes. The initial FY75 phase was directed toward investigation of the feasibility of utilization of forest residues to achieve energy self-sufficiency within the forest industry.

TABLE OF CONTENTS

The major objective of the total proposed Forest Service program is to provide technology by which the primary wood processing industries can approach internal energy self-sufficiency at individual plant operations. The recent trends in curtailment and interruption of natural gas service, the increases in oil prices and the growing constraints of air pollution control have prompted a search for alternate and "locally" available substitute fuels which can avoid many of these problems through achievement of energy self-sufficiency. The Forest Industry Energy Program (FIEP) is a major Forest Service effort to explore the use of wood residues to meet the energy requirements of individual forest industry operations within the forest land management environmental objectives.

APPROACH

The feasibility phase addressed two major objectives: direct energy conversion and chemical conversion. Direct energy conversion is based on the combustion of residue as fuel and includes not only combustion but also alternative methods for harvesting, transportation and residue preparation that may improve efficiency. Chemical conversion of residue offers opportunities to supplement energy needs by converting wood to petrochemical substitutes such as methyl and ethyl alcohol, and chemicals for adhesives.

FOREST INDUSTRY ENERGY PROGRAM

Objectives

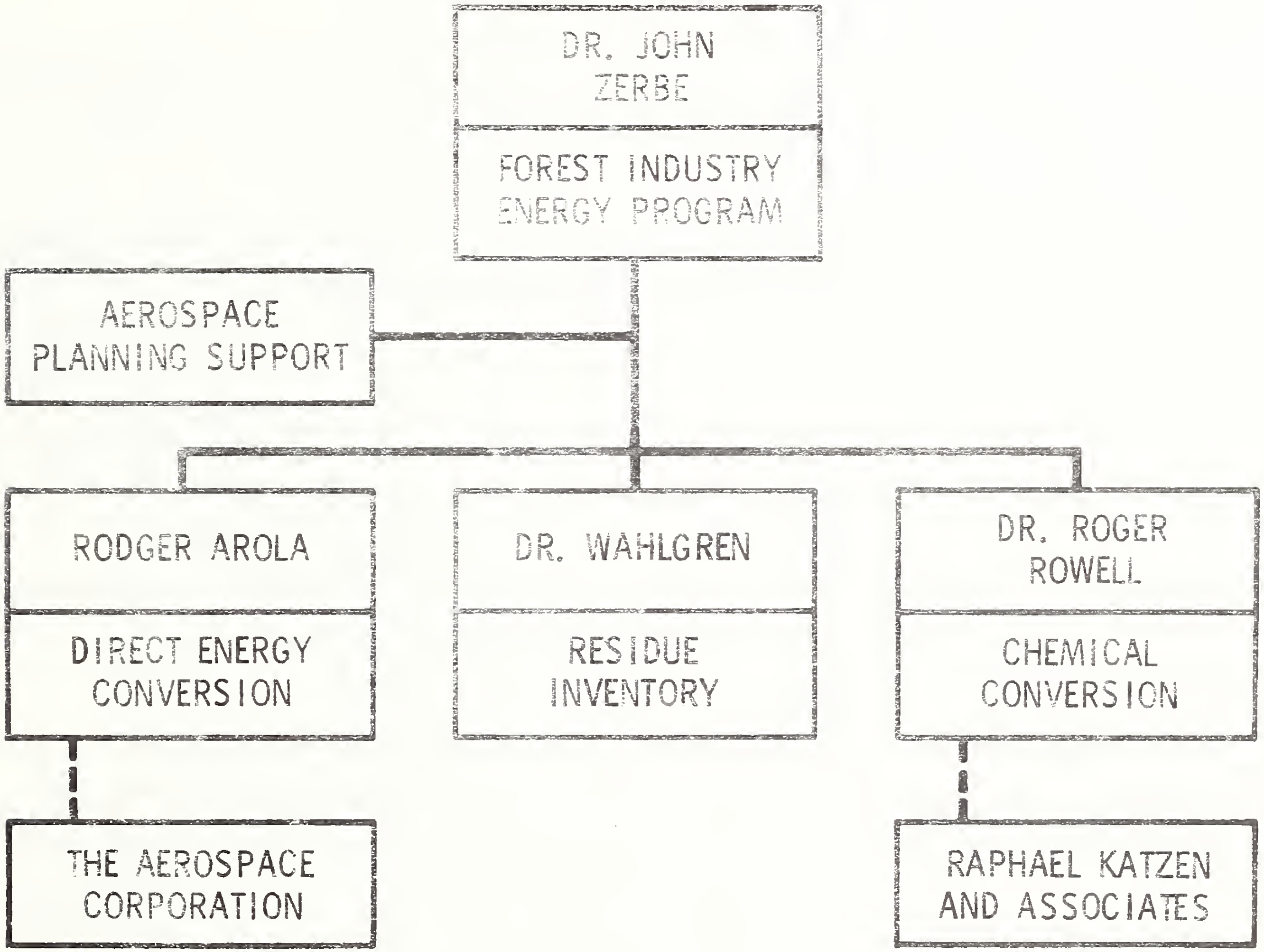
- DIRECT ENERGY CONVERSION
    - TO ESTABLISH TECHNIQUES FOR DIRECT CONVERSION OF FOREST INDUSTRY RESIDUES TO ENERGY WHICH ARE TECHNICALLY AND ECONOMICALLY FEASIBLE FOR VARIOUS TYPES AND SIZES OF OPERATIONS

- CHEMICAL CONVERSION
    - TO ESTABLISH TECHNIQUES FOR CONVERSION OF FOREST INDUSTRY RESIDUES INTO PETROCHEMICAL SUBSTITUTES (or other critical chemicals) UPON WHICH THE FOREST INDUSTRY DEPENDS

The overall coordination of the Forest Industry Energy Program is vested in Dr. John Zerbe, Director of Forest Products and Engineering Research, Washington, D.C. The Aerospace Corporation, El Segundo, California, has and will continue to provide support to the Washington Office during the course of the Program. Technical Coordinator for the Direct Energy Conversion Study is Mr. Rodger Arola, Forest Engineering Laboratory, Michigan Technological University, Houghton, Michigan. The Aerospace Corporation is under contract for the Direct Energy Conversion Study. The Chemical Conversion is under the direction of Dr. Roger Rowell, Forest Products Laboratory, Madison, Wisconsin. Raphael Katzen and Associates is under contract for the Chemical Conversion Study. An inventory of available residue resources was made by Dr. H. Wahlgren of the Forest Products Laboratory, Madison, Wisconsin.

FIEP - Feasibility Study

ORGANIZATION



The Forest Industry Energy Program is organized into a five-year, four-phase program culminating in use of commercially developed equipment to demonstrate the feasibility of energy self-sufficiency within the Forest Industry.

FEASIBILITY STUDY

Included in this study were investigations of current industry energy utilization, requirements for and the availability of residue, research on process alternatives to meet energy and/or chemical requirements, and an economics and technical feasibility analysis.

SYSTEM DEFINITION AND ANALYSIS

This phase will analyze and define candidate systems for direct energy and/or chemical conversion of wood residue and select preferred concepts for later Proof-Of-Concept Experiments (POCE).

DESIGN/DEVELOPMENT OF PROOF-OF-CONCEPT EXPERIMENT

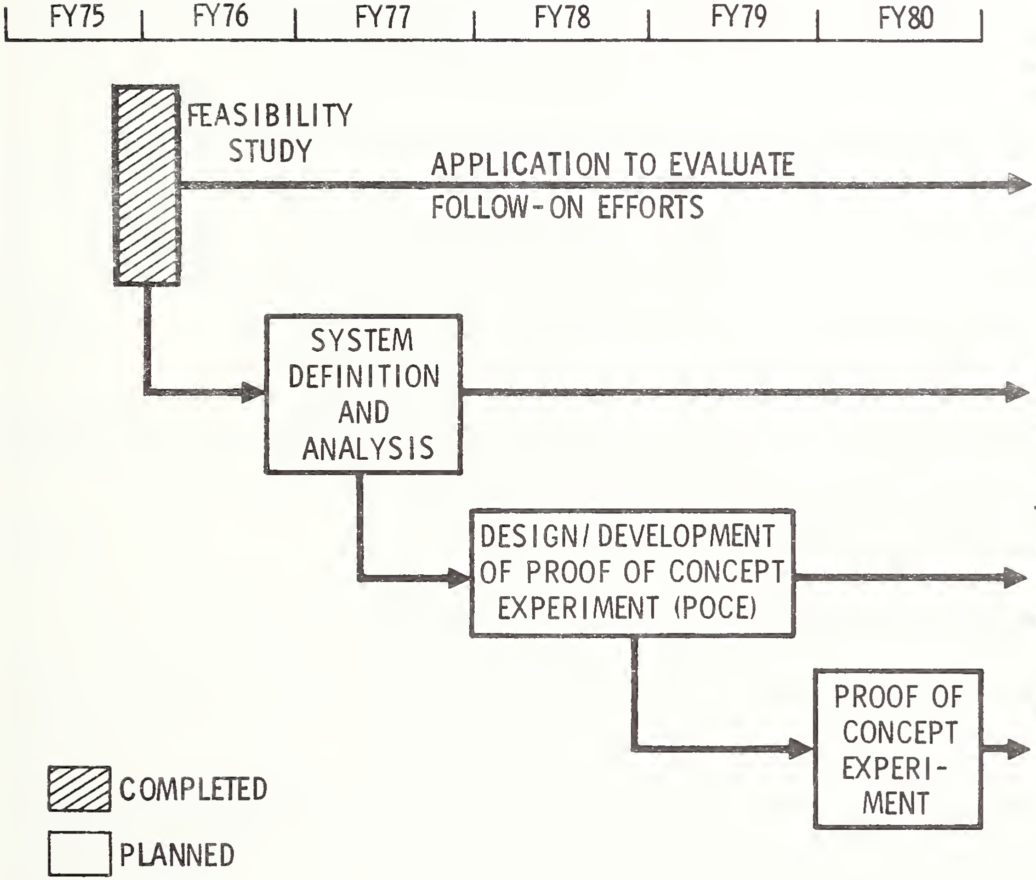
After selection of preferred concepts for demonstration, the necessary hardware will be designed and developed. Manufacture of long lead time items will be initiated and contractors to conduct the demonstration will be selected.

PROOF-OF-CONCEPT EXPERIMENT

The POCE will evaluate selected concept(s) for commercial demonstration. The necessary hardware will be fabricated and assembled at sites selected for demonstration purposes.

5 Year Program Overview

STATUS AND APPLICATION



- ENERGY UTILIZATION BY SOURCE TYPES, AND SIZE
- ANALYSIS OF PROCESS ALTERNATIVES
- CONCEPTUAL DEFINITION
- PRIORITIZE CANDIDATE APPROACHES

- DETAILED ANALYSIS USING OPERATIONAL DATA
- DETERMINE PREFERRED CONCEPT
- DESIGN STUDIES OF SELECTED SYSTEM FOR POCE

- DESIGN AND DEVELOPMENT OF POCE
- SELECTION OF CONTRACTORS

- IMPLEMENTATION OF POCE INCLUDING FABRICATION AND OPERATION OF COMMERCIALLY DEVELOPED EQUIPMENT

The feasibility of direct energy conversion or chemical conversion of wood residue required a more complete understanding of the quantities and types of residue which are available in various geographic locations. The results of a residue inventory of gross availability are contained in this section.

Specific classes of residues examined were:

- "Noncommercial" timber (rough trees, rotten trees and salvable dead)
- Harvesting residues (growing, and non growing residues, uncut trees and bark)
- Softwood and hardwood removal (land clearing, stand improvement, etc.)
- Byproduct residues (used and unused both wood and bark).

Estimates of residue availability were obtained by weight and volume in each of the major sectors of the U.S. (Pacific Coast, Rocky Mountain, South, and North) as used by U.S. Forest Service in the outlook for timber in the U.S.

INVENTORY OF "NONCOMMERCIAL" TIMBER BY REGIONS IN THE U. S.[1]

REGIONS	ROUGH TREES[2]		ROTTEN TREES[3]		SALVABLE DEAD TREES[4]		TOTAL	
	Million cu. ft.	Million tons[5]	Million cu. ft.	Million tons	Million cu. ft.	Million tons	Million cu. ft.	Million tons
Pacific Coast	2,640	39.6	2,381	35.7	4,860	72.9	9,881	148.2
Rocky Mountain	2,523	37.8	2,794	41.9	6,699	100.5	12,016	180.2
South	17,718	265.8	7,071	106.1	227	3.4	25,016	375.3
North	11,037	165.6	7,463	111.9	247	3.7	18,747	281.2
Total	33,918	508.0	19,709	295.7	12,033	180.5	65,660	984.9

[1] U.S. Forest Service. 1973. The Outlook for Timber in the United States. USDA Forest Res. Rpt. No. 20, 367 pp.

[2] Rough trees are live trees of commercial species that do not contain at least one 12-foot sawlog or two noncontiguous sawlogs each 8 feet or longer and contains defects because of roughness or poor form. Also included are live trees of non-commercial species. Includes volumes of trees only 5 inches dbh and larger and only to a 4-inch top diameter.

[3] Rotten trees are those having more than 50 percent of their volume classified as rotten.

[4] Standing or down dead trees that are considered merchantable.

[5] Oven-dry tons.

REGIONAL DISTRIBUTION OF FOREST RESIDUES FROM HARVESTING OPERATIONS

Regions	1970[1] Growing Stock Residues	1973[2] Growing Stock Residues	1973 Nongrowing Stock Residues: Over 4 inches	1973 Nongrowing Stock Residues: 1 to 4 inches	Uncut Trees Over 1 inch In diameter	Total Residues	Bark
	Vol. -Million cu. ft.	Millions of tons, ovendry basis					
Pacific Coast	526	8	10[3]	4	4	26	4.4
Rocky Mountain	103	2	1[4]	1	2	6	1.2
South	683	11	7[4]	16	18	52	9.5
North	283	4	2[4]	9	11	26	4.9
Total	1,595	25	20[4]	30	35	110	20.0

[1] U.S. Forest Service. 1973 The Outlook for Timber in the United States. USDA Forest Res. Rpt. No 20, 367 pp

[2] Ellis, T. H. 1975 The role of wood residue in the national energy picture Proceedings of the Forest Products Research Society meeting on Wood Residue as an Energy Source, Denver, September 1975

[3] Nongrowing stock residues on Pacific Coast in 1970 was approximately 8.8 million tons (587 million cubic feet at 30 pounds per cubic foot). Lumber production in the California redwood region and in the Coast region was up 20 percent in 1973 as compared to 1970. Plywood production was up 7 percent. Log exports increased 15 percent. Weighting these by 1970 roundwood consumption, roundwood harvest should have increased approximately 17 percent. Assuming nongrowing stock residues increased the same percent, then 1973 nongrowing stock residues over 4 inches should have been approximately 10 million tons.

[4] Distribution of nongrowing stock residues over 4 inches in diameter to Rocky Mountain, South, and North is assumed to be proportional to 1973 growing stock residue.

OTHER SOFTWOOD AND HARDWOOD REMOVALS[1] BY REGIONS IN THE U.S.

REGIONS	SOFTWOODS		HARDWOODS		ALL SPECIES	
	Million cu. ft	Million tons[2]	Million cu. ft.	Million tons	Million cu. ft.	Million tons
Pacific Coast	99	1.48	9	.14	108	1.62
Rocky Mountain	16	.24	--	----	16	.24
South	158	2.37	630	9.45	788	11.82
North	61	.92	342	5.12	403	6.04
Total	334	5.01	981	14.71	1,315	19.72

[1] Refers to net volume of trees removed from the inventory by such operations as timber stand improvement, land clearing, changes in land use and, therefore, not utilized for timber products.

[2] Oven-dry tons.

ESTIMATED U.S. PRODUCTION BY REGION OF BYPRODUCTS AND RESIDUES (USED AND UNUSED) IN THE PRIMARY MANUFACTURE OF LUMBER AND WOOD PRODUCTS[1] -- 1973

REGIONS	PRODUCTION		UNUSED	
	Wood	Bark	Wood	Bark
	Millions of tons, ovendry basis			
Pacific Coast	25	7	2	2
Rocky Mountain	7	2	2	1
South	20	6	5	3
North	7	2	2	2
Total	59	17	11	8

[1] Ellis, T.H. 1975. The role of wood residue in the national energy picture. Proceedings of the Forest Products Research Society meeting on Wood Residue as an Energy Source, Denver, September 1975.

The Direct Energy Conversion Feasibility Study assessed energy utilization within the forest industry to establish where conservation of critical fuel resources would produce the maximum payoff. This required a realistic evaluation of the energy used for the manufacture of wood related commodities and the amount of energy required to be generated from residues to achieve energy self-sufficiency. Alternative conversion systems were examined to identify concepts which would lead the industry to achieve energy self-sufficiency.

The four major subtasks which comprised the five month feasibility study were:

INDUSTRY SURVEY

A survey of forest industry data established gross estimates of the industry's utilization of energy from various sources, and categorized energy usage by mill size, type and geographic location.

SITE SURVEY

On-site visits to representative mills were conducted to obtain site specific data on energy needs, mill residue volumes, and current energy usage patterns.

COMBUSTION SURVEY

This survey was a technical evaluation of combustion equipment to determine cost, performance, and applicability to the industry's energy self-sufficiency problems.

SYSTEM ANALYSIS

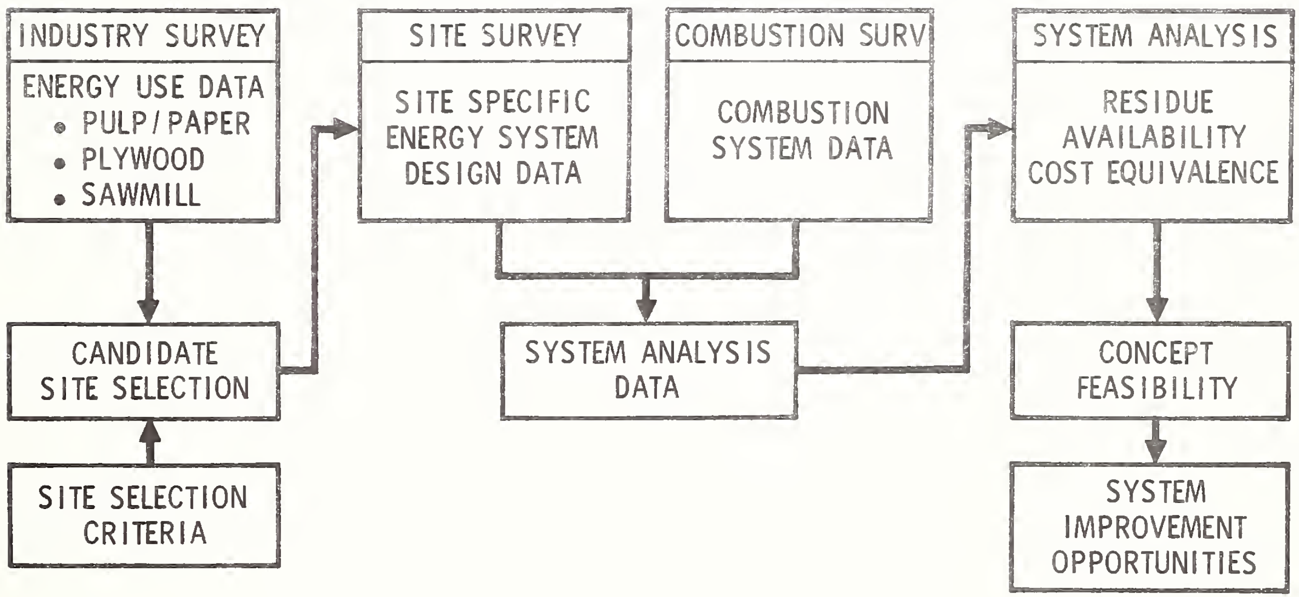
Selected mills were analyzed to establish cost equivalence of residue necessary to make each mill energy self-sufficient. Concepts of direct energy conversion systems which would lead to energy self-sufficiency within the forest industry were identified for follow-on study.

Feasibility Study - Direct Energy Conversion

OBJECTIVES

- TO ASSESS FOREST INDUSTRY ENERGY UTILIZATION FOR POTENTIAL CONSERVATION OF CRITICAL ENERGY SOURCES THROUGH USE OF WOOD RESIDUE AS FUEL
- TO STUDY DIRECT ENERGY CONVERSION SYSTEM ALTERNATIVES AND SELECT PREFERRED CONCEPTS FOR ACHIEVING FOREST INDUSTRY ENERGY SELF-SUFFICIENCY

APPROACH



INDUSTRY SURVEY

An exploratory literature survey was made to establish gross estimates of the industries utilization of energy sources (e.g., petroleum, natural gas, electricity, residue, etc.) and use of various petrochemical feedstocks or gums, resins, glues, etc. Although this task relied primarily on data published from industry sources, data collected in the site survey task was factored in, as deemed appropriate.

TASK OUTPUT

The product of this effort was a compilation of information on the relationships between energy sources and usage trends as a function of mill characteristics. From the data collected in this survey it was possible to identify the more promising opportunities for achieving energy self-sufficiency in terms of the type of operation its size and location.

Forest Industry Survey

OBJECTIVES

- TO IDENTIFY THE SOURCE AND USE OF ENERGY WITHIN THE FOREST INDUSTRY AND TO UNDERSTAND THE EXTENT TO WHICH THIS INDUSTRY HAS ALREADY BECOME ENERGY SELF-SUFFICIENT
- TO IDENTIFY THE PROBLEMS OF THE FOREST INDUSTRY WHICH RESULT FROM CURRENT AND PROJECTED TRENDS IN ENERGY AVAILABILITY, COST, AND ENVIRONMENTAL CONCERN
- TO COLLECT GROSS INDUSTRY DATA INCLUDING THE USE OF PETROCHEMICALS AS FEEDSTOCKS

APPROACH

- REVIEW AND ANALYSIS OF DATA
  - INDUSTRY DATA
  - RESEARCH DATA

A "top-down" analysis was made to assess the impact of converting the forest industries to energy self-sufficiency. The data on this chart were collected from various sources hence there are some minor inconsistencies.

TOTAL U.S.

Standard categories of energy users shows that the Industrial segment represents a significant amount (about 1/3) of energy consumption within the entire U.S.

INDUSTRIAL SECTOR

Within the Industrial sector, the forest industries are identified as the fourth largest user of purchased energy. Although this represents only 2% on a National level, it is a major identifiable segment of energy usage.

FOREST INDUSTRIES

The primary forest industries covered in this study include the pulp/paper, sawmills, and plywood manufacturers. Of these the pulp/paper industry is the largest energy user and hence is the principal candidate for energy self-sufficiency. Other users who could potentially convert are sawmills and plywood mills provided they have a demand for process heat.

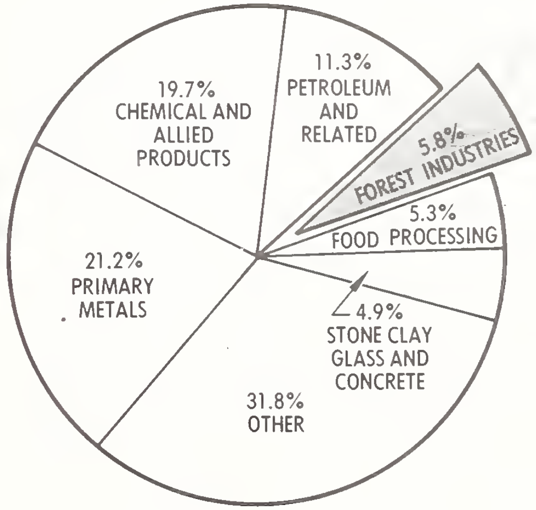
Purchased Energy By Industry

ANNUAL BASIS*

TOTAL U. S.

ITEM	ENERGY 10^{15} BTU	%
• HOUSEHOLD AND COMMERCIAL	15.8	25%
• TRANSPORTATION	16.3	25%
• INDUSTRY	20.7	32%
• OTHERS	11.8	18%
	64.6	100%

INDUSTRIAL SECTOR (1)



FOREST INDUSTRIES (2)

ITEM	ENERGY 10^{12} BTU	%
• PAPER AND ALLIED PRODUCTS	1310	85.3
• SAWMILLS AND PLANING MILLS	83	5.4
• PLYWOOD AND VENEER	35	2.3
• LOGGING CAMPS AND CONTRACTOR	46	3.0
• MILLWORK	10	0.7
• OTHER*	51	3.3
		100.0

*Data from various sources and years

(1) SOURCE - ENERGY, C. AND J. STIENHART, UNIV OF WISC. (adjusted to show total forest industry)

(2) SOURCE - BUREAU OF CENSUS 1972
* Includes containers, kitchen cabinets, misc. wood products, and wood preserving /treating

A literature survey was made to determine how much energy is consumed, purchased, and internally generated in each of the three selected industries (i.e., pulp/paper, sawmill and plywood manufacture) covered in this study.

PULP/PAPER INDUSTRY

Energy use within this industry is the best documented of the three industries studied. Of these three industries the pulp/paper segment is the most energy intensive and accounts for 92% of the energy purchased. The industry has achieved 40% energy self sufficiency as a result of continuing improvements over recent years by consuming spent pulping liquors and burning some hogged wood and bark.

SAWMILL OPERATIONS

Little detailed data on energy use by this industry is found in the literature. Estimates made from limited data indicated that the energy self-sufficiency may range between 20% and 40%. From these estimates it may be inferred that the pulp/paper segment uses about 15 times as much energy to produce a comparable tonnage of product hence the sawmill operations are much less energy intensive and are much smaller users of total energy.

PLYWOOD MANUFACTURING

The literature shows that this industry which purchases about 1/50 as much energy as the pulp/paper industry and is about 1/3 as energy intensive as that industry has attained about 50% energy self-sufficiency.

Energy Use in Selected Forest Industries

ANNUAL BASIS

FOREST INDUSTRY	GROSS ANNUAL PRODUCTION	TYPICAL PROCESS ENERGY		ENERGY FROM RESIDUE OR PROCESS WASTE		TOTAL PURCHASED ENERGY	
	(10^6 tons)	SPECIFIC CONSUMPTION (106 BTU/ton)	CONSUMP (10^{12} BTU)	(10^{12} BTU)	ENERGY SELF-SUFFICIENCY (%)	(10^{12} BTU)	%
PULP AND PAPER MANUFACTURING	65 (1)	33	2154 (2)	854	40% (1)	1300 (2)	92%
SAWMILL OPERATIONS	~52 (38×10^9 Bdf) (4)	~2.3 (3.1×10^3 BTU/Bdf) (5)	118 (5)	35 (5)	20-40% (5)	83 (3)	6%
PLYWOOD MANUFACTURING	~8 (16×10^9 sq ft) (6)	~8.8 (4.4×10^3 BTU/sq ft)	70	35	50% (6)	35 (3)	2%
					TOTALS	1418	100%

DATA SOURCES

(1) Lockwood's Directory 1975
(2) American Paper Institute 1972 Survey
(3) Bureau of Census 1972
(4) Timber Outlook 1974
(5) Estimate
(6) American Plywood Association Data

Pulp/paper is produced by a number of different processes each with its own energy demands. In order to properly understand the energy use of the industry it was necessary to categorize the processes used and to establish the contribution of each to current and projected production. The largest portion (about 3/4) current pulp/paper production is based on the Kraft process. The dominance of the Kraft process is projected to increase through the year 1985. Hence the Kraft process was selected for major emphasis in this feasibility study.

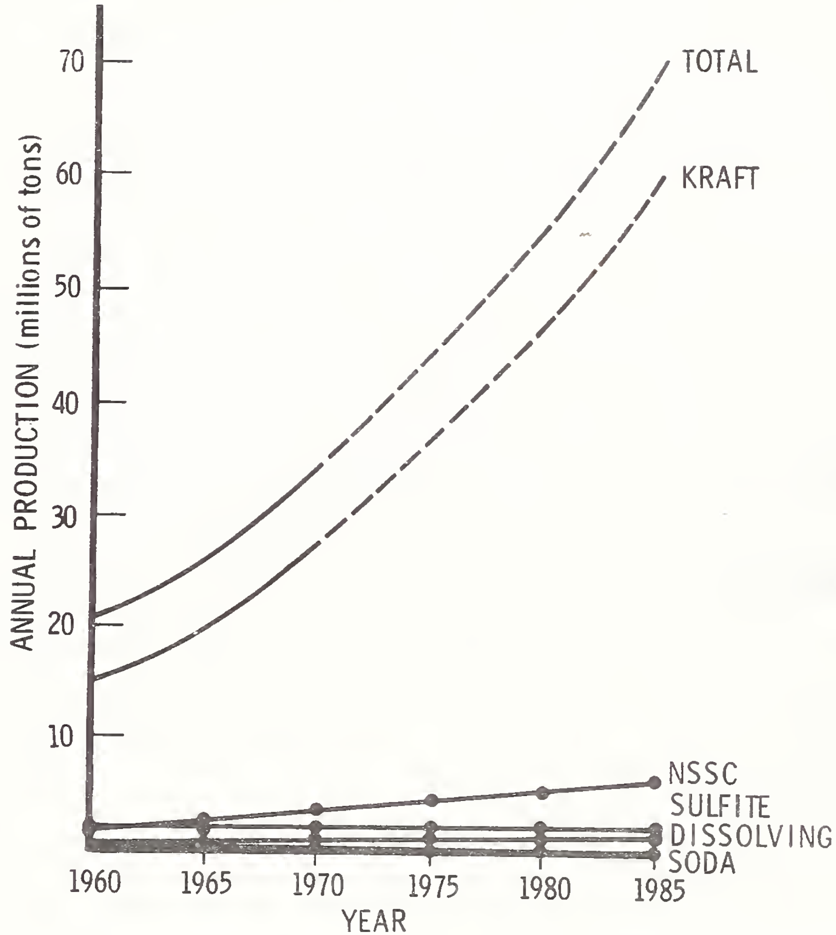
U.S. Pulp Production

TYPE OF MILL	No. OF MILLS	PRODUCTION (millions of tons)
KRAFT	119	32.4
SULPHITE	32	2.2
SEMI-CHEMICAL	44	3.8
GROUND WOOD	63	4.8
OTHER MECHANICAL[1]	72	2.9
MISC[2]	86	NOT AVAIL

(1) Includes steam and hot water defibrated, exploded, shredded, cold soda, and chemi-mechanical wood pulp mills

(2) Includes deinking, rag, soda, rope, flux, bagasse and cotton pump mills.

Source: Lockwood's Directory, 1975 Edition
Data on Number of Mills is for 1973 while Production Data is for 1974



Source:
Control of Atmospheric Emissions in the Wood Pulping Industry (Hendrickson et al.)

Data were collected in order to examine possible correlations between mill sizes, locations, processes, etc. and purchased energy consumption. The purchased energy has been shown to be about 60% of the total process energy used in the pulp/paper industry.

APPROACH

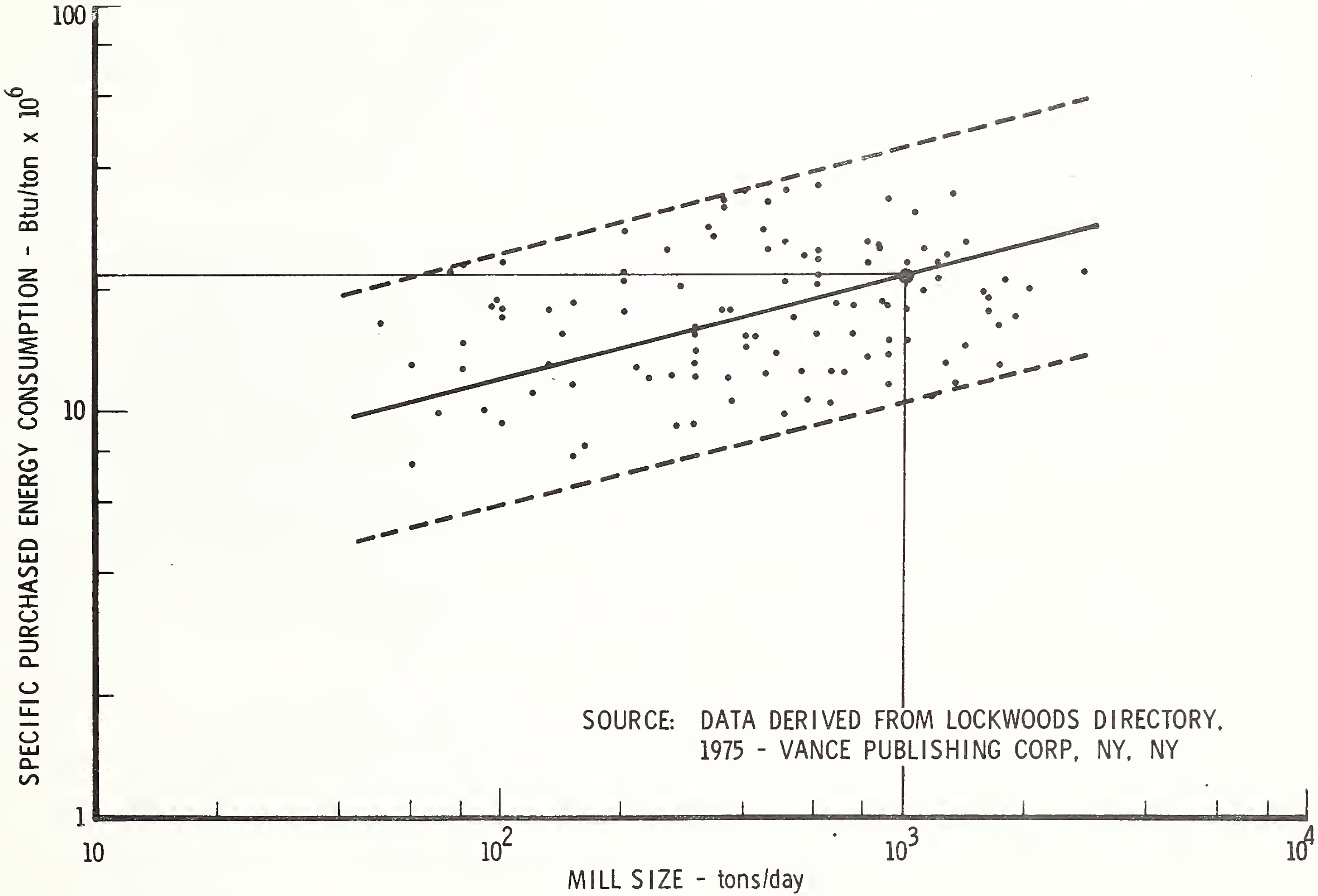
Lockwood's directory, 1975 issue, reported information on steam capacity, electricity generated and/or purchased along with mill product output for a significant sample of mills. The data identified as purchased energy were converted to a common energy unit (Btu) and plotted as a band of data points for specific energy consumption vs mill size (based on 1000 Btu/lb steam and 3413 Btu/kwh electricity).

RESULTS

Data points obtained (approximately 115 mills) were primarily for the Kraft process. There were insufficient samples of other type mills to separate or obtain a trend by process. No significant trend or difference in energy consumption was noted by mill location. Although the data were widely scattered, a least squares fit to the samples was obtained and is shown on the chart.

An example of a typical value for specific purchased energy in the pulp/paper industry is 22.4×10^6 Btu/ton for a mill size of 1000 tons/day.

Specific Purchased Energy vs Mill Size - Pulp/Paper



The pulp/paper industry is energy intensive and relies heavily on natural gas and oil (about 73%) as energy sources. Because of this the industry is facing energy related problems. Natural gas shortages, which are becoming wide spread, will require shifting to other sources. If oil is used to replace natural gas certain vulnerabilities still remain. If a shift to coal were to take place environmental pollution problems could arise. Along with these issues fuel price trends continue upward which could force mills to change their current fuel source mix and/or search for alternate fuel sources.

SPECIFIC ISSUES

Natural Gas: U.S. consumption has exceeded new discoveries since 1968 with the exception of Prudhoe find. In recent years as much as 32% of the Nation's energy needs were supplied by natural gas. Recent curtailments and interruptions are forcing many industrial users to switch to other fuels. New Canadian restrictions on the export of their natural resources are producing additional limitations on previous users of Canadian gas (principally in Northern States).

Oil: The oil embargo of 1973 signalled the start of a rapid escalation in petroleum prices and demonstrated the critical U.S. dependence on an interruptable fuel source. Actions such as the construction of a trans-Alaskan pipeline and extensive off shore drilling are being undertaken to offset the long term U.S. dependency on interruptable foreign sources of fuel.

Coal: This fuel, long a principal source of energy in the U.S., now supplies less than 18% of energy needs of the Nation. In the West however, a substantial lead time would be required to acquire needed environmental approval of mining techniques, and equipment and an adequate transportation system.

Electricity: Shortages have been forecast in the availability of electricity based on fuel considerations discussed above and generating capabilities. The hesitation of the public to approve additional generation capacity reflects the growing concern over such issues as air pollution in fossil plants, safety in nuclear plants and environmental impacts such as thermal pollution on rivers, streams or lakes. Since electricity provides only 8% of the energy of the forest industry it was not stressed in this study.

Purchased Energy Issues - Pulp/Paper Industry

PULP/PAPER INDUSTRY PURCHASED ENERGY	AVAILABILITY (interruption/ curtailment)	ECONOMICS	ENVIRONMENTAL IMPACT
OIL 37%	VULNERABILITY TO FOREIGN CURTAILMENT	SUBSTANTIAL PRICE INCREASES EXPERIENCED TO DATE	ATMOSPHERIC LIMITATIONS ON BURNING HIGH SULFUR FUELS
GAS 36%	EXPERIENCING SHORTAGES FOR INDUSTRIAL USE (increased interruptions)	UPWARD PRICE TREND PROJECTED	MINIMAL
COAL 20%	ADEQUATE LONG TERM SUPPLIES FROM U.S. RESOURCES-MINING AND TRANSPORTATION LIMITATIONS	UPWARD PRICE TREND PROJECTED	ATMOSPHERIC LIMITATIONS ON SO_2 AND PARTICULATE EMISSION SURFACE MINING CONSTRAINTS
ELECTRICITY 8%	AVAILABILITY OF BOTH FUEL AND GENERATION CAPACITY MAY BE LIMITED	SHARP PRICE INCREASES PROJECTED	ATMOSPHERIC POLLUTION WATER POLLUTION

Note: Due to rounding, total does not add to 100%.

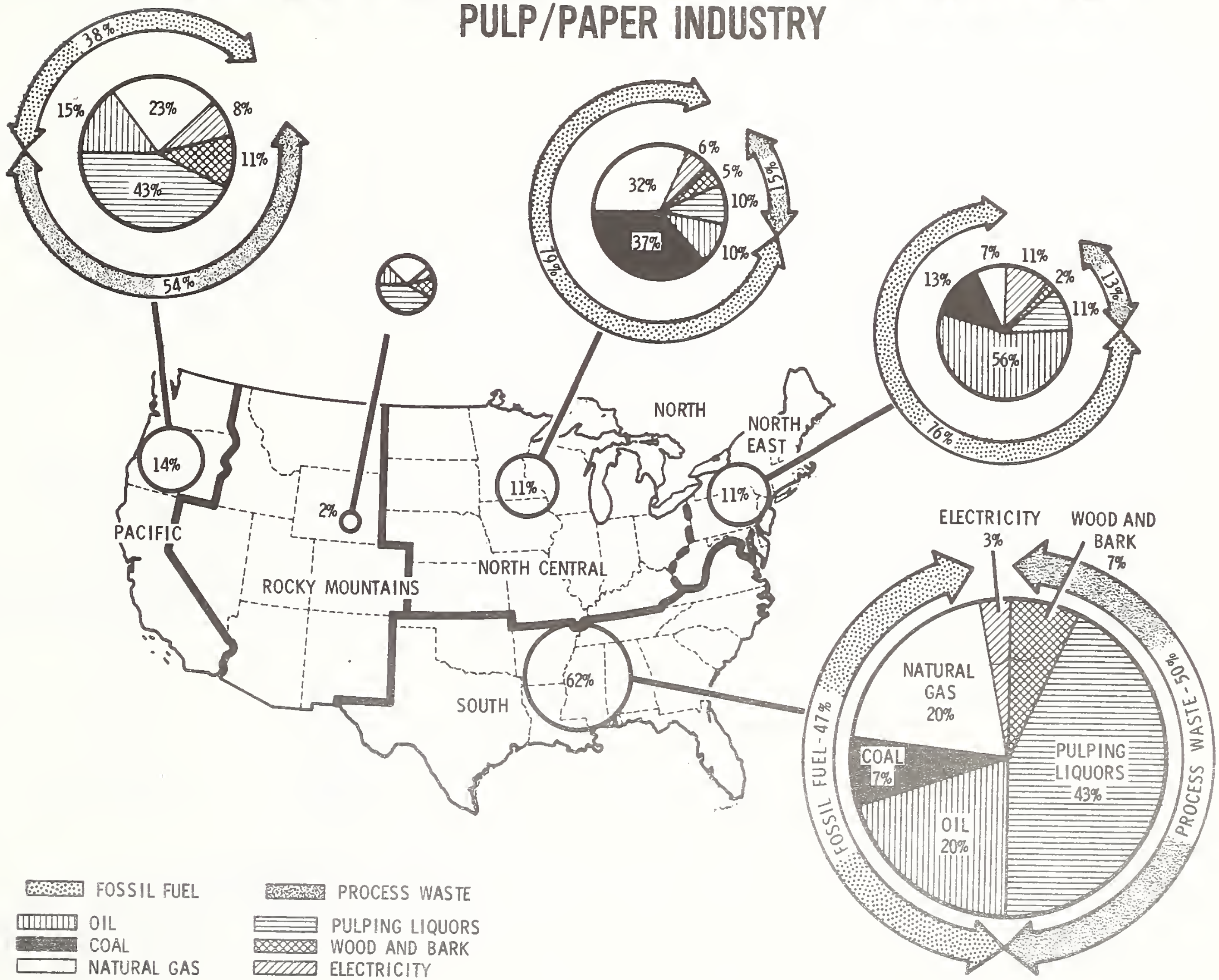
The sectional variations in the energy consumption of the pulp/paper industry were investigated to determine usage patterns by location. The objective was to identify areas of potential payoff for residue conversion implementation.

ENERGY USE PATTERNS

The two largest energy use sectors in the Nation (e.g., the South and the Pacific Coast) are also among the most energy self-sufficient (50% or more). Pulp/paper mills in these sectors use oil and natural gas to supply over 90% of their fossil fuel needs and hence are vulnerable to curtailment or interruption. Southern mills accounted for 62% of the energy purchased while Pacific Coast mills account for only 14%.

The North Eastern and North Central sectors have substantially less energy self-sufficiency (15% or less). The North Central mills obtain almost half their fossil energy from coal, while the North Eastern mills show a greater dependency (over 50%) on oil. Radical reductions in the availability of natural gas from Canada may have a special impact on this area. The Rocky Mountain sector accounts for less than 2% of purchased energy - hence it is not a key sector in achieving energy self-sufficiency in the total U. S. industry.

Energy Consumption-Sector Locations
PULP/PAPER INDUSTRY



The recent upward trends in the prices of fossil fuels has caused concern in the forest industry. The projection of future fossil fuel prices are dependent upon many economic and international factors; the analysis of which is clearly beyond the scope of the present study. A recently published projection of fossil fuel prices by a specialist in this field was used to establish the trend of future fossil fuel prices. All price projections were made using 1975 dollars hence inflation could add as much as 8% to 10% more per year. Natural gas was assumed to become much less available for forest industry applications.

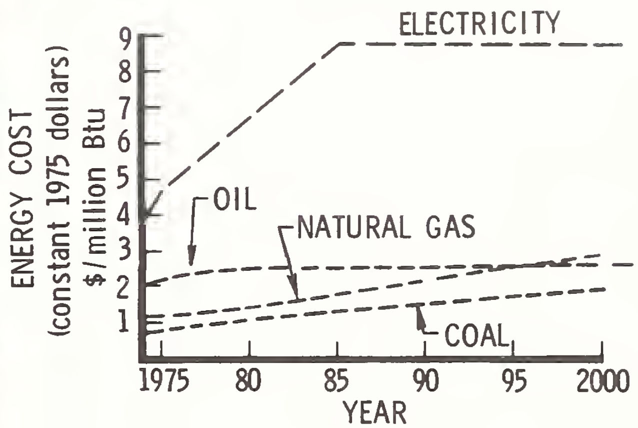
RESULTS

An upward price trend is projected through the next 25 years for the mix of fossil fuels used by the forest industries (Figure B). The ranges of the price projections of the major fossil fuels over next decade are identified for use in trade-off studies with the projected 1975-1985 prices of various mixes of oil and coal are shown in figure D. If the current fuel consumption mix of the pulp/paper industry were modified to reflect the replacement of natural gas with oil the projected fossil fuel cost for various sectors are shown on figure D.

Projected Energy Prices

- PROJECTED FUEL COSTS (1975 - 1985)
  - ALL COST PROJECTIONS ARE SHOWN IN 1975 DOLLARS-INFLATION WILL CAUSE ADDITONAL PRICE INCREASES

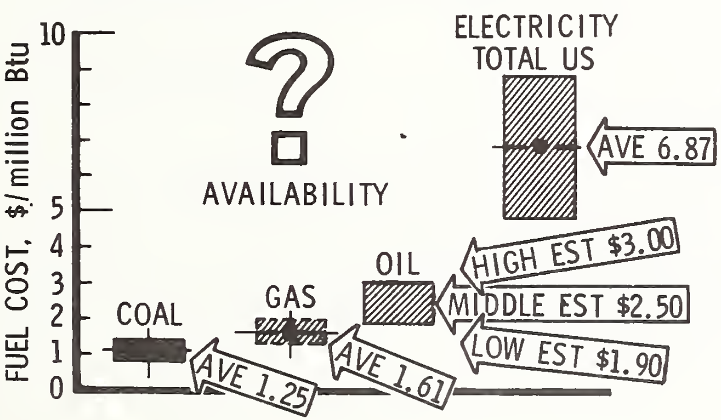
FUEL COST TRENDS



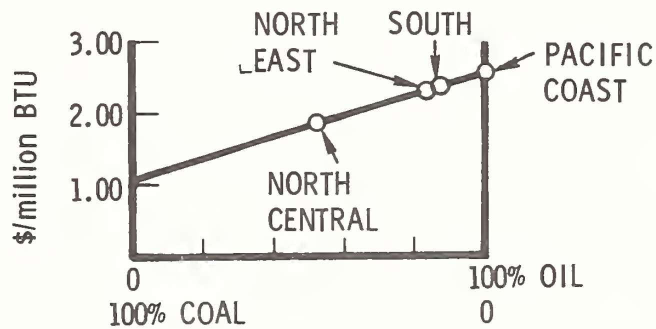
Source:
SHERMAN H. CLARK ASSOC. (with adjustments to natural gas prices for transportation and distributor margin - assuming continued FPC regulation)

A B
C D

PROJECTED PRICE RANGES (1975-1985)



PROJECTED COST OF FUEL MIXES*



*Based on 1975-80 projected prices with oil replacing gas in pulp/paper plants in various locations

Currently petroleum feedstocks are used in the compounding of special chemicals used by the forest industry in the manufacture of wood or paper products. Data were collected on the gross utilization of chemicals which include glues, extenders, resins, sizing etc. The use of petrochemical as feedstocks in making chemicals and the potential conversion to forest residue feedstocks are the subjects of other efforts.

FINDINGS

Most of the chemical used (over 80% of the gross tonnage) by the forest industry are inorganic and hence not part of the petroleum and residue feedstock issue. Of the remaining organic compounds about half can be identified as non-petroleum compounds. Even the most optimistic estimates of organic compounds, where there might be an opportunity to convert from petroleum to residue feedstocks can be shown to represent less than 1/4% of the U.S. petroleum consumption.

Chemical Consumption - Forest Industries

ANNUAL BASIS

INORGANIC CHEMICALS	AMOUNT 10^3 tons
● PULP / PAPER MFG*	
KAOLIN-a	2,192
CHLORINE	1,575
CAUSTIC SODA (sodium hydroxide)	1,575
SALT CAKE (sodium sulfate)	1,175
LIME (calcium oxide)	1,060
ALUMINUM SULFATE	750
(17% Al_2O_3	540
SULFUR	500
SODA ASH (sodium carbonate)	400
SALT (sodium chloride)	295
LIMESTONE (calcium carbonate)	215
SODIUM SULFITE	160
TITANIUM DIOXIDE	130
TALC	53
ZINC OXIDE	35
SODIUM CHLORATE	3
CARBON BLACK	2

ORGANIC CHEMICALS	AMOUNT 10^3 tons
● PULP / PAPER MFG*	
STARCHES	925
ROSIN (1)	308
LATEXES, SYNTHETIC (1)	63
WAX SIZES (1)	50
AMINO RESINS (1)	33
● VENEER AND PLYWOOD MFG**	
GLUES AND ADHESIVES (1) (soybean, casein, blood, albumen, synthetics, etc)	583
THERMOSETTING RESINS (1) (melamines, phenolics, polyesters, ureas, etc)	160

*Source: Marketing Guide to the Paper and Pulp Industry, Charles Kline and Co. 1972

**Source: U. S. Department of Commerce, Census of Manufacturers, 1972

(1) NOTE: Organic items excluding starches as noted represent approximately 2.5×10^9 lb / year
Total U. S. petroleum use about 2×10^{12} lb / year

The forest industries are the fourth largest sector of industrial energy purchasers and represent about 6% of the total U.S. industry purchase. This amount is equivalent to about 2% of the total U.S. consumption. Within the forest industry about 90% of this energy is used by the pulp/paper segment making them the major candidate for significant improvements in the current levels of energy self-sufficiency (about 40%) within the forest industry.

GEOGRAPHIC ISSUES

Overall about 84% of all energy purchases by the pulp/paper industry occur in the eastern half of the U.S. Each of the major geographic sectors has significantly different energy consumption patterns (e.g., fossil fuel mix, energy self-sufficiency ...)

FUEL ISSUES

Overall the industry uses oil and natural gas to supply about 72% of their purchase energy requirements. This mix of fuel presents special problems in the event of curtailment, interruption and/or price increases. Emission control standards are impacting the use of coal or higher sulfur oils for fuels.

Industry Survey

FINDINGS

- FOREST INDUSTRY - FOURTH LARGEST INDUSTRIAL ENERGY USER IN U. S.
- PULP/PAPER - MOST ENERGY INTENSIVE SECTOR OF FOREST INDUSTRY
- STRONG GEOGRAPHIC VARIATIONS IN FUEL TYPES AND QUANTITY WITHIN PULP/PAPER INDUSTRY
- FOSSIL FUEL ISSUES
    - AVAILABILITY OF OIL/NATURAL GAS
    - CONTINUED COST INCREASES
    - ENVIRONMENTAL PROTECTION IMPACT
- PETROCHEMICAL FEEDSTOCKS REPLACEMENT THROUGH WOOD RESIDUE CONVERSION WOULD NOT SIGNIFICANTLY IMPACT NATIONAL PETROLEUM CONSUMPTION

SITE SURVEY

The site survey provided the feasibility study with realistic data on the sources and consumption of energy in actual forest industry operations in various geographic sectors.

The survey was accomplished in four major subtasks:

SITE SELECTION

Criteria for site selection were developed jointly with the Forest Service. Data from the industry survey were used to identify the 94 candidate sites from which nine sites were utlimately selected.

DEFINITION OF THE DATA TO BE COLLECTED

An eight-page list of key data requirements were compiled for discussion with industry personnel at each of the sites visited.

DATA COLLECTION ON SITE

A series of visits were arranged to candidate mills and discussions were held with plant personnel. While most of the data requested were obtained, some were not due to lack of data keeping (typically in smaller mills) or concern over the release of proprietary cost data.

DATA REDUCTION

Raw data collected on site during the survey were analyzed and prepared for use in subsequent analyses.

Site Survey

OBJECTIVES

- TO OBTAIN ACTUAL OPERATING DATA AT SELECTED FOREST INDUSTRY SITES:
  - PULP/PAPER
  - SAWMILL
  - PLYWOOD

- TO ORGANIZE DATA FOR ANALYSIS OF:
  - ENERGY USES, SOURCES, AND COSTS
  - ENERGY CONVERSION CAPABILITIES
  - RESIDUE USE AND AVAILABILITY
  - PARTICULATE EMISSION CONTROL

APPROACH

- SITE SELECTION CRITERIA AND ANALYSIS
- DEFINITION OF DATA TO BE COLLECTED
- DATA COLLECTED (at site)
- ANALYSIS AND DOCUMENTATION OF FINDINGS

The industry survey (in the preceding section) revealed that the pulp/paper industry purchases about 92% of the energy of the primary forest industries. It also showed that within the pulp/paper industry about 3/4 of the total tonnage produced was from the Kraft process, hence Kraft (pulp/paper) operations were given priority in this effort.

SITE SELECTION CRITERIA (See page 53)

Site selection criteria were developed jointly by the Forest Service and The Aerospace Corporation. The objective was to identify a set of candidate mills by type, size, and locations which reflect typical national problems.

SECTOR DEFINITION

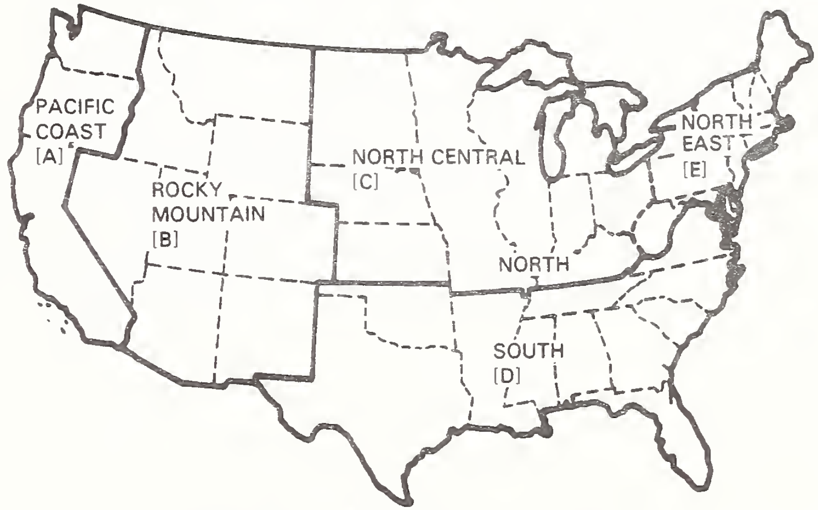
The U.S. was divided into five geographic sectors in order to facilitate identification of geographic differences in the site survey. The sectors were based on areas of homogeneity in terms of forest and forest industry. The sectors selected were those used by the Forest Service in reporting timber resources.

Site Survey

SITE SELECTION CRITERIA

- PRODUCTION/ENERGY USE BY SECTOR
- GEOGRAPHICAL DIVERSITY
- PRODUCTION SIZES PREDOMINANT FOR REGION

SECTOR MAP



SECTORS-TIMBER OUTLOOK
(U.S.F.S. publication)

Working definitions were created to avoid confusion in the feasibility study. These definitions include primary and secondary industries.

PRIMARY FOREST INDUSTRIES are defined as ones which use wood directly from the forest. Examples of primary forest industries included in the feasibility study are pulp plants, pulp/paper plants, sawmills, dimension mills, plywood mills, and veneer mills.

SECONDARY FOREST INDUSTRIES are defined as ones which do not use wood directly from the forest, but rely instead upon products from primary wood industries. Examples of some of the secondary industries which were not included in the study are paper converters, construction and wood products industries.

Site Survey — Forest Industry Definitions

PRODUCT	PRIMARY FOREST INDUSTRIES AS DEFINED AND INCLUDED IN FEASIBILITY STUDY	SECONDARY FOREST INDUSTRIES NOT INCLUDED IN FEASIBILITY STUDY
• PAPER AND BOARD	• WOOD STOCK PULP AND PULP/PAPER MILLS	• PAPER CONVERTERS • PAPER AND RAG STOCK MILLS
• LUMBER	• SAWMILLS AND DIMENSION MILLS	• WOOD PRODUCT MANUFACTURERS
• PLYWOOD	• PLYWOOD AND VENEER MILLS	• SECONDARY USERS AND MANUFACTURERS

Pulp/paper site survey candidate characteristics were identified by type, size and geographic distribution.

RAW DATA

The raw data on location and size of 307 pulp and paper mills is shown in Figure A. Inspection reveals that only 1% of mills are located in Rocky Mountains while over 1/3 are located in the South.

INDUSTRY ENERGY PURCHASES

A cummulative plot of the energy purchases (Figure B) shows both pulp and paper manufacturing operations. Secondary (papermaking only) operations purchase only about 15% of the total energy and typically produce less than 1000 tons per day. It should be noted that they do not receive wood directly from the forest and hence may not have ready accessibility to mill or forest residues.

LOCATION OF ENERGY USE

The geographic distribution of energy purchased shown on Figure C, indicates that the Rocky Mountain sector represents only about 2% of the total. The North East sector contains many secondary operations of paper converters.

ENERGY CONSUMPTION BY MILL SIZE

The frequency distribution on Figure D appears to have four natural size ranges:

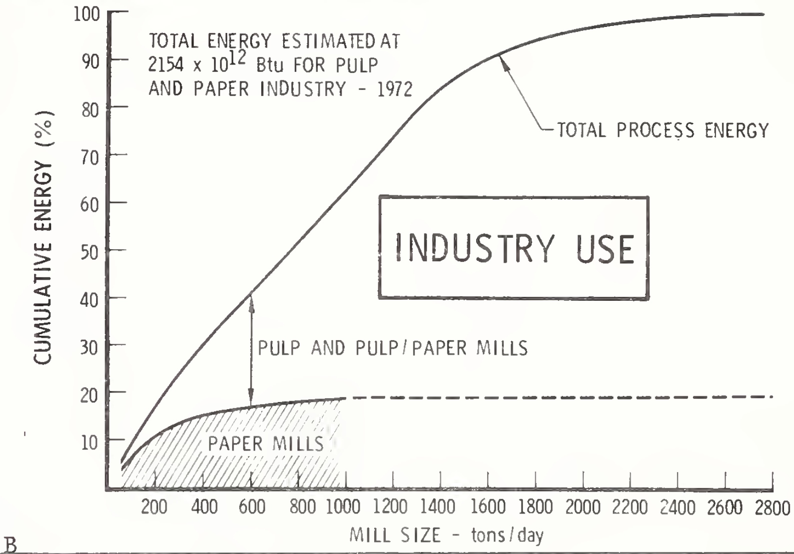
200 to 400 tons/day
400 to 700 tons/day
700 to 1000 tons/day
1000 to 1600 tons/day

Pulp/Paper - Site Selection Data[1]

DATA

NUMBER OF MILLS IDENTIFIED

SIZE tons/day	SECTOR PAC	RKY MTN	N.C	SOU	N.E	TOTALS
- 100	6	1	24	9	15	55
101- 200	10		13	7	17	47
201- 300	4		17	12	5	38
301- 400	5		15	4	3	27
401- 500	3		3	12	8	26
501- 600	7		5	7	3	22
601- 700	2	1	1	6	2	12
701- 800	2		2	3	3	10
801- 900	3	1	1	10		15
901-1000	2			10	3	15
1001-1100	1			3	1	5
1101-1200	1	1		5		7
1201-1300	1			6		7
1301-1400				4		4
1401-1500				4		4
1501-1600				5		5
1601-1700				3		3
1701-1800				1		1
1801-1900	1					1
1901-2000				1		1
2000-2100				1		1
2701-2800				1		1
	48	4	81	114	60	307

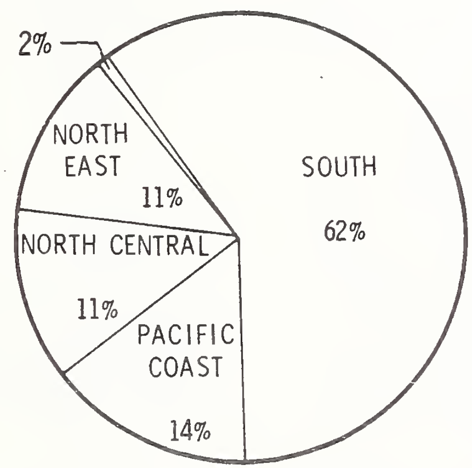


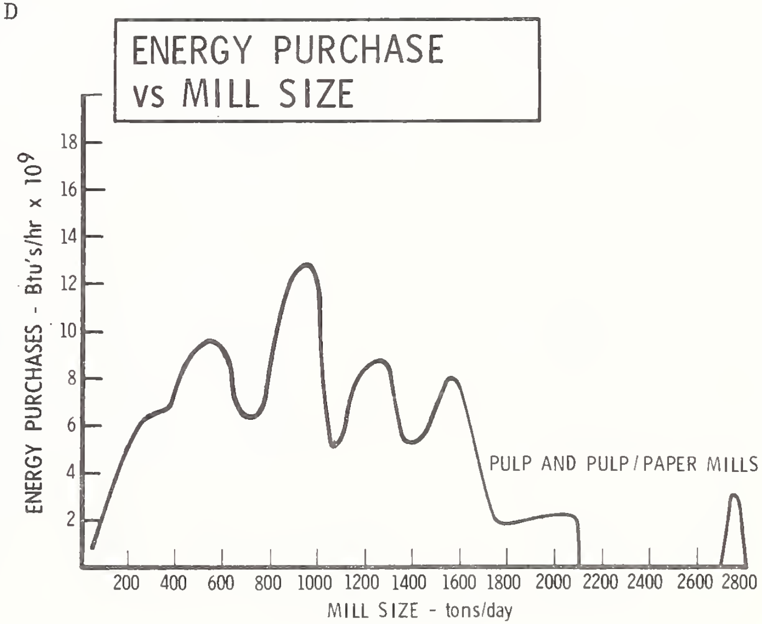
A B

C D

ROCKY MOUNTAIN

LOCATION OF ENERGY USE





1) Source: Data derived from Lockwood's Directory 1975 and TAPPI 1972 Survey

A histogram of the distribution of energy used by pulp/paper mills in various sectors was generated for each mill size category. The selection process used data from the histogram as well as judgements.

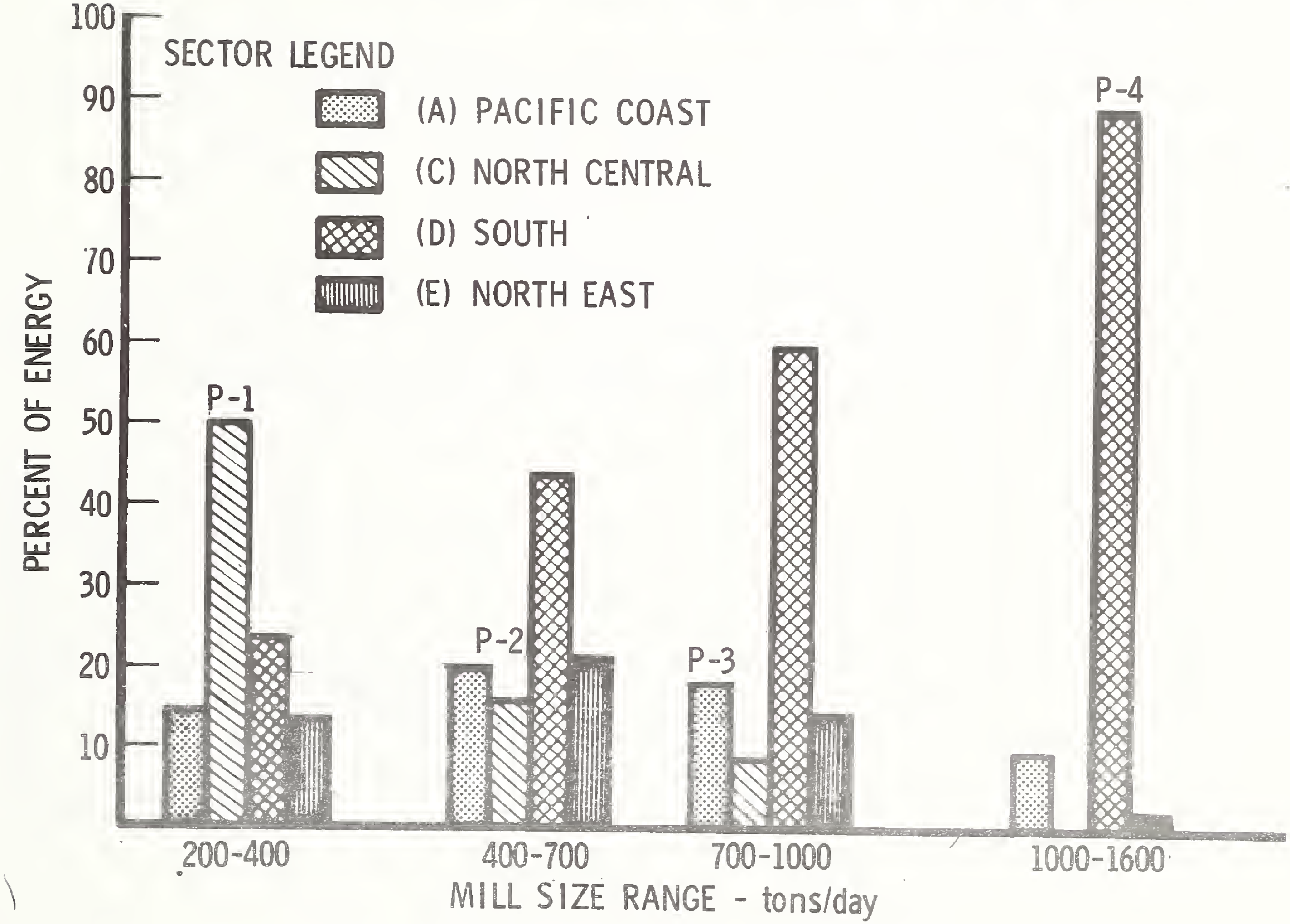
The largest mill category (1000 to 1600 tons/day) was selected in the South where over 90% of the mills this size are located. (P-4)

The smallest mill size category (200 to 400 tons/day) was selected in the North Central sector since most mills in this size are located in that area. (P-1)

An intermediate size mill in the 700 to 1000 tons/day size category was selected on the Pacific Coast to provide geographic dispersal. (P-3)

Finally a mill of 400 to 700 tons/day was selected in the North Central area as a replacement for North Eastern mills which were found to be largely paper converters and hence not part of this study. (P-2)

Energy Histograms for Four Pulp/Paper Mill Size Ranges by Sector



The selection of sawmill and plywood mill site survey candidates was scaled to reflect their limited (8%) contribution to energy purchases of the primary forest industry. (See Figure A)

PLYWOOD MILL

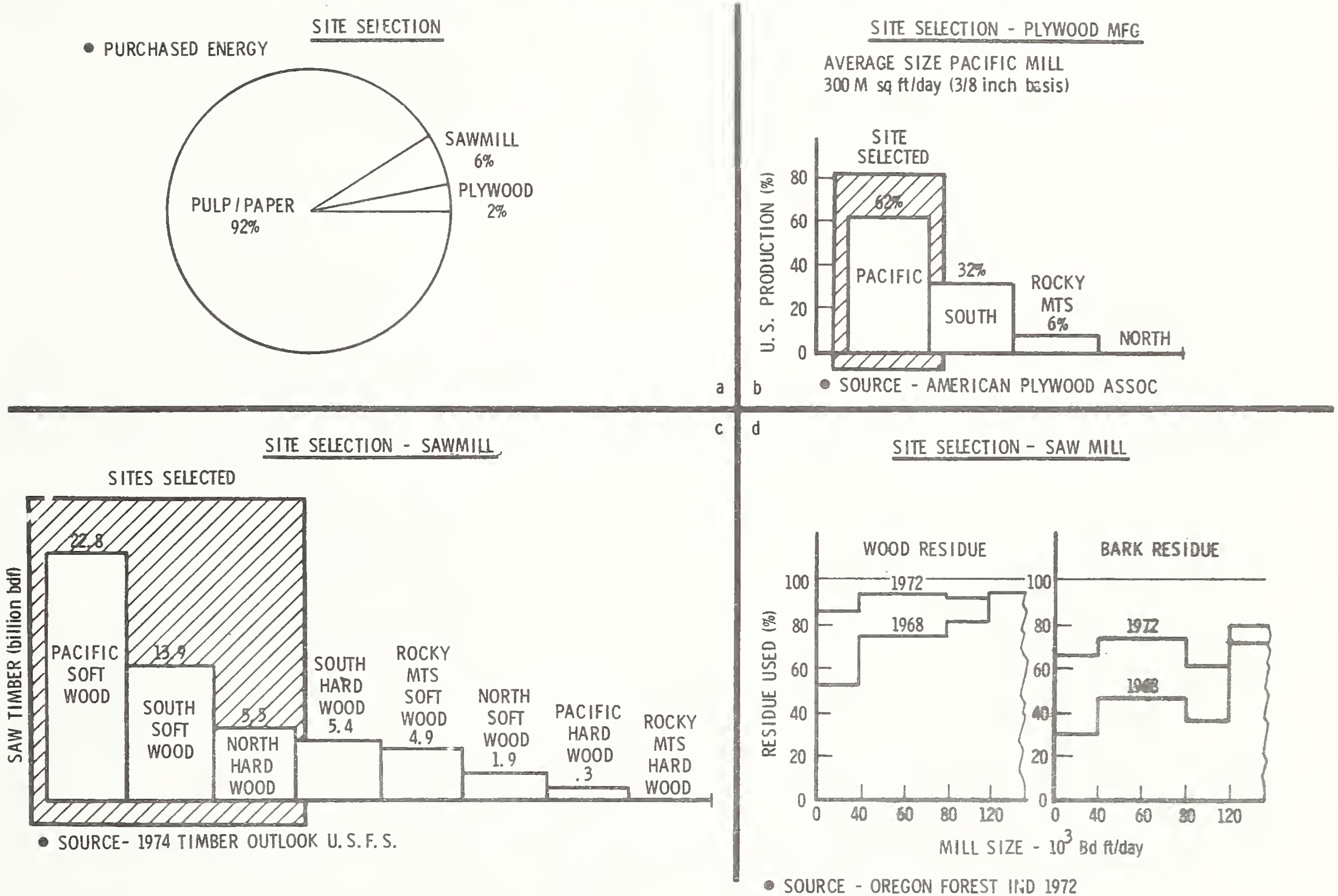
A single plywood manufacturing site was selected since plywood accounts for only about 2% of the purchased energy of the primary forest industry. A histogram (see Figure B) of production within various sectors, shows the Pacific Coast as the sector with 62% of all production. Candidate mill size was selected 300 M sq. ft/day which is the average mill for this sector.

SAWMILLS

Sawmills purchase about 6% of the primary forest industry energy. Four sawmills were selected the site survey in order to cover both hard and softwood, yard and kiln drying, as well as geographic and size distribution.

A histogram (Figure C) of the wood type and sector location indicated that candidate sites should include: Pacific Coast softwood, Southern softwood and Northern hardwood. Sizes were selected to reflect various levels of residue utilization (see Figure D).

Site Selection - Sawmill and Plywood Mill



The characteristics of site survey candidates which define the type of mill, its sector location, and production were used to identify 94 specific candidates by name. These candidate mills were reviewed with the Forest Service and preliminary discussions were held with mill personnel at the candidate sites. The preliminary discussions covered issues such as the availability of required data and its releasability based upon maintenance of source confidentiality. Ultimately nine sites were visited.

Site Survey - Site Selection

PULP / PAPER

CODE *	PRODUCT	PRODUCTION tons / day	LOCATION (sector)	PRINCIPAL FUEL (purchased)
P-1	KRAFT	250	NO. CENTRAL	COAL & GAS
P-2	KRAFT	360	NO. CENTRAL	COAL
P-3	KRAFT	840	PACIFIC	GAS
P-4	KRAFT	1600	SOUTH	OIL, GAS, COAL

SAWMILL

CODE	PRODUCT	PRODUCTION MBdf / day	LOCATION (sector)	DRYING
S-1	SHORING LUMBER	30	SOUTH	NO KILN
S-2	CASE GOODS	32	NO. CENTRAL	STEAM KILN
S-3	YARD LUMBER	50	PACIFIC	NO KILN
S-4	YARD LUMBER	185	PACIFIC	STEAM KILN

PLYWOOD

CODE	PRODUCT	PRODUCTION M sq ft / day	LOCATION (sector)	DRYING
PW-1	PLYWOOD	300	PACIFIC	STEAM KILN

* Code to Protect Identity of Source

The data requirements which were used in the site survey investigation were documented in an eight-page itemized list which was used at each of the sites in the survey. The itemized list was developed from initial assessments of the data required to perform the analysis of system options.

Three major flows were considered in the preparation of the itemized data requirements test:

<u>MATERIAL FLOW</u>

This flow, which describes the manufacturing process, begins with raw material, proceeds through the manufacturing process, and ends with a description of products and or residues.

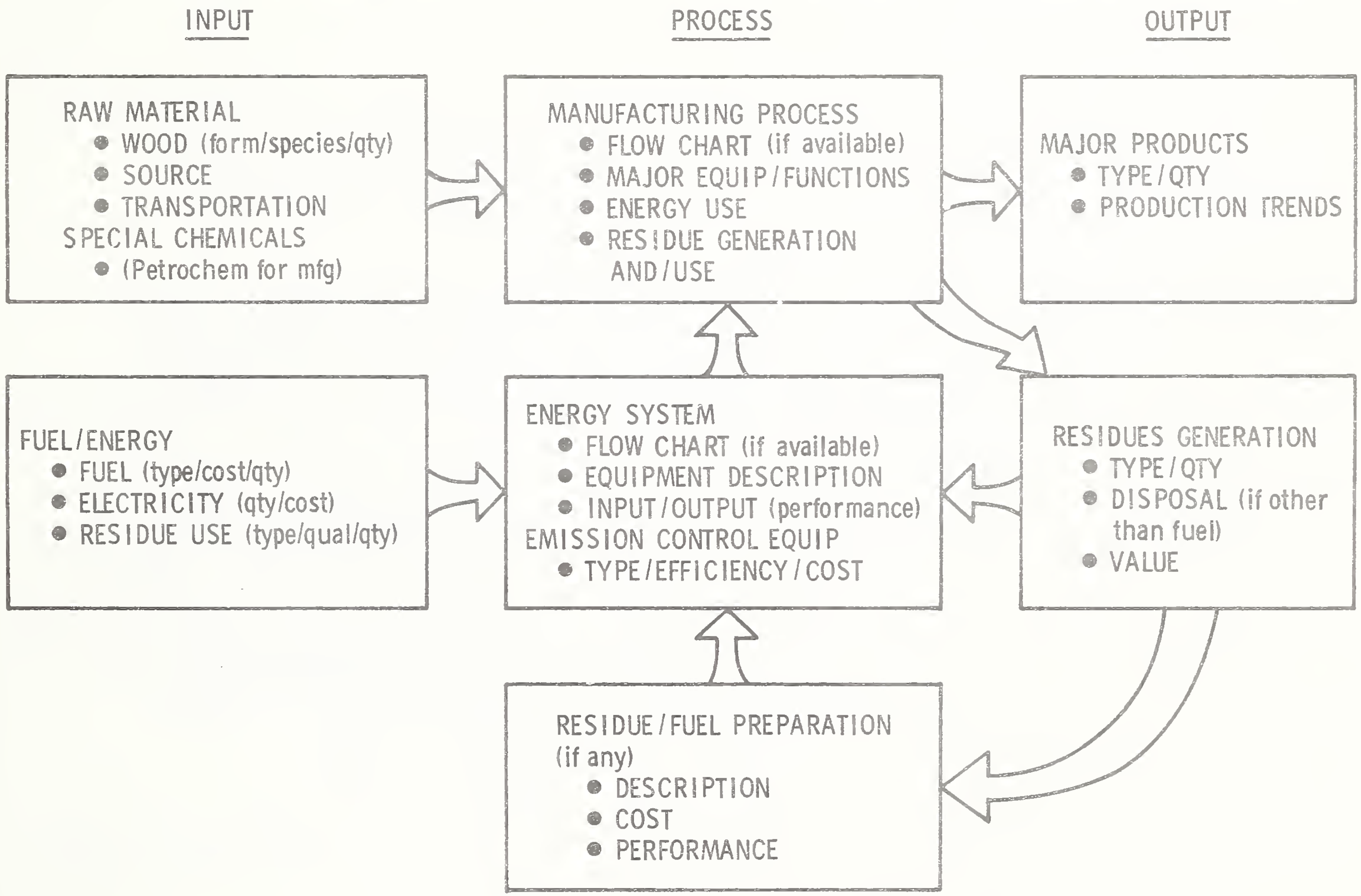
<u>ENERGY FLOW</u>

This flow begins with the inputs of fuels, proceeds through the energy system to energy utilization within the manufacturing process. Combustion equipment and emission control equipment were emphasized in this survey.

<u>RESIDUE FLOW</u>

The generation, utilization, and/or disposition of residues for fuels or other uses were given special attention.

Site Survey Definition of Data Collection Requirements



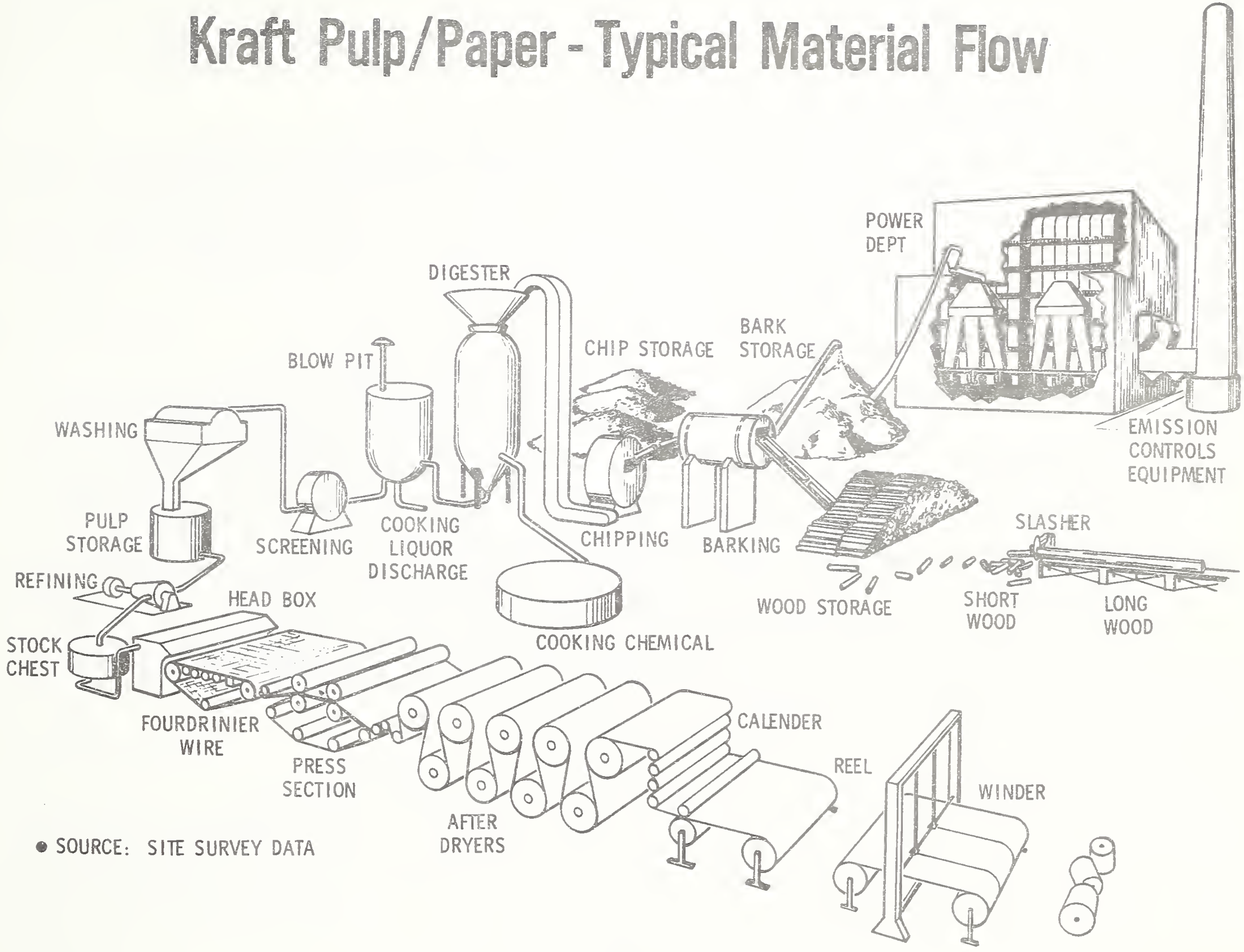
The Kraft process was first used in Sweden in the late 1800's. The process name which literally translates as "strength" was first introduced in the U. S. about 1911. Since its introduction, the Kraft process has become the principal method of manufacture in this country. The dominance of this method is reflected in the selection of Kraft mills for the site survey.

Originally the process resulted from substitution of salt cake (sodium sulfate), for reasons of economy, in place of soda ash (sodium carbonate) in makeup cooking liquor chemicals. Cooking liquor consists of aqueous alkaline solution of high sulfide content, obtained through reduction of salt cake in the recovery furnace. Present practice involves continuous flow digestion of wood chips which causes de-lignification and separation of pulp fibers for later paper making.

The major process is well illustrated by the flow obtained from one of the mills in the site survey. This mill flow includes chip preparation, cooking, pulp separation, refining, and final paper making and drying. Supplementary processes such as chemical recovery, and spent liquor combustion are not shown in the illustration.

Approximately 10% of purchased energy is consumed as electricity, the remainder as steam. Nearly 1/3 of steam used by plant goes to paper machinery for heating and drying with the majority of the remainder used for digestion, evaporation, and other processes.

Kraft Pulp/Paper - Typical Material Flow



• SOURCE: SITE SURVEY DATA

The raw data from the site survey were analyzed and summarized for use in follow-on studies. Some of the data were not available, either because records were not kept or because mill personnel were concerned over release of proprietary data. In some cases it was possible to make estimates of the missing data with reasonable assurance of correctness and in others it was not.

HIGHLIGHTS

The mills were sized based on estimated production at the time of the survey and not on their capacities which were often much larger. The selected mills in the North Central and Pacific Coast sectors reflected the trends of fossil fuel utilization typical of those sectors, while the mill selected in the South used more coal than is typical of that sector. Net specific energy purchases which ranged from 18 to 27×10^6 Btu/ton were scattered evenly about the industry trends. The mills surveyed had all achieved energy self-sufficiency ranging from 39% to 51% and three of the four mills are consuming at least some wood or bark residues. Fuel cost which was among the most difficult type of data to obtain in this survey indicated that currently the mills investigated are paying from $.85 to $1.25 per 10^6 Btu.

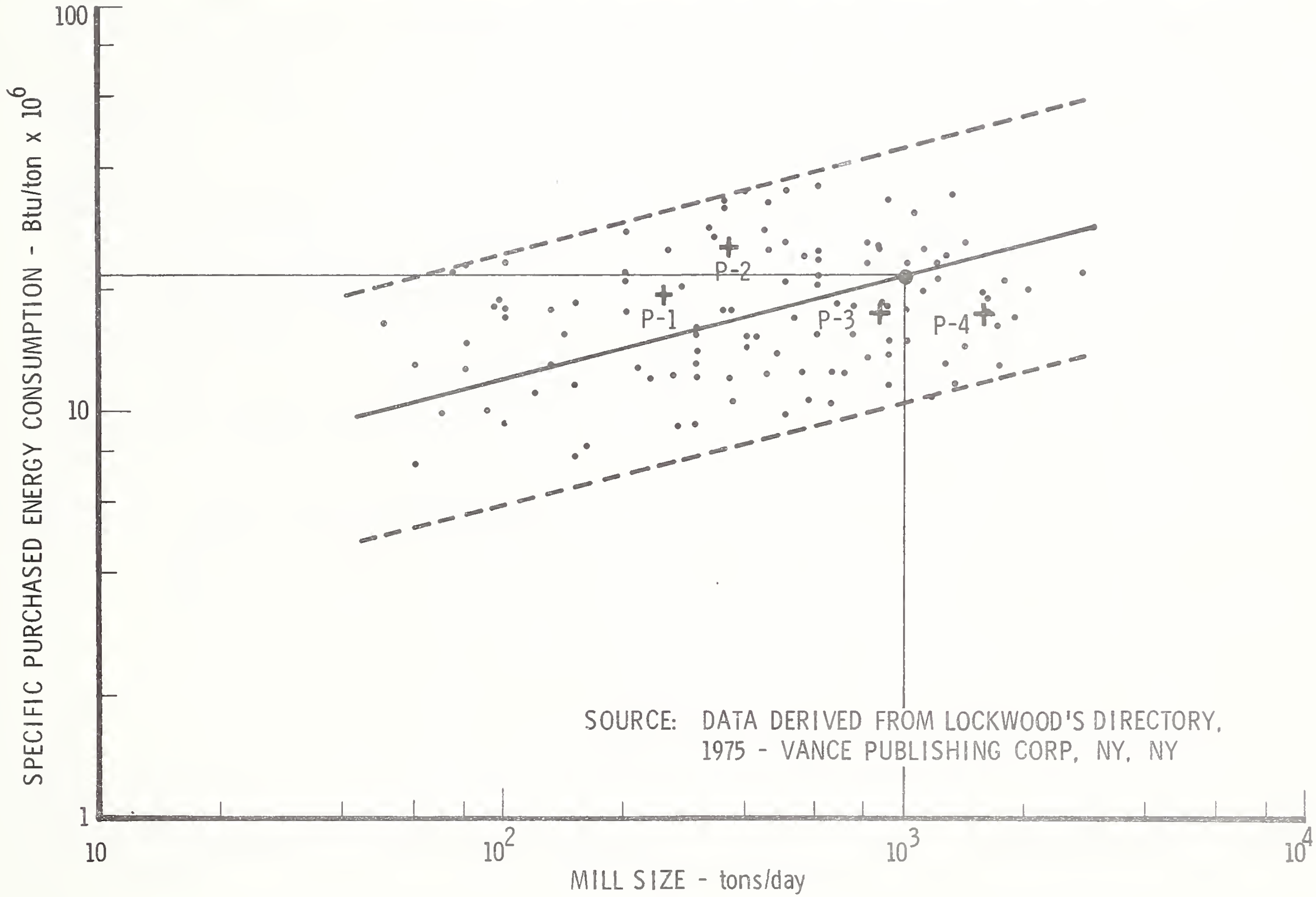
Site Survey Data Summary – Pulp/Paper

	P-1	P-2	P-3	P-4
PRODUCTION, tons/day	250	360	840	1,560
ENERGY PURCHASES, 10^{12} BTU/yr				
• COAL	1.128	3.360	-	6.144
• GAS	0.640	-	3.580	0.776
• OIL	0.024	-	-	2.766
• ELECTRICITY	-	-	1.904	0.150
TOTAL ENERGY	1.792	3.360	5.484	9.836
SPECIFIC ENERGY USE (purchases), 10^6 BTU/ton	20.6	26.66	18.65	18.01
RESIDUE (and wood) USED FOR FUEL, 10^{12} BTU/yr				
• SPENT LIQUOR	1.279	1.842	4.309	7.957
• BARK	-	0.315	-	1.881
• CHIPS (green)	0.570	-	-	-
TOTAL	1.849	2.157	4.309	9.838
PERCENT OF TOTAL ENERGY FROM RESIDUE AND WOOD	51%	39%	44%	50%
CURRENT ENERGY COST, $\$10^6$/yr				
• COAL	1.410	4.200	-	7.000*
• GAS	0.310	-	NA	0.300*
• OIL	0.052	-	-	0.145*
• ELECTRICITY	-	-	NA	0.880
TOTAL ANNUAL	1.772	4.200	NA	8.325
ENERGY PURCHASE PRICE, $\$/10^6$ BTU	0.99	1.25	NA	0.85

NA - not available
*Best estimate when data not available

The specific energy purchases of the four pulp/paper mills surveyed, which ranged between 18 and $27x10^6$ Btu/ton, were compared with industry trends. The specific energy consumption from the site survey was found to lie within the scatter of industry data.

Specific Purchased Energy vs Mill Size - Pulp/Paper



The collection of data from sawmills and plywood mills was accomplished using the same approach which was used with pulp/paper mills. There were a number of significant differences however, in the quantity and quality of data obtained.

RESULTS

In conducting the survey it quickly became apparent that many of the smaller operations and particularly those without kilns did not have detailed data on energy use.

The great variation from mill to mill in energy utilization and sources also became apparent in the survey. Energy self-sufficiency in the sample mills surveyed ranged from 0 to 90%.

The smaller sawmills without kilns appear to represent one of the most difficult types of mills for achieving energy self-sufficiency. On the Pacific Coast the very low cost hydro-electric sources would make this problem even more difficult.

Site Survey Data Summary - Sawmills and Plywood Mill

	S-1	S-2	S-3	S-4 (1)	PW-1 (1)
PRODUCT	SHORING TIMBER	CASE GOODS	YARD LUMBER	YARD LUMBER	PLYWOOD
LOCATION	SOUTH	NO. CENTRAL	PACIFIC	PACIFIC	PACIFIC
PRODUCTION					
MBdf/day	30	32	50	185	
M sq ft/day (3/8 inch basis)					300
PRIMARY ENERGY PURCHASED					
ELECTRICITY, 10^6 KWH/yr	NA	NA	1.0	9.5	
OIL, MBbl/yr	0	7.5	2.0		
HOG FUEL, Mton/yr	0	0	0	57	
ESTIMATED ENERGY USE, 10^9 BTU/yr					
ELECTRICITY	NA	NA	3.3	32	
GAS	0	0	0	3.6(LPG)	
OIL	0	45	2.6	0	
HOG FUEL	0	0	0	570	
			5.9	606	
ENERGY USE (steam)	(none)	45% PRE-DRY 20% KILN 25% DIMENSION 10% SAWMILL	(none)	USES INCLUDE KILN DRYING, AND DIMENSION	USES INCLUDE SOFTENING, PRESSING, DRYING
EMISSION CONTROL	(none)	NA	CYCLONE	MULTICYCLONE	

(1) Common energy plant both mills
NA - Not Available

Information and insight were obtained from the site survey which were useful in the analysis of energy self-sufficiency options. Priority in this survey was given the pulp/paper industry because of its potentially greater contribution to national energy self-sufficiency. The site surveys at pulp/paper operations produced the more significant data, which, it was felt, reflected the greater engineering emphasis given to energy problems by the larger and more intense energy users. The smaller energy users (such as small sawmills) in most cases did not have the personnel assigned or the record keeping established that was required to provide the requested data. Overall, the lack of data from the smaller mills was not considered critical to the study since the potential contributors of these operations to energy self-sufficiency are not large.

Site Survey

FINDINGS

- PULP/PAPER - FOUR PLANTS SURVEYED
  - ENERGY SELF SUFFICIENCY - 40% TO 50%
  - PURCHASED ENERGY COSTS \$0.85 TO \$1.25/10^6 Btu
  - THREE PLANTS CURRENTLY BURNING WOOD RESIDUE
- SAWMILL AND PLYWOOD - FIVE SITES SURVEYED
  - ENERGY SELF SUFFICIENCY - 0% SMALL MILLS TO 94% LARGE MILLS
  - SAWMILL RESIDUES (except bark) - HIGH VALUE AS PULP CHIPS
  - VERY LARGE ENERGY USE VARIATION NOTED AMONG MILLS SURVEYED (i.e., kilns, steam pre-treating of logs...)
- ENERGY ISSUES
  - CONCERN OVER NATURAL GAS AVAILABILITY/INTERRUPTION
  - ANXIETY OVER CONTINUED FOSSIL FUEL PRICE INCREASES
  - CONCERN OVER IMPACT OF NEW EMISSION CONTROLS STANDARDS ON CONVERSION TO RESIDUE FUELS

COMBUSTION SURVEY

The purpose of the Combustion Survey was to understand the current state of the art and to provide candidate combustion systems inputs for systems analysis. This study covers direct energy conversion of wood residues to achieve energy self-sufficiency.

This survey is oriented toward identification of critical or high payoff areas and is not intended as a text on combustion technology. This report assumes a fundamental knowledge of such technology on the part of the reader.

METHOD

The survey included both the collection of information regarding combustion equipment, operating data and data reduction into a form suitable for input to analysis. Data collection included a strong reliance upon manufacturer data as well as published sources and site survey queries. Some data on combustion equipment cost and emission control equipment performance had to be developed due to lack of availability in the survey.

Combustion Survey

<u>OBJECTIVES</u>

- TO IDENTIFY AVAILABLE SYSTEMS/EQUIPMENT FOR SPECIFIC TYPES AND SIZES OF OPERATIONS
- TO COLLECT DATA
  - PERFORMANCE, FUEL REQUIREMENTS, CAPACITY...
  - COST (purchase, operating)
  - EMISSION CONTROL (cost and performance)

<u>APPROACH</u>

- REVIEW AVAILABLE LITERATURE
  - PERIODICALS/JOURNALS
  - BOOKS
  - MANUFACTURER'S PUBLICATIONS
- CONTACT MANUFACTURERS
- COLLECT DATA DURING SITE SURVEY

The combustion stage is a part of a larger material and energy flow system which include harvesting, fuel processing, and transportation operations. The feasibility study has shown that opportunities for improvement may lie in several operations including those which precede the combustion of wood as a fuel.

ISSUES

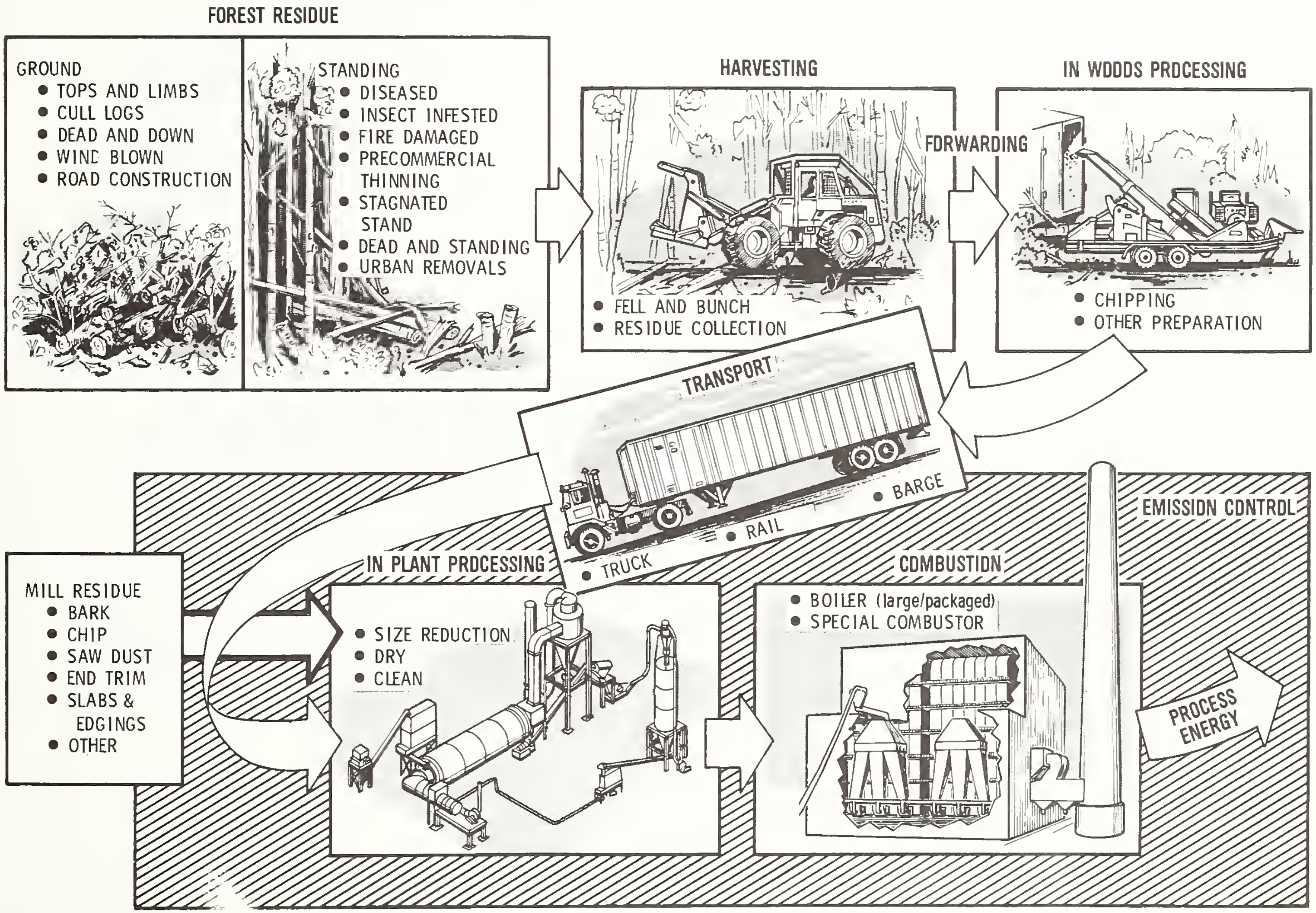
Forest residues appear to represent a more significant source of fuels than do mill residues which are becoming increasingly committed to other (higher value) applications.

Current harvesting and/or chipping of sound standing trees could be expanded to include harvesting of ground and mortality residues. Forest operations could be expanded to include cleaning, sizing, grading, drying and/or transportation of wood to pulp/paper operations.

At present, transport is typically accomplished by truck up to 50 miles, by rail up to 200 miles, and by barge at distances of 200 miles or greater.

Combustion systems, as considered in this study, include the boiler or combustor plus any emission control equipment as well as in-plant fuel preparation equipment. In this study, certain auxiliaries such as electrical generators were not considered as primary combustion equipment adjuncts except in one specialized case.

Residue Fuel Flow Concepts



EQUIPMENT SIZES FOR TYPICAL FOREST INDUSTRY APPLICATIONS

The thermal equipment demands of the principal forest industries are shown (Figure A) in terms of the capabilities of various types of single units.

Steam is used in most of the primary forest industry applications (except for sawmills without kilns) for processing, heating, pretreating, drying, plus other uses. Figure A shows the thermal equipment capabilities and typical range of industrial demands as steam. The highest steam generation demand rates are found in the pulp/paper industry.

EQUIPMENT SURVEY DATA SOURCES

The list of manufacturers in Figure B identifies the data sources used in this study and does not imply any evaluation or endorsement. The reader is cautioned against construing the list as a comprehensive vendor source list.

RESIDUE COMBUSTION SYSTEM DESIGN CANDIDATES

The power boilers design candidates shown in Figure C were selected in terms of specific energy purchase requirements for fossil fuel developed from the source site survey. The purpose was to examine hourly steam rate requirements (which vary from approximately 200,000 lb/hr to slightly above 1,000,000 lb/hr) in order to conceptually consider alternatives in the analysis.

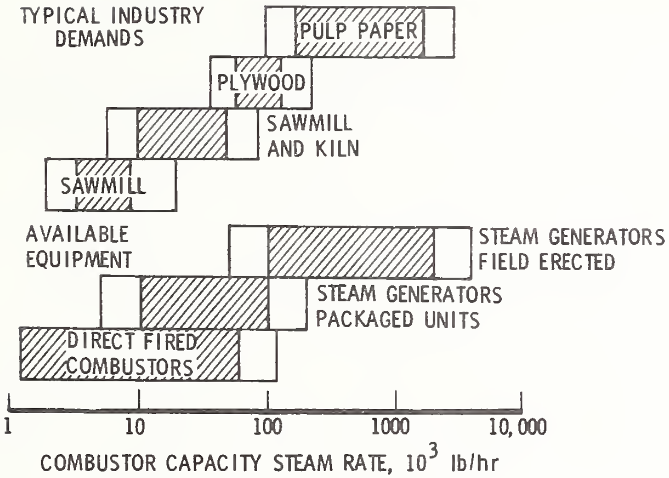
RESIDUE REQUIREMENTS

Residue requirements were established to replace all purchased fossil fuel in order to achieve 100% self-sufficiency. Assumptions used in developing the results include both wet (50%) and dry residue. These estimates were used to size and cost the fuel preparation equipment.

Available Combustion System Options

A

TYPICAL INDUSTRY DEMANDS



B

EQUIPMENT SURVEY DATA SOURCES

BOILERS AND STEAM GENERATORS

FIELD ERECTED
- RILEY STOKER
- FOSTER WHEELER
- DETROIT STOKER
- COMBUSTION ENGINEERING
- BABCOCK AND WILCOX
- UNION IRONWORKS

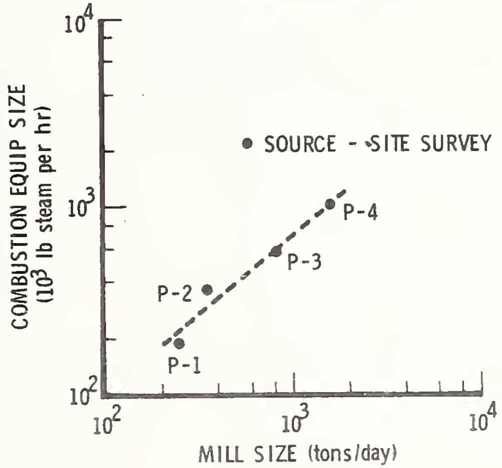
PACKAGED UNITS
- YORK SHIPLEY
- BUMSTEAD WOLFORD
- INDUSTRIAL BOILER
- GASKELL
- ULTRA SYSTEMS

SPECIAL COMBUSTORS
- ENERGEX
- ENVIROMETRIX
- COEN
- COMBUSTION POWER
- HEIL
- THOMPSON DEHYDRATING
- MEC CO

EMISSION CONTROL
- JOY MFG
- COMBUSTION POWER
- CEILCOTE COMPANY

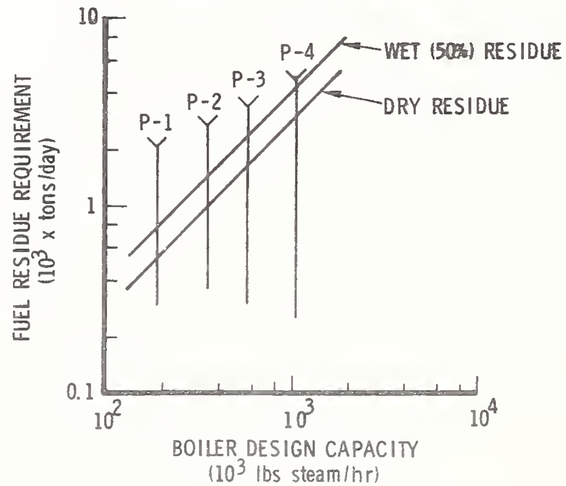
C

RESIDUE COMBUSTION POWER BOILER DESIGN CANDIDATES



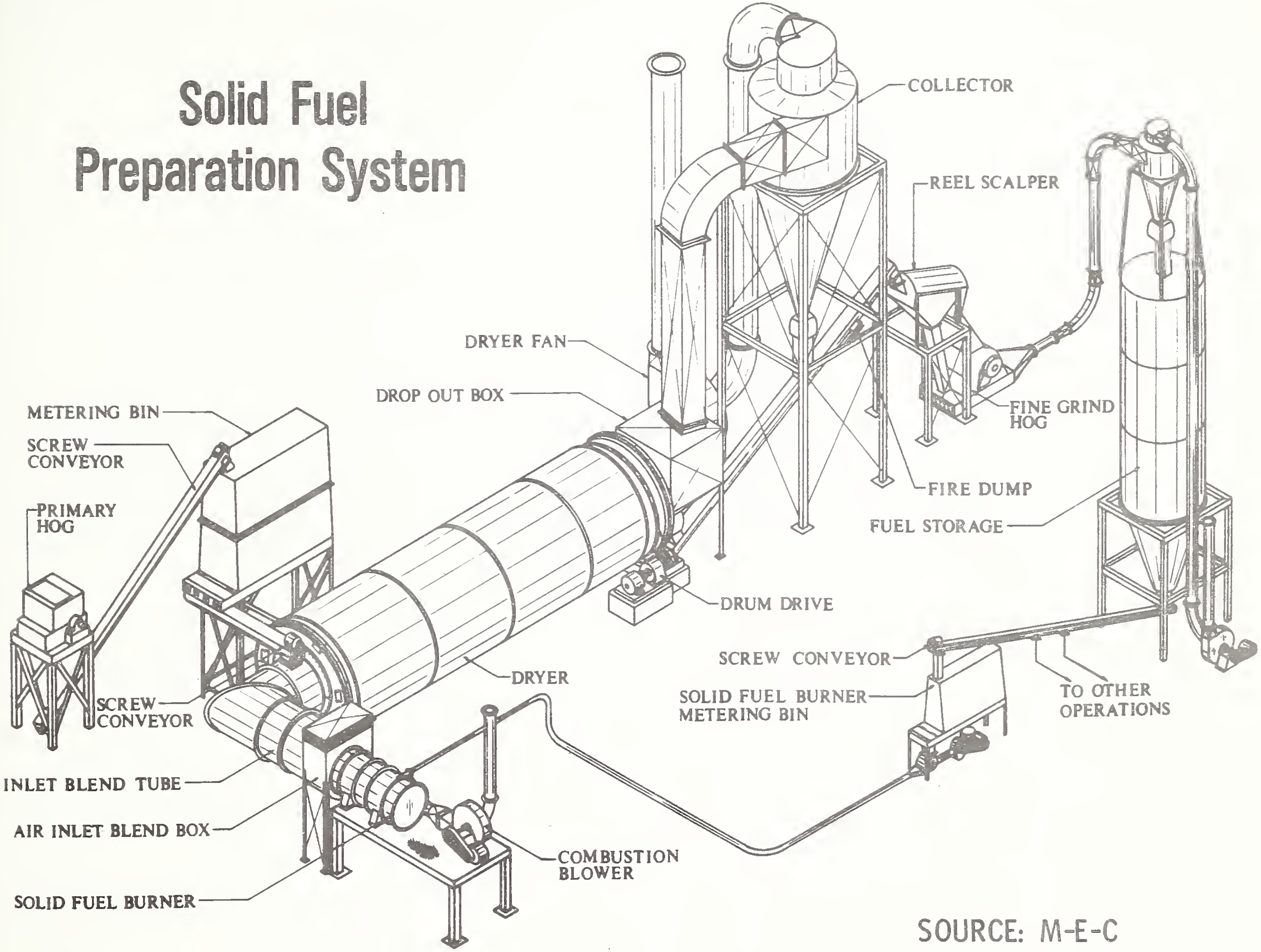
D

RESIDUE REQUIREMENTS



Many installations fire as-received hog fuel which varies in size/density, contains excessive moisture (50% moisture content or more), and may be contaminated with sand, dirt, tramp iron, etc. Residue fuel may be enhanced by in-plant fuel preparation (as shown) which may include: sizing (hogging), cleaning, drying, collecting, storing, conveying, and metering.

Solid Fuel Preparation System



SOURCE: M-E-C

Packaged boilers are small firetube or water tube units which are factory built and hauled to the site intact. Physical dimensions are limited to transport clearances.

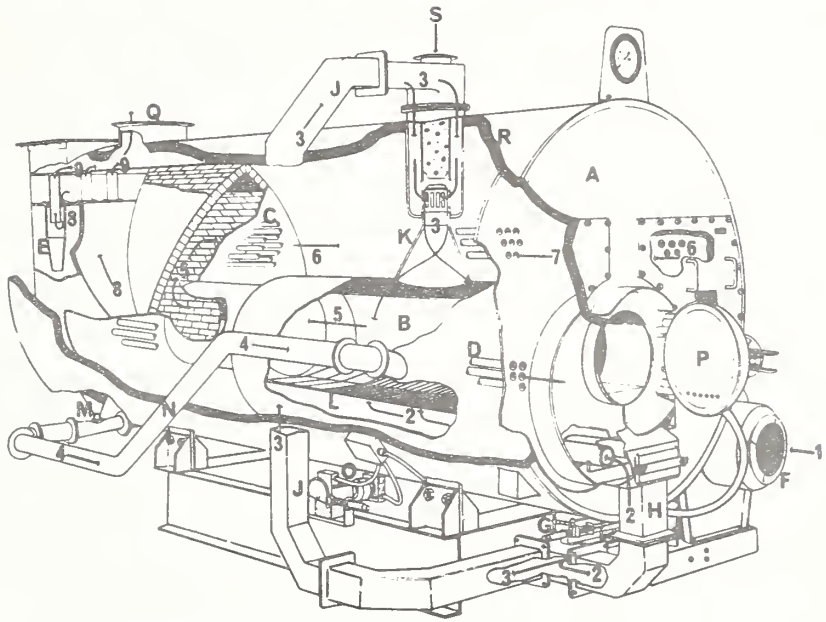
Procurement, installation, operation, and manning requirements for packaged boilers are simpler than with larger field erected units. Firetube boilers are typically limited to 30,000 lb/hr, low-pressure steam. Water tube boiler ratings increase the applications of packaged boilers to about 100,000 lb/hr with high-pressure steam. The size limitation restricts this type of unit from applications requiring large steam rates in a single unit which are typical with pulp/paper or the larger plywood and sawmill operations.

KEY ISSUES

Most manufacturers recommend burning dry wood (less than 15% moisture) however, many units can and do burn wetter fuels. Fuel size depends on allowable emissions and type of control as well as combustion chamber design (i.e., suspension or grate system). In a typical grate system fuel particles are 2 to 3 inches while much smaller particles are used in suspension systems.

Some package boiler designs are commerically available which incorporate bark and hog fuels as well as multi-fuel firing capability. No radical improvements are anticipated in this technology beyond evolutionary development and design improvement.

Small Firetube Packaged Boiler



- A Front of Boiler.
- B Furnace.
- C 1st pass (tubes).
- D 2nd pass (tubes).
- E Grit arrester.
- F Fan.
- G' Modulating dampers.
- H Underfire air.
- J Overfire air.
- K Fuel/air tube.
- L Grate.
- M Venturi.
- N Grit re-firing tube.
- O Master modulating control.
- P Fire door.
- Q Flue gas outlet.
- R Boiler shell.
- S Fuel inlet.

1. Air inlet.
2. Primary air supply (under grate)
3. Secondary air supply.
4. Grit transporting air.
5. Products of combustion leaving furnace.
6. Products of combustion in first pass smoke tubes.
7. Products of combustion in second pass smoke tubes.
8. Products of combustion entering grit arrester.
9. Products of combustion leaving grit arrester.

Source: Jimarco Ltd

Field-erected hog fuel/bark boilers are typically custom engineered for each application and assembled in the field. Some components may be prefabricated. The capacities of these boilers can meet even the very large demands of pulp/paper plants. Capacities of large field erected boilers firing solid fuels (such as coal) can exceed 1.0×10^6 lb/hr of steam. However, it does not appear that any industrial boilers firing wood alone have such capacity at present.

Design considerations of wood-fired units are similar to coal-fired units. They are generally sized for low volumetric heat release rates (on the order of 25,000 Btu/hr - cu ft) to provide time for complete combustion and low carryover. Top suspension is used to allow downward thermal expansion of the water tube walls. Grating systems are used for ash removal and/or thin pile burning. Types of gratings include vibrating, reciprocating, oscillating, and traveling grates. The most popular arrangement is the endless traveling grate which can burn a wide variety of coals and waste fuels or municipal residues. Pinhole grating systems for supplying combustion and cooling air are preferred for wood fuels where varying or high moisture content is prevalent. The figure shows several variations of such designs. A claimed feature of tangentially fired designs is that local hot spots are minimized which reduces nitrogen oxide formation rates. Where residue or municipal wastes are burned in conjunction with coal, pneumatic fuel distributors are typically added in the front of the furnace - above the spreader stokers handling coal.

An issue associated with wood firing, field-erected boilers is that they are larger, more complex and more costly than oil or gas boilers, but resemble coal-fired boilers whose technology is well supported by industry and government. Wood boilers with multifuel firing capability are currently available to meet industry needs.

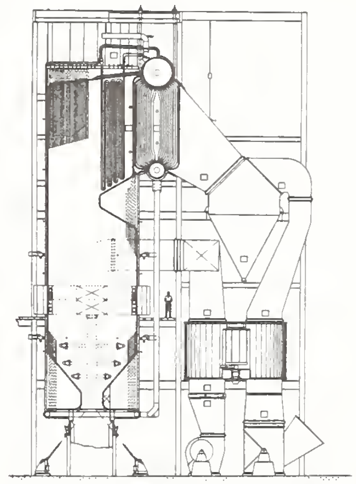
Field Erected Bark Burning Boilers

1
Type VU-40s
Firing Arrangement Stoker and tangential firing
Steam Capacity 600,000 lb/hr
Pressure (design) 1450 psig
Temperature (sho) 900 F
Fuels Bark, gas, oil

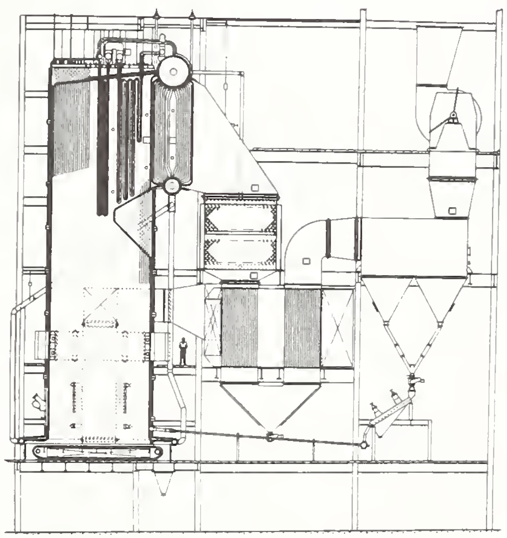
2
Type VU-40s
Firing Arrangement Tangential firing (bark supplied pneumatically)
Steam Capacity 500,000 lb/hr
Pressure (design) 1000 psig
Temperature (sho) 825 F
Fuels Bark and oil

3
Type VU-40s
Firing Arrangement Stoker and horizontal firing
Steam Capacity 450,000 lb/hr
Pressure (design) 1475 psig
Temperature (sho) 925 F
Fuels Bark and natural gas

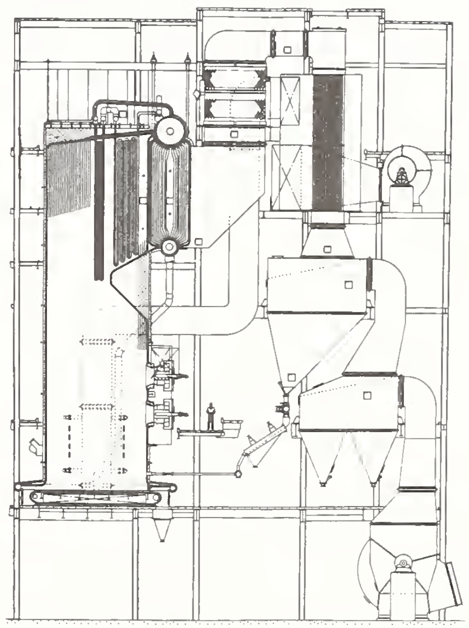
2



1



3



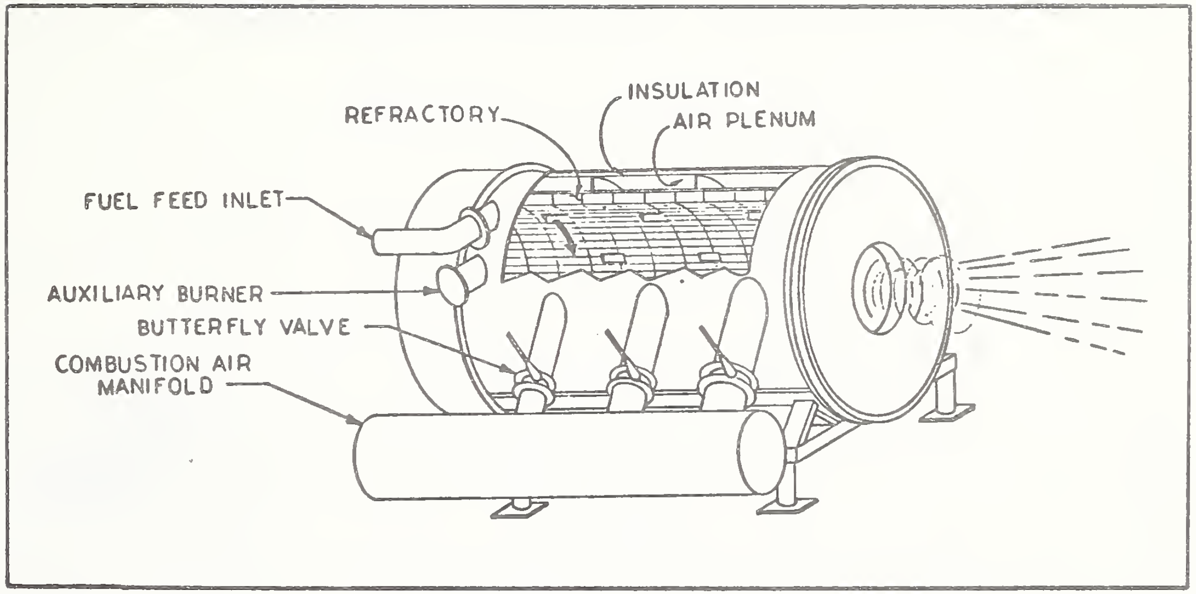
SOURCE: COMBUSTION ENGINEERING

The Energex burner is an example of the modern combustors being marketed which use wood residues or other solid fuels. The system, comprised of 1) air blower, 2) burner, 3) operating controls, and 4) any optional auxiliaries, may be used for direct drying, steam generation, or other needs.

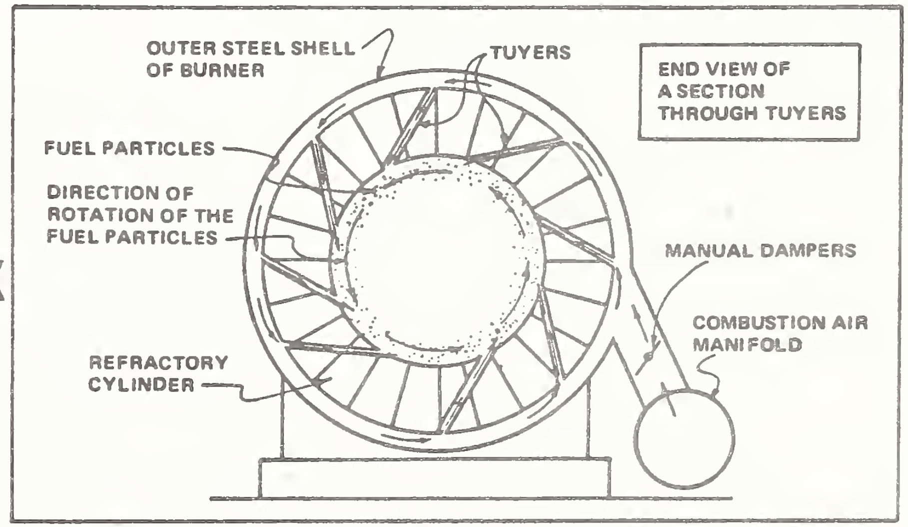
DESIGN CONCEPT

The burner is a refractory lined, cylindrical combustor which receives a metered supply of pneumatically conveyed fuel at the inlet end. The air is introduced to the combustor annulus from three individually throttled manifolds leading from a main header and tangential entry establishes a highly turbulent forced vortex flow regime intended to achieve high combustion efficiency, and complete combustion of fixed carbon within the burner. The burners are supplied in capacity ranges from 5×10^6 to 60×10^6 Btu/hr. The combustors may be procured for operation in either non-slagging or slagging mode in which the fuel mineral ash is removed in a liquid state.

Another version of a horizontal forced vortex combustor is known as the Loddby furnace.



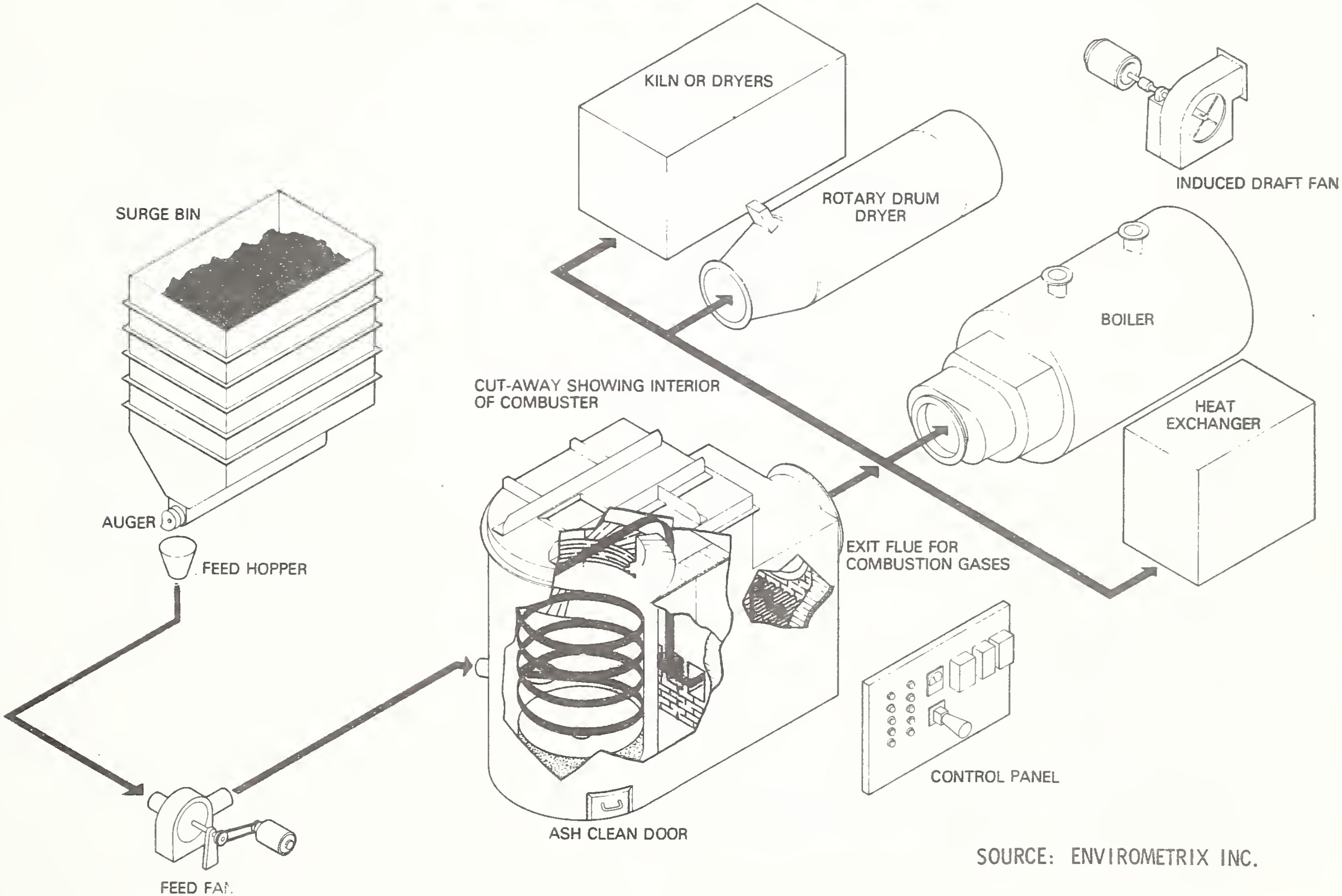
Special Combustor - Horizontal Forced Vortex



Source: Energex Ltd.

Another furnace design concept is the vertical vortex combustor as shown in the illustration. The manufacturer claims up to 90% efficiency for this unit. Another claim is that low particle emission is achieved due to radial particle acceleration in the centrifugal field. The illustration shows four applications for the combustion gases. The gases may be fed to a kiln, rotary dryer, boiler, or heat exchanger equipment. Steam outputs range up to about 100×10^6 Btu/hr. Hogged fuel up to 1" in particle size with less than 38% moisture can be burned.

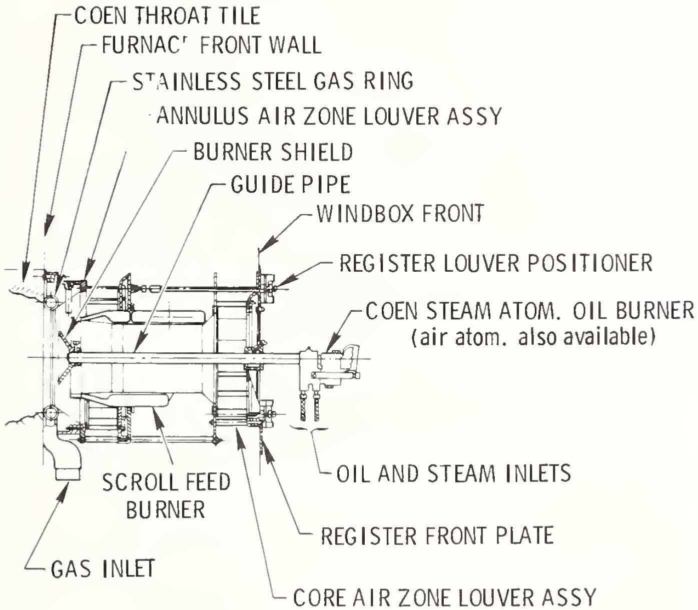
Special Combustor with Options - Vertical Forced Vortex

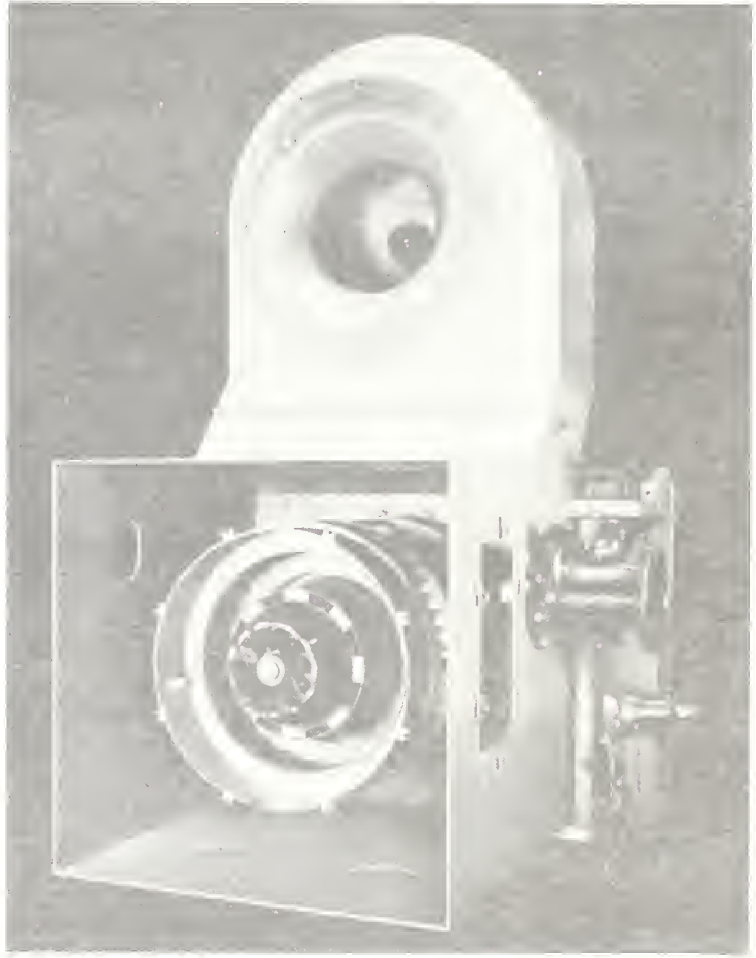


SOURCE: ENVIROMETRIX INC.

The scroll burner is a combustor design in which highly turbulent air flow is achieved with counter rotation of annular flowing streams. The burner provides a capability to convert some existing boilers to wood residue combustion. Dual air inlets are used in the burner design to introduce two concentric air streams together with pneumatically-conveyed fine solid fuels. As the concentric counter rotating air streams scrub each other, turbulent eddy mixing occurs with the fuel thereby inducing a rapid and complete combustion process in the immediate vicinity of the burner.

Special Combustor - Scroll Feed Burner





Source: Coen Co.

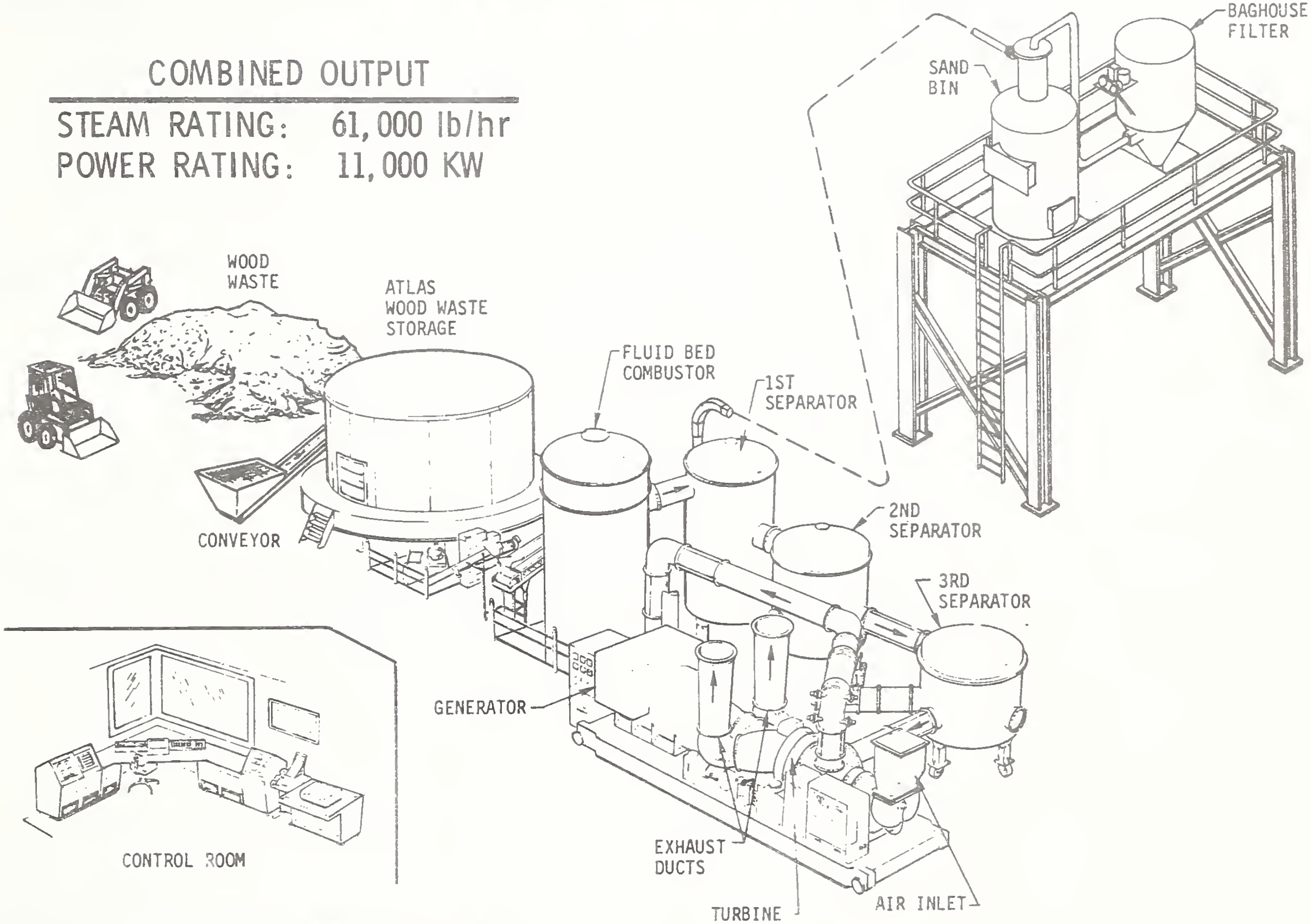
In the powerplant system cycle, the gas flow from the fluidized bed passes through a particulate collection system before expansion in a gas turbine. The turbine drives a generator. Heat is further extracted from turbine exhaust gases in a separate boiler. The system which produces both shaft work and steam is currently in pilot plant development. This system uses about 10 1/2 tons of residue per hour to produce 61,000 lb steam/hour and 11,000 kw of electricity when shaft-coupled to a generator.

FLUIDIZED BED COMBUSTOR

The CPU-400 is an example of a combined powerplant cycle having a pressurized fluidized bed combustor capable of utilizing wood residues. The principle of fluidized combustion implies suspended combustion of fuel particles in an upward air flow. Inert solid particles, also contained within the combustor, enhance fuel heat transfer to initiate combustion. Combustion efficiencies up to 99% have been claimed for these types of systems.

Energy System Concept - Fluid Bed

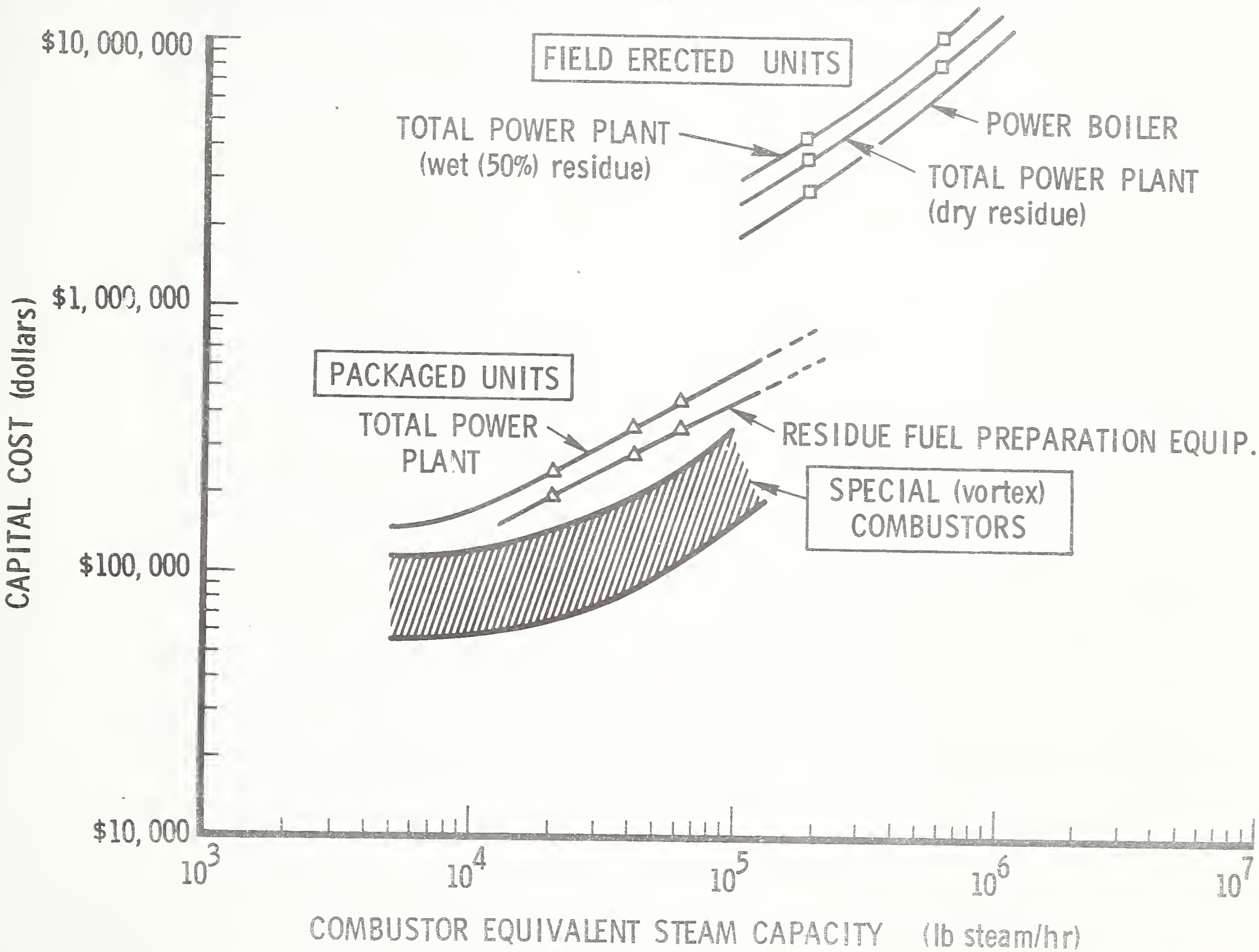
COMBINED OUTPUT	
STEAM RATING:	61,000 lb/hr
POWER RATING:	11,000 KW



Source: Combustion Power Co., Inc.

The procurement cost of combustion equipment options is a dominant factor in their selection. In the combustion equipment survey, cost data were found to be very difficult to obtain without establishing point designs. Repetitive contact with manufacturers and review of published data ultimately resulted in a set of cost curves. The equivalent steam generating capacity of roughly 100, 000 pounds per hour appears to divide the equipment options into two groups. Above 100, 000 pounds per hour the large field erected boiler is essentially the only option, while below this value there are packaged units as well as special combustors.

Combustion Equipment Costs



Primary emission discharges from combustion of hog wood fuels, bark, or other residues occur as finely divided particulate matter consisting of unburned carbon, fly ash, and sometimes seawater salts. Generally, combustion conditions of stoichiometry and temperature are such that unburned hydrocarbons, carbon monoxide, and nitrogen oxides are not discharged. The negligible amounts of sulfur normally assayed in wood allows minor sulfur oxide formation (except in cases where combination firing occurs with high sulfur fuel).

COLLECTION EFFICIENCY

Removal of particulates is accomplished by a variety of devices generally known as collectors, and the ability to separate particles (either in solid or liquid phase) depends upon the collector efficiency. Collection efficiency is the term which expresses the percentage removal of particulates from the gas stream relative to the inlet composition. The particle concentration, called grain loading, is given in terms of mass/gas volume and is usually measured as grains/dry standard cubic foot (gr/DSCF). The figure shows outlet grain loadings vs inlet loadings for various collection efficiencies between 80 and 99%.

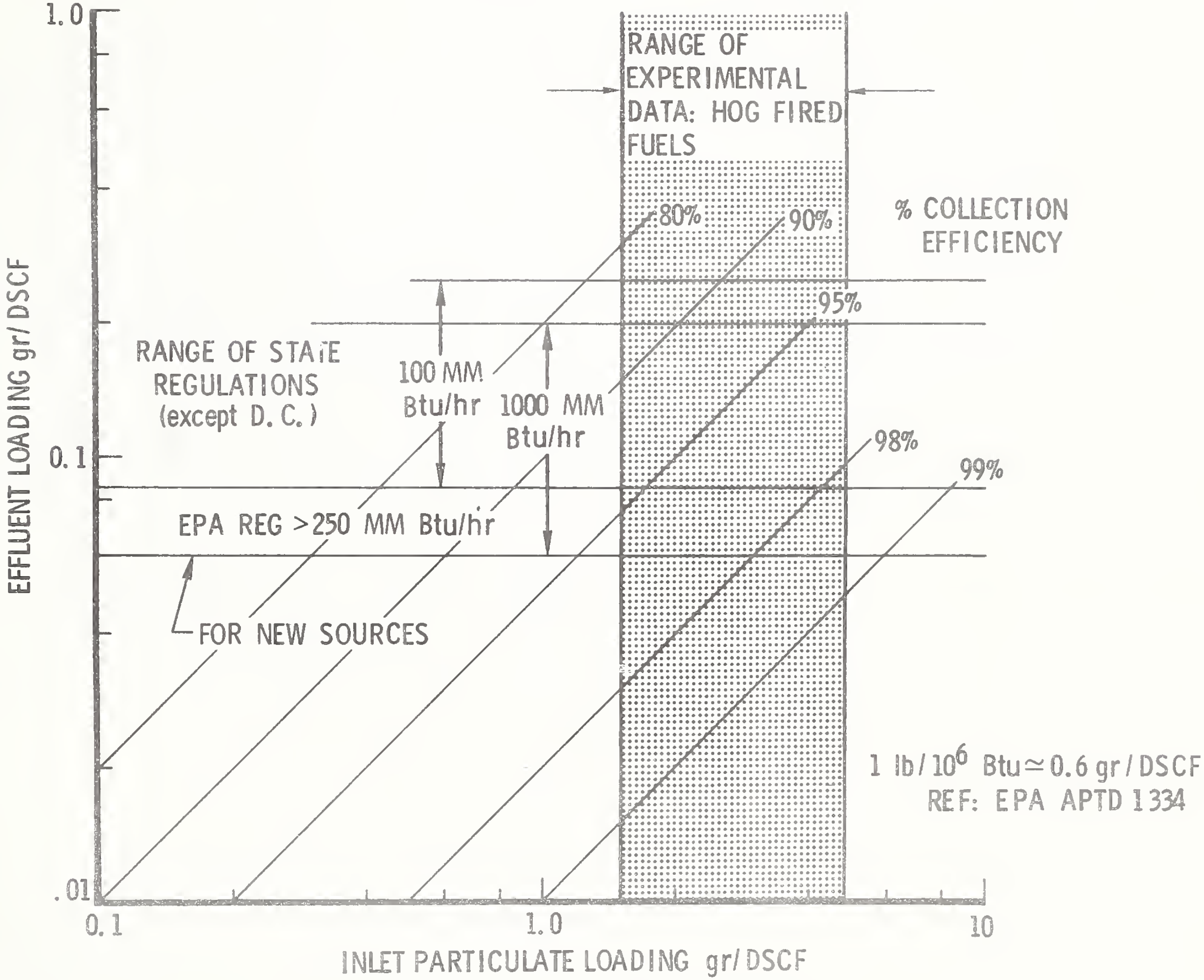
EXPERIMENTAL DATA

The range of experimental inlet loading data from hog-fired boilers (shown by the shaded area) generally lies between 1 1/2 - 5 gr/DSCF. Up to 50% of wood fly ash is below 10 microns.

EMISSION CONTROL STANDARDS

Some differences exist between States and also Federal air quality control regulations. Standards often are expressed in terms of furnace firing capacity and become more restrictive with increasing firing rates. EPA regulations for new fossil sources with capacity exceeding 250 x 10^6 Btu/hr are 0.1 lb/10^6 Btu. This has been approximated using the factor of 1 lb/10^6 Btu $\approx$ 0.6 gr/DSCF. The range of allowed emissions is rather broad because each state applies its own standards. The independent variable is usually defined in terms of furnace firing capacity. At 100 x 10^6 Btu/hr the range of allowed effluents is between .09 and 0.3 gr/DSCF amongst the states. At 1000 x 10^6 Btu/hr, the allowable range is lowered as indicated.

Emission Control Standards - Collection Efficiencies



There are a number of types of emission control equipments which are commercially available. These may be used individually or in combination as needs and overall costs dictate for residue combustion systems.

Some of the physical characteristics which affect the selection process are collection efficiency (which is a measure of performance), typical pressure drop (which affects combustion flue gas flow and blower power requirements), and maximum temperature (which determines suitability for specific flue gas temperatures).

Other considerations strongly affecting selection include procurement, installation, maintenance, and operation costs as shown in a later illustration.

Emission Control Equipment Options

	CYCLONE	DRY SCRUBBER	WET SCRUBBER	ELECTROSTATIC	BAG FILTER
GENERAL TYPES	SINGLE MULTIPLE	GRANULAR BED	CYCLONE PACKED TOWER etc	PRECIPITATIOR	REVERSE FLOW REVERSE PULSE SHAKER
TYPICAL APPLICATIONS	VARIOUS DUST AND PARTICLE SEPARATIONS	REPORTED GOOD FOR WOOD RESIDUE COMBUSTION	HIGH TEMP GASES	HIGH EFFICIENCY REPORTED (2) NOT BEST SUITED TO BARK ASH	USUALLY LOW TEMPERATURE; SUB-MICRON PARTICLES
TYPICAL EFFICIENCY	50%-95%	95%	90-98%	$97\text{-}99^{+}\%$	$99^{\pm}$-99.9%
TYP PRESS LOSS	3.2" H_2O	5" H_2O	15" H_2O	0.5" H_2O	3.3" H_2O
MAX TEMP	750°F	700°F	NO LIMIT	750°F	300°F

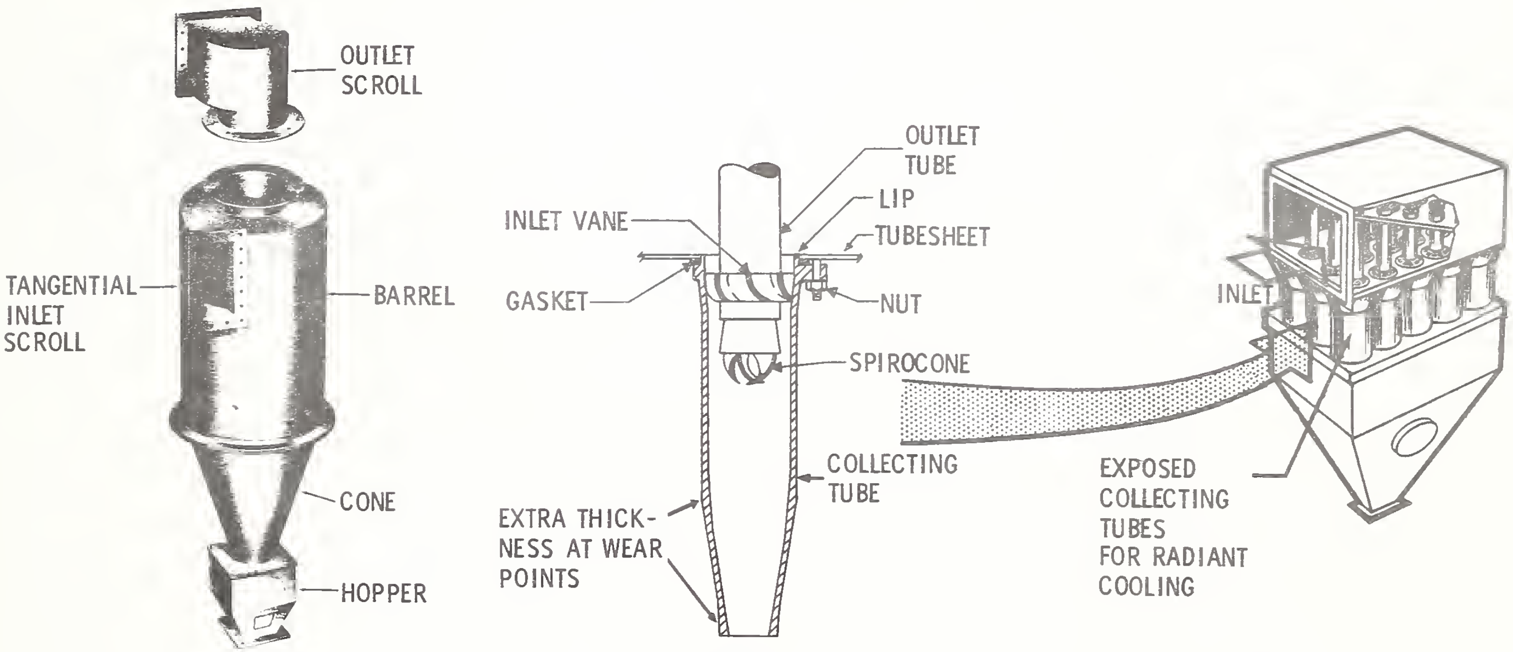
The simplest type of mechanical collectors are the cyclone and multicyclone.

Particulate removal is based upon the inertial separation principle in which particulate-bearing gases enter an involute passage or are caused to swirl within a cylindrical tube at high velocity. Radial acceleration forces the denser particles to be thrown towards the tube walls where they drop downward to a discharge throat. Gases then exit through a concentric top outlet tube.

The fundamental advantages of these devices are simplicity, no moving parts, low cost, low pressure drop. Disadvantages include lowered efficiency with smaller particles, and a tendency to plug with wet or sticky particles.

They are frequently used in combination with other collectors to reduce the loads and the overall cleanup cost.

Cyclones and Multicyclone Emission Controls



SINGLE CYCLONE

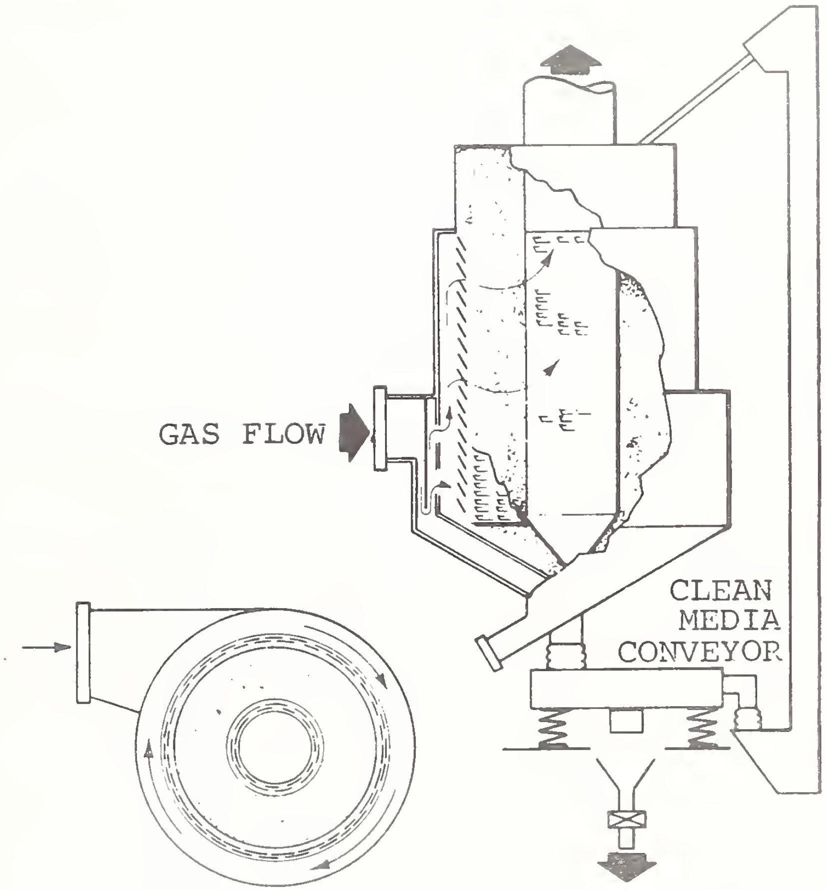
COLLECTING TUBE CROSS-SECTION

MULTICYCLONE

Source: Joy Mfg. Co.

The granular dry scrubber was recently introduced for flue gas cleanup and was demonstrated on hog fuel fired boilers. The operating principle involves fly ash/particulate separation through impaction with a moving bed of dry, granular filtering medium. Plugging of the granular filter material is prevented by continuously removing, screening and conveying it back to the top of the scrubber for reuse. Models currently under test show efficiencies to 95% with flue gas temperatures of 750°F. Their present disadvantage appears to be high annual cost.

Granular-Filled Dry Scrubber



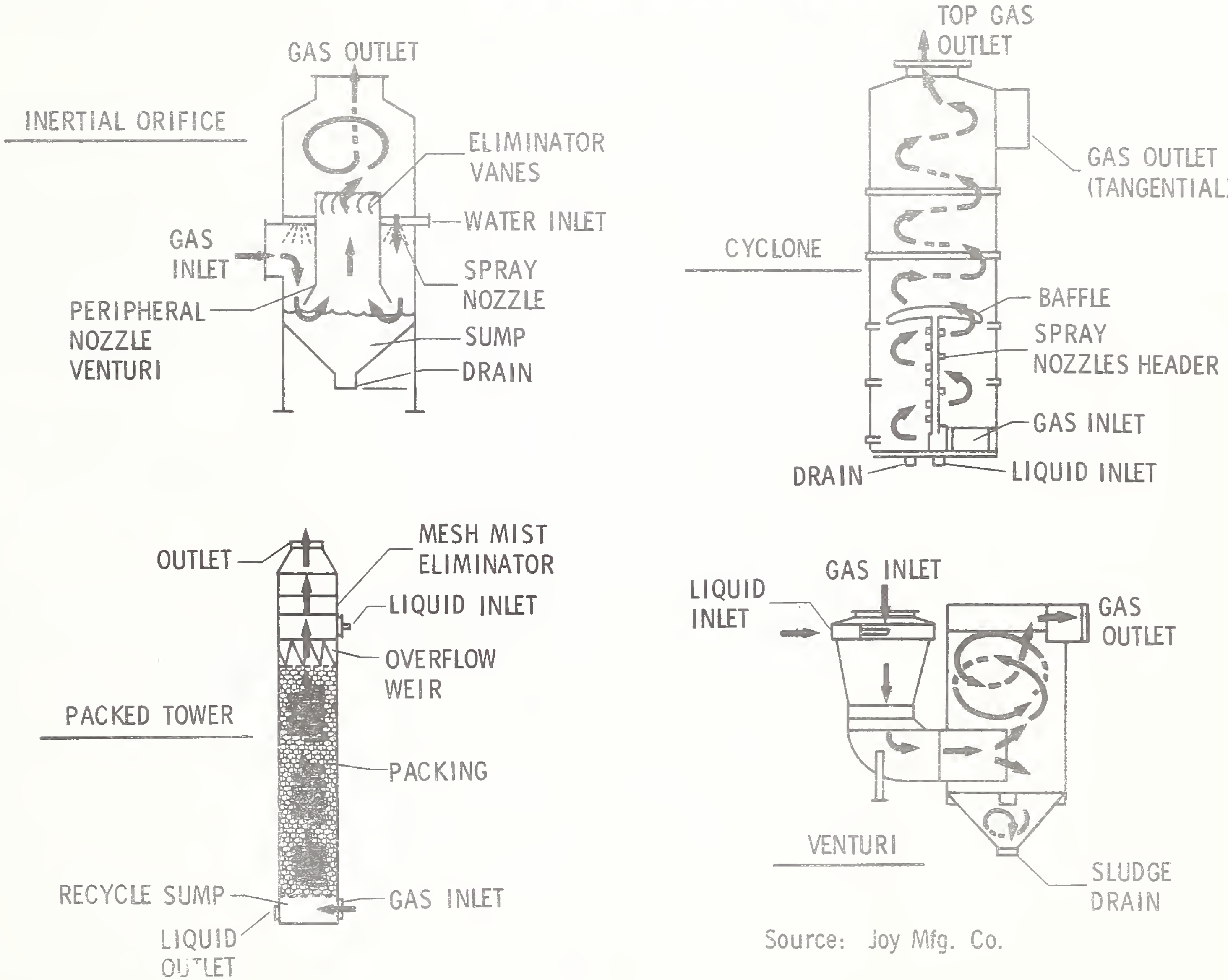
Source: Combustion Power Co. Inc.

A variety of wet scrubbers as shown are available for dust/mist separations. The basic principle involves inertial separation through contact between high velocity dirty gas and scrubber liquid streams (usually water) which wets the particles and enhances agglomeration of fine particulates. Clean gas exits one way, liquid another.

A basic advantage involves the capability to tailor an individual scrubber to the requirements, since scrubber categories include low, medium and high energy types with corresponding efficiencies to 99.9%.

Possible disadvantages are that large amounts of scrubber liquid are required, and liquid may require after-treatment before disposal.

Wet Scrubber Types



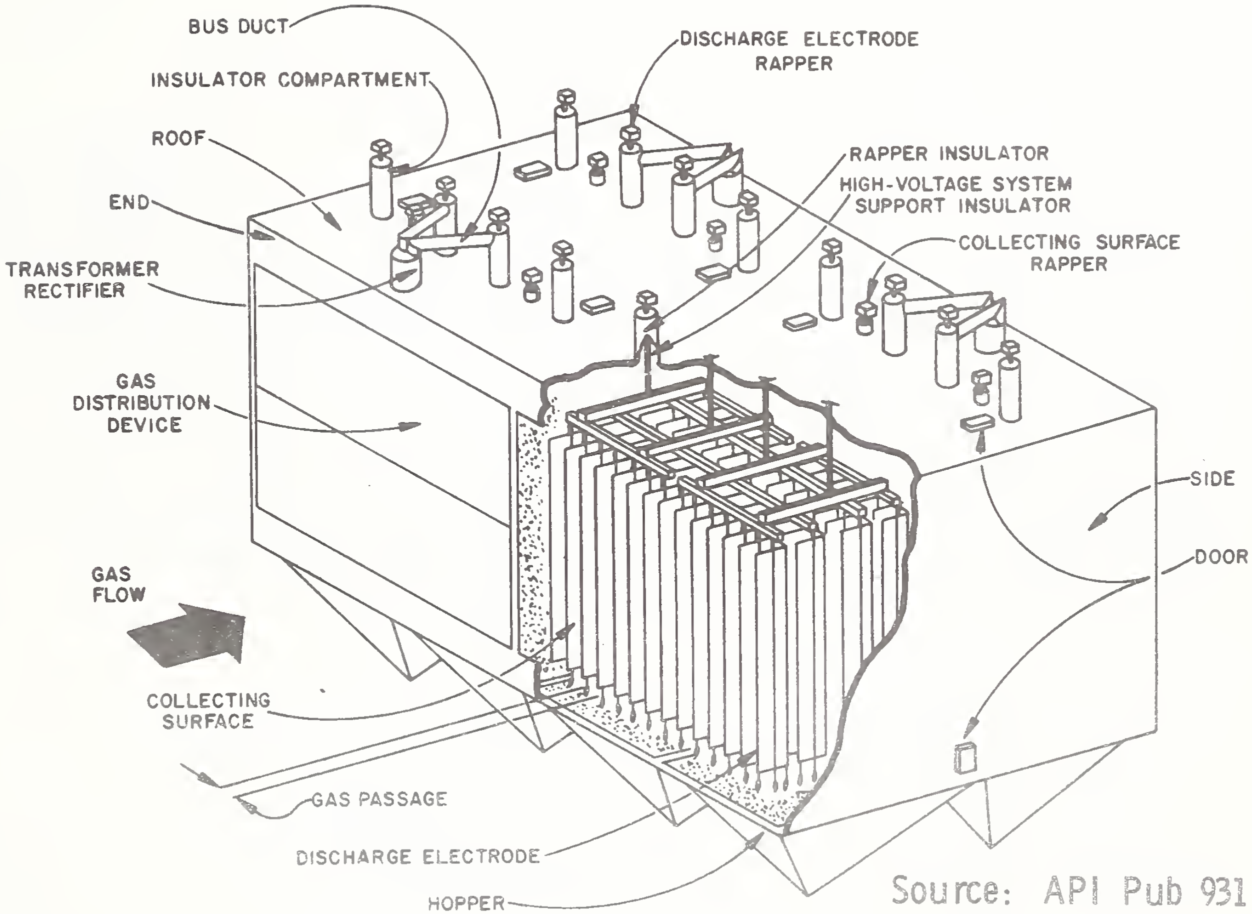
Source: Joy Mfg. Co.

In the electrostatic precipitator, as gas flows through the device, an electrical field causes dust solids or particles to become charged, migrate toward grounded collecting surfaces, and adhere to the plates. Periodic removal of the debris layer is accomplished by mechanical or pneumatic rapping, vibration, or other methods. The agglomerate particles that break loose drop to the compartment bottom hopper.

The advantages of the electrostatic precipitators are: they can be bought as modules to treat large gas volumes, they have very high efficiency, they can remove sub-micron particles, they need no water (also recovers dry materials), they operate at high flue gas temperatures, low power consumption, and have low draft loss.

Their disadvantages are: high initial cost, generally require custom engineering and testing for a given application, have large space requirements, and high voltages (over 35, 000) are a potential hazard.

Electrostatic Precipitator

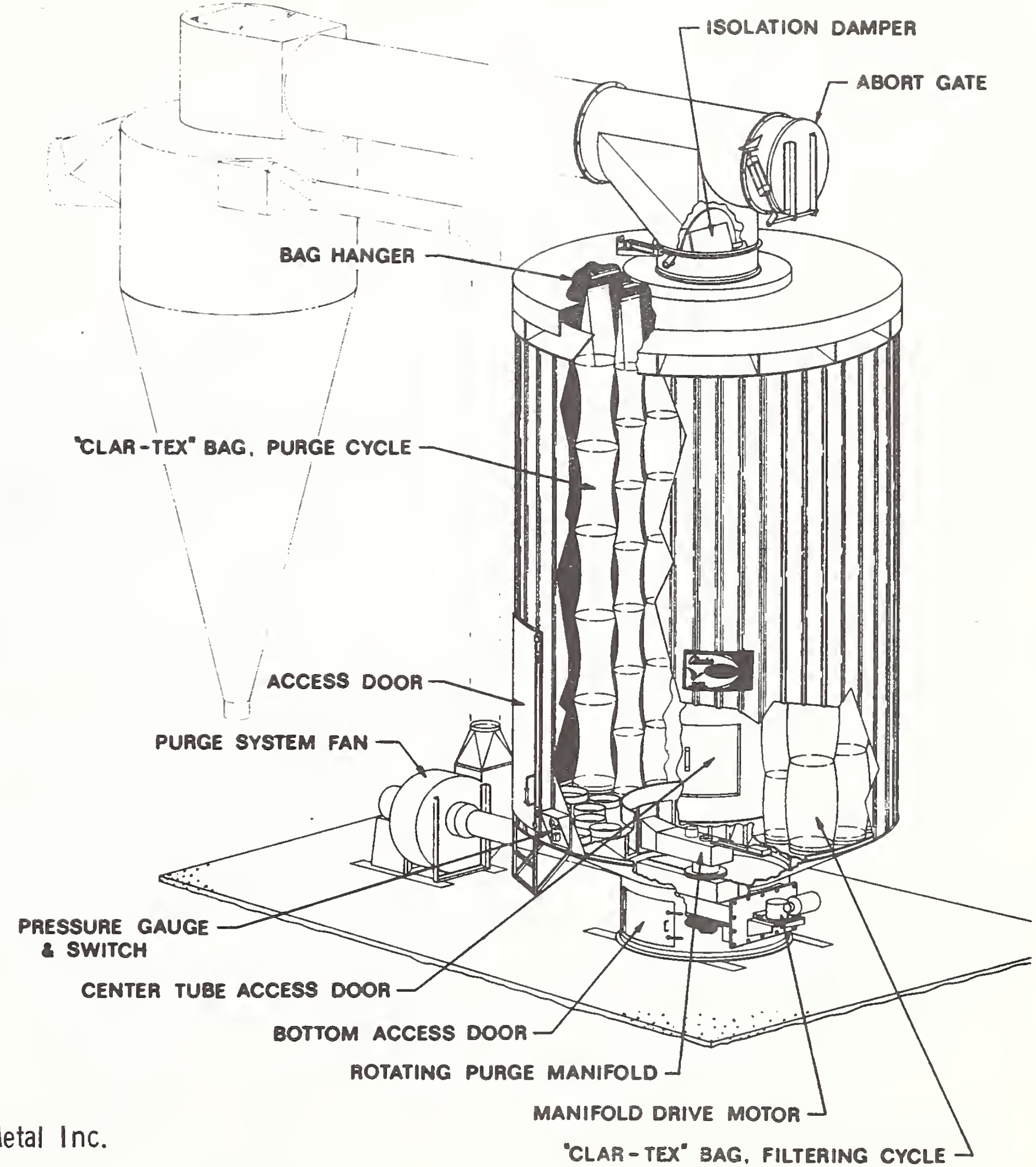


Source: API Pub 931

In the bag filter, solid contaminants are removed when dirty gas passes through a porous filtering medium. A set of tubular shaped bags are suspended within the filter housing. Flow is from inside to outside of the bag. The baghouse has provision for periodic reverse flow cleaning or shaking of the bags so that dust drops to the bottom of the compartment for removal.

The main advantage is high efficiency, disadvantages include the need to limit operating temperature. High overall cost usually accompanies the high efficiency since the filters usually require frequent (once or twice annually) replacement.

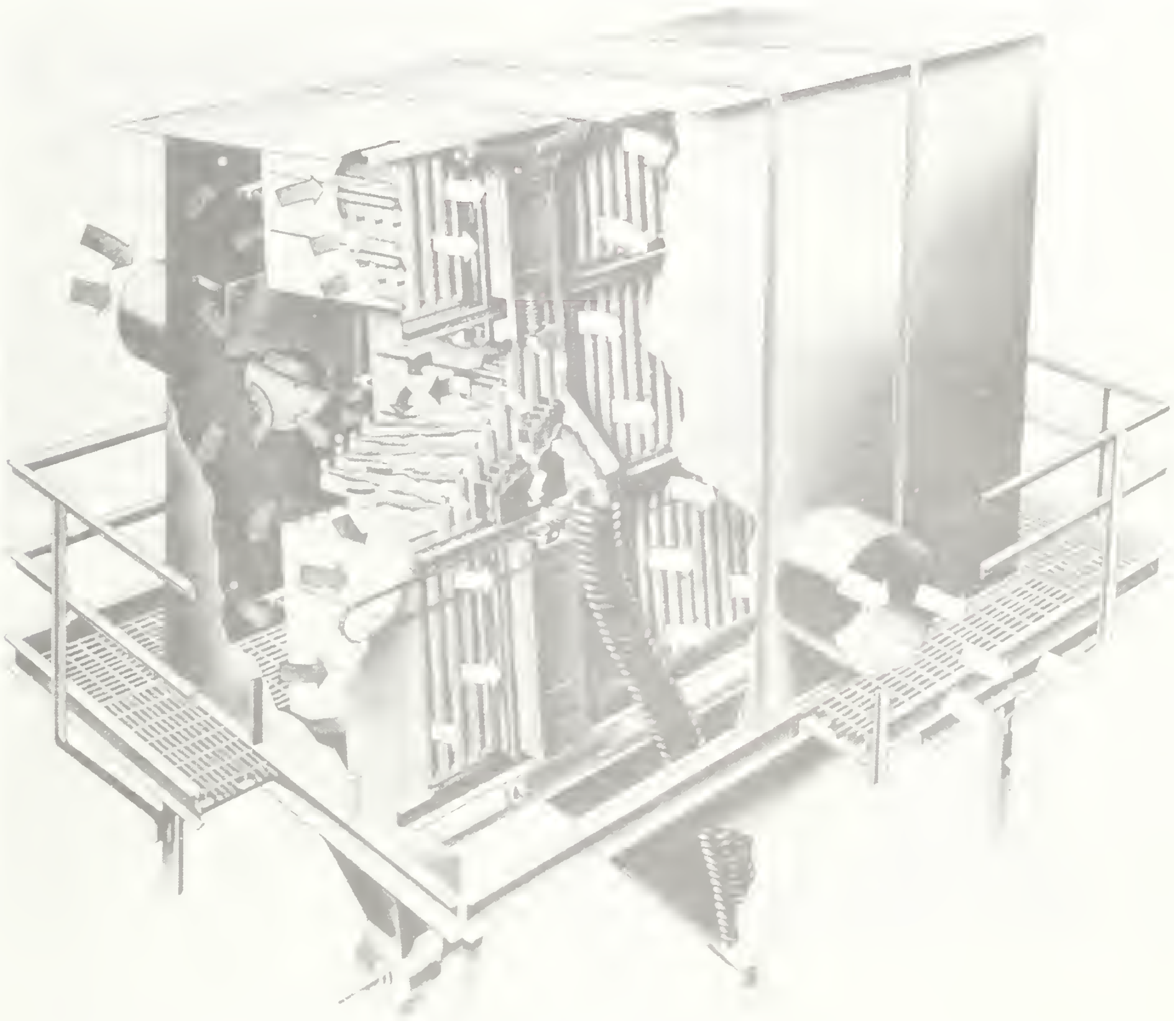
Bag Filter



Source: Clark Sheet Metal Inc.

In the envelope bag filter, the filtering surface consists of rectangular-shaped bags as shown in the illustration. Dust-carrying gas passes through the fabric as in the bag filter. This type of filter is more compact and has a higher efficiency than similar capacity bag filters, otherwise the operating conditions and considerations are similar to the bag types.

Envelope Bag Filter

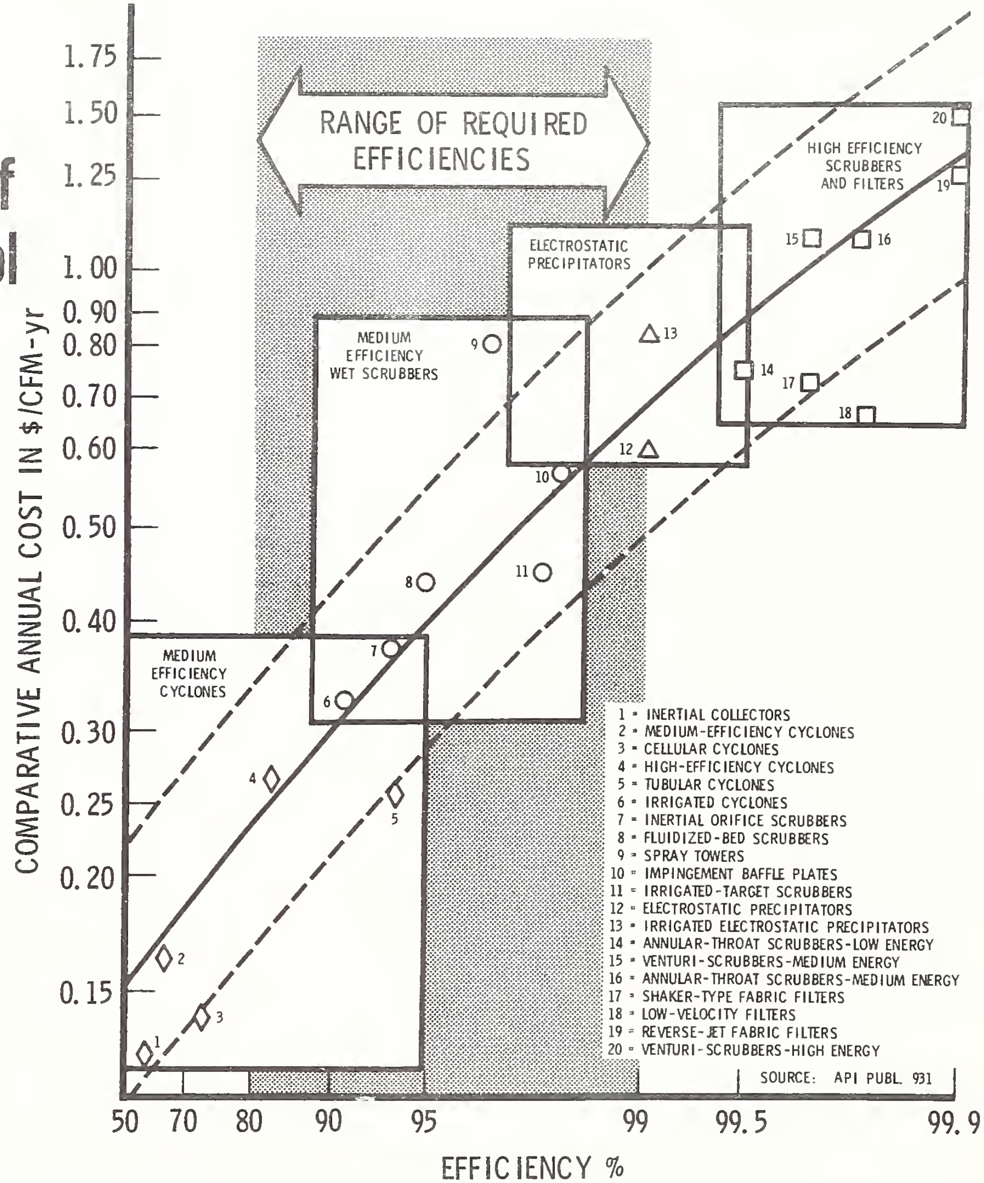


Source: American Petroleum Institute Pub 931

The cost of emission control has been annualized to include both capital recovery and operational costs. These costs are strongly dependent on the design concept, the collection efficiency (typically 80% to 99% for residues) and the flue gas flow rates. The cost and collection efficiencies of twenty different particulate collection equipments were summarized.

The principal categories of emission control equipment considered were cyclones, wet scrubbers, and electrostatic precipitators. High efficiency scrubbers and filters were also considered, however, their capabilities generally exceed current collection requirements. The cost efficiency trade-offs may lead to using several lower efficiency equipments in combination. While a general trend in cost and efficiency were found for the equipments examined it was also noted that a large range of cost variation exists within specific equipment categories.

Cost and Efficiencies of Typical Emission Control Equipment

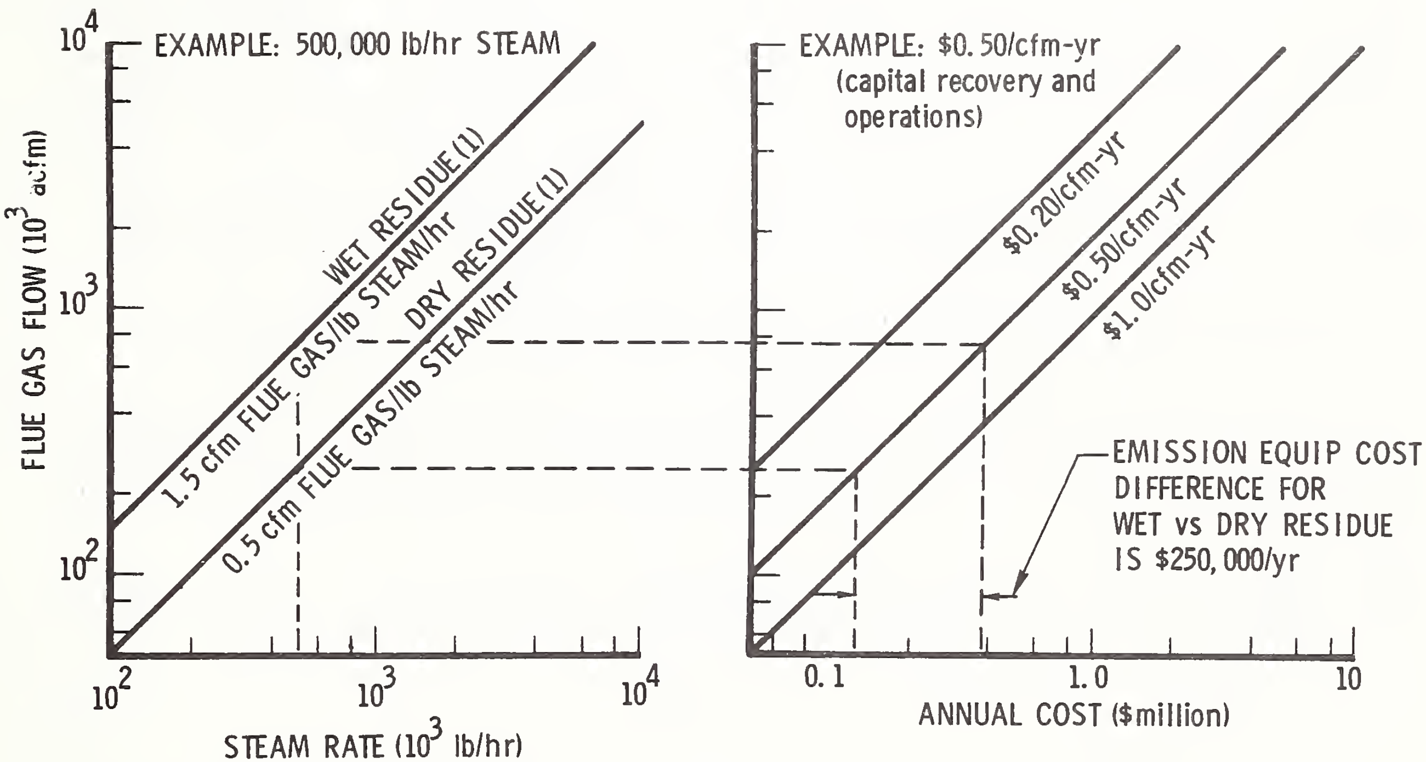


SOURCE: DERIVED FROM AMERICAN PETROLEUM INSTITUTE PUPL 931

The annualized cost of emission control (including both capital recovery and operation) was found to be primarily dependent on the moisture content of the residue being burned. It was shown that by reducing residue moisture content, the annual cost of emission control could be substantially diminished. The figures which plot flue gas flow as functions of steam rate and annual cost, can be used as a nomograph to compute the cost of various cases. In the examples shown, annual emission control costs are reduced by $250,000 by replacing wet residues with dry residues in a unit with a steam rate of 500,000 lb/hr and an emission control unit cost of $.50/cfm-yr.

Wet vs Dry Residue Emission Control Equipment

ANNUAL COST DIFFERENCE



(1) Basis assumes flue gas temp = 500°F,
20% excess air (dry), 100% excess air (wet)
Boiler Eff (η_c) = 65%(wet), 80%(dry)

The moisture content of wood residue impacts upon several aspects of the combustion process. In combustion, heat is released during the process of rapidly combining oxygen from the air with various constituents which exist in a bound form (such as carbohydrates in photosynthetically originated plant matter). Since water is already an oxidized species, it tends to reduce the energy availability of the fuel. Typically, when 50% wet residues are dehydrated, the heating values of both wood and bark can double (see Figure a).

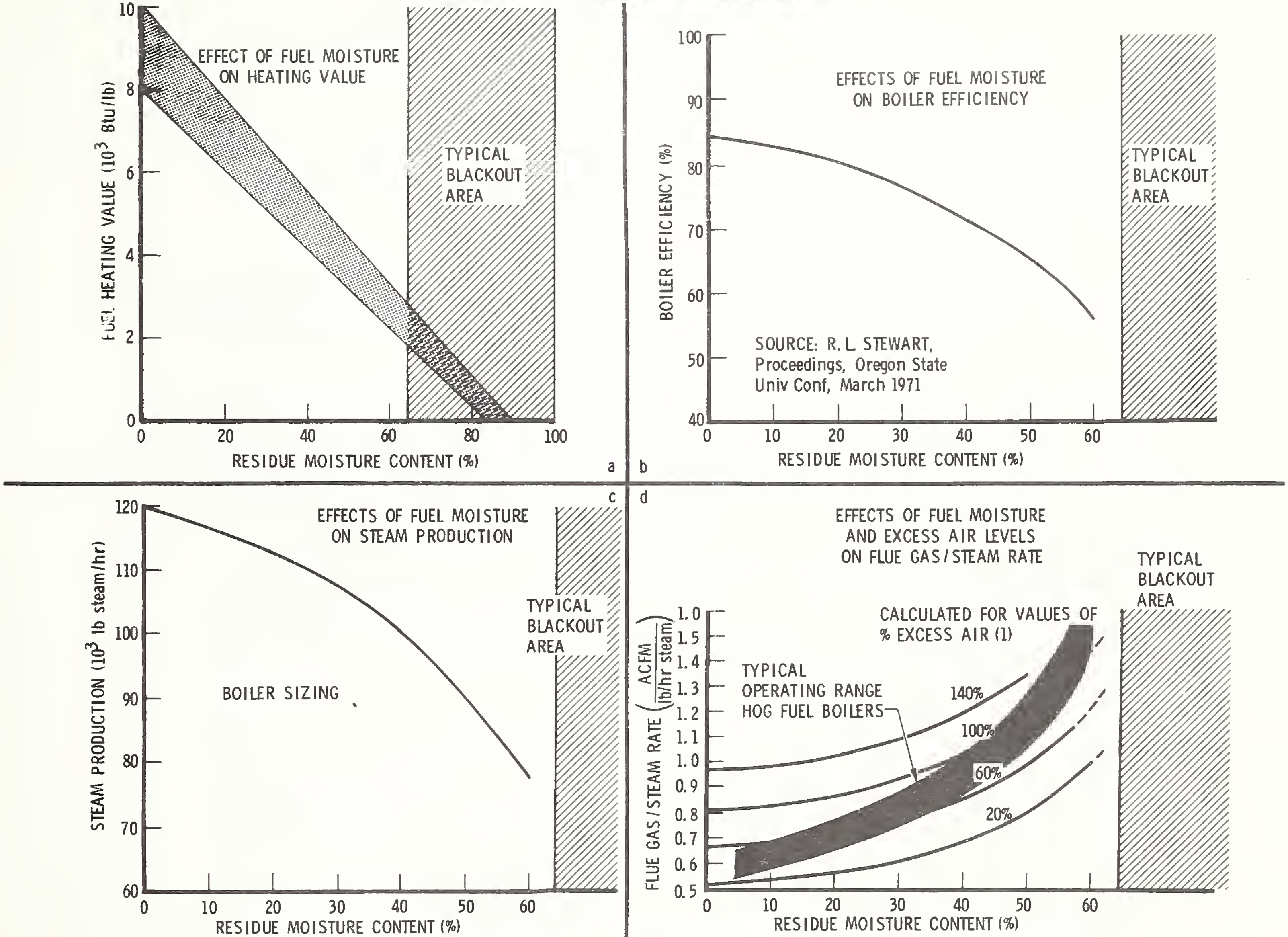
Combustion efficiency reportedly can increase from 65% to about 80% with lower moisture content residue fuels (Figure b). The combustion industry has estimated that research may improve these efficiencies by as much as 5% in the next five years.

Boiler sizes (and hence capital cost) of boilers decrease with dryer fuels (see Figure c). With a given boiler, dry fuel increases the steam generation rate.

Emission control costs are a function of flue gas volume (as previously discussed). Typical effects of residue moisture on flue gas/steam rate calculated for various excess air ratios are shown on Figure d . Typical operating range of hog fuel boilers is depicted in superposition.

There are other system impacts of moisture in the residue (e.g., size of residue harvest required, size and cost of fuel preparation, residue transport . . . .).

Residue Fuel Moisture



SOURCE: R. C. JOHNSON, TAPI Journal, Vol 58 No. 7, 1975

(1) Residue anal: 52% C, 6% H, 42% O, H.V. = 8000 Btu/lb(dry), flue gas temp = 500°F, steam vap enthalpy = 1000 Btu/lb

The combustion survey resulted in the identification of those equipments which are most suited to supplementing the energy needs of typical forest industries through the use of residue fuels.

Existing boiler and emission control technology can be adapted to support the majority of the residue combustion requirements for processing steam, drying lumber and/or generating electricity. The demands of the larger (pulp/paper) operations can be met by the field erected boilers, while demands the smaller sawmills can be met by packaged units. Special combustors were also examined and found to have applications in operations such as drying of lumber and/or residue fuels.

The dominant issue in the size and efficiency of combustors and emission control equipment was found to be the moisture content of the residue.

Combustion Survey Findings

- RESIDUE COMBUSTION EQUIPMENT IS AVAILABLE TO MEET MOST OF THE INDUSTRIES' NEEDS

- STEAM BOILER TECHNOLOGY IS WELL ESTABLISHED AND IMPROVEMENTS ARE SUPPORTED BY THE INDUSTRY

- SPECIAL COMBUSTORS PRESENT NEW CAPABILITIES FOR SOME SPECIAL APPLICATIONS

- EMISSION CONTROL STANDARDS IMPACT RESIDUE COMBUSTION IMPLEMENTATION

- THE KEY ISSUE IN RESIDUE COMBUSTION SYSTEMS IS THE MOISTURE CONTENT OF THE FUEL WHICH CAN ADVERSELY INFLUENCE OVERALL COSTS OF ACHIEVING THERMAL RECOVERY AND MEETING ENVIRONMENTAL STANDARDS

SYSTEM ANALYSIS

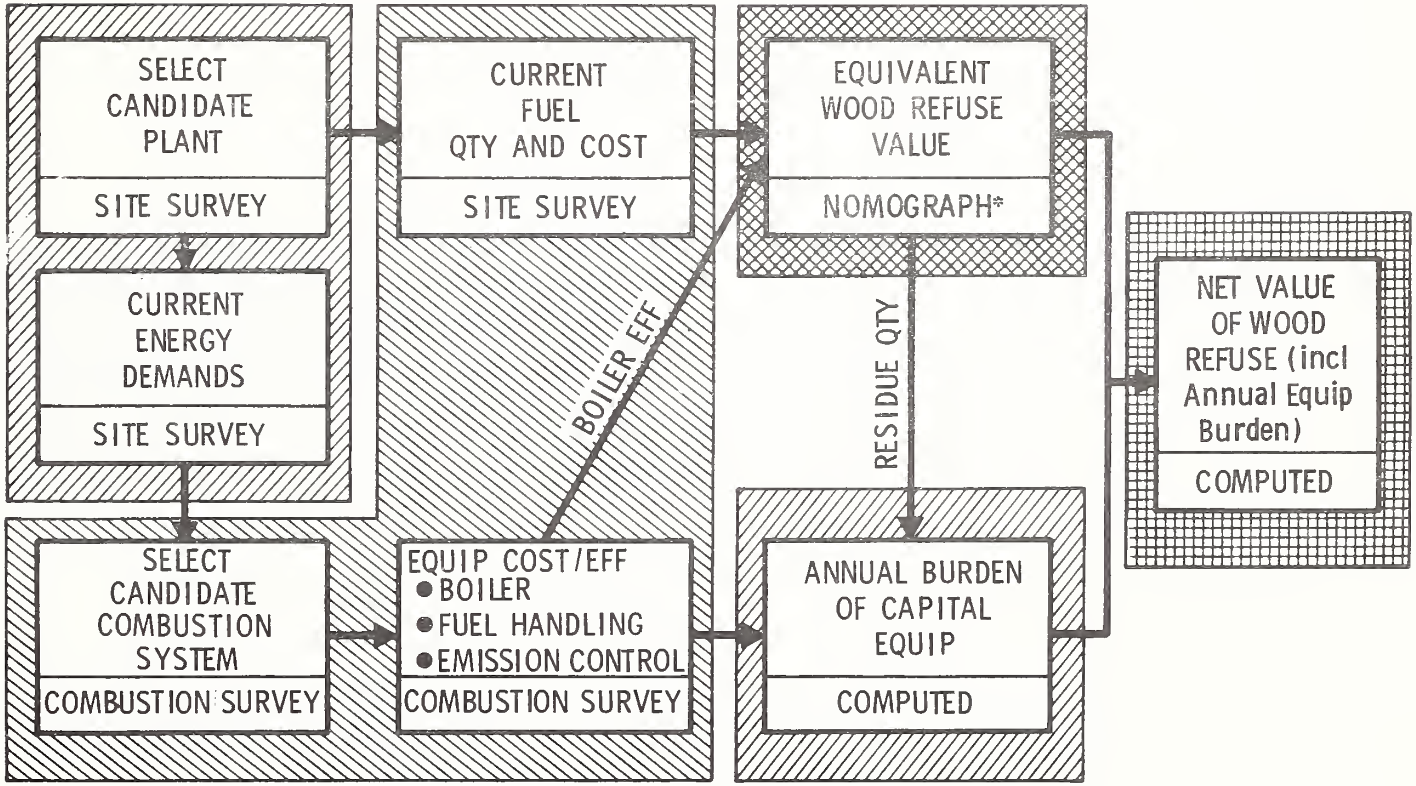
The combustion systems analysis used the data obtained during the site and industry survey tasks to develop the economic feasibility of implementing energy self-sufficiency for the pulp/paper mills visited. The residue requirements for these pulp/paper mills were also established. The analysis results can be applied to a wide range of actual mill operations.

Combustion System Analysis

- OBJECTIVES
  - SYNTHESIZE CANDIDATE SYSTEMS
  - EVALUATE COST/PERFORMANCE
  - ESTABLISH RESIDUE REQUIREMENTS
- APPROACH
  - ESTABLISH LOAD REQUIREMENTS
  - DETERMINE EQUIVALENT FUEL COSTS
  - ESTABLISH CAPITAL COSTS
  - DETERMINE MILL FIBER/FUEL REQUIREMENTS

An economic trade-off study was conducted of residue and fossil fuels combustion systems in order to establish an equivalent price which could be paid for fossil fuels delivered to the using pulp/paper plant. These equivalent prices were based on the energy demands of typical mills using both current and projected fossil fuel prices and boiler efficiencies. These equivalent residue fuel prices were then adjusted for various levels of other costs such as annualized capital recovery. The annualized capital costs were computed from cost differentials of residue and fossil combustion systems recovered over a fixed period at a given interest rate. Finally all costs are normalized on the basis of residue tonnage. Some added adjustments for annual operating cost were also included.

Combustion System Analysis – Flow



*USFS Nomograph for equiv fuel value - Rodger Arola

The computation of equivalent fuel cost was accomplished by use of nomograph developed by the Forest Service, North Central Forest Experiment Station (U.S. Government Printing Office 1975 -667-794). Using this nomograph and given a fossil fuel cost, the heating values of the fossil and residue fuels, as well as the equivalent combustion process efficiencies of residue and fossil fuels, one can obtain comparable fuel costs.

Three sets of lines appear on the nomograph for the three classes of fuel considered: (1) oil, (2) coal, bark/wood, and municipal waste, and (3) gas. A fourth set represents efficiency values to allow for losses when converting heat to steam.

Heating values used for solid fuels are "as-fired," i.e. at the moisture content as burned. If the as-fired value for any moisture-laden fuel is not available, it may be computed as follows: $\frac{(100\text{-moisture content})}{100} \times \text{oven-dry heating value}$

The nomograph has three primary uses:

- To determine the cost of heat
- To determine the cost of steam
- To compare alternative fuels

Nomograph for Equivalent Fuel Values

How to Use the Nomograph to Determine the Cost of Heat

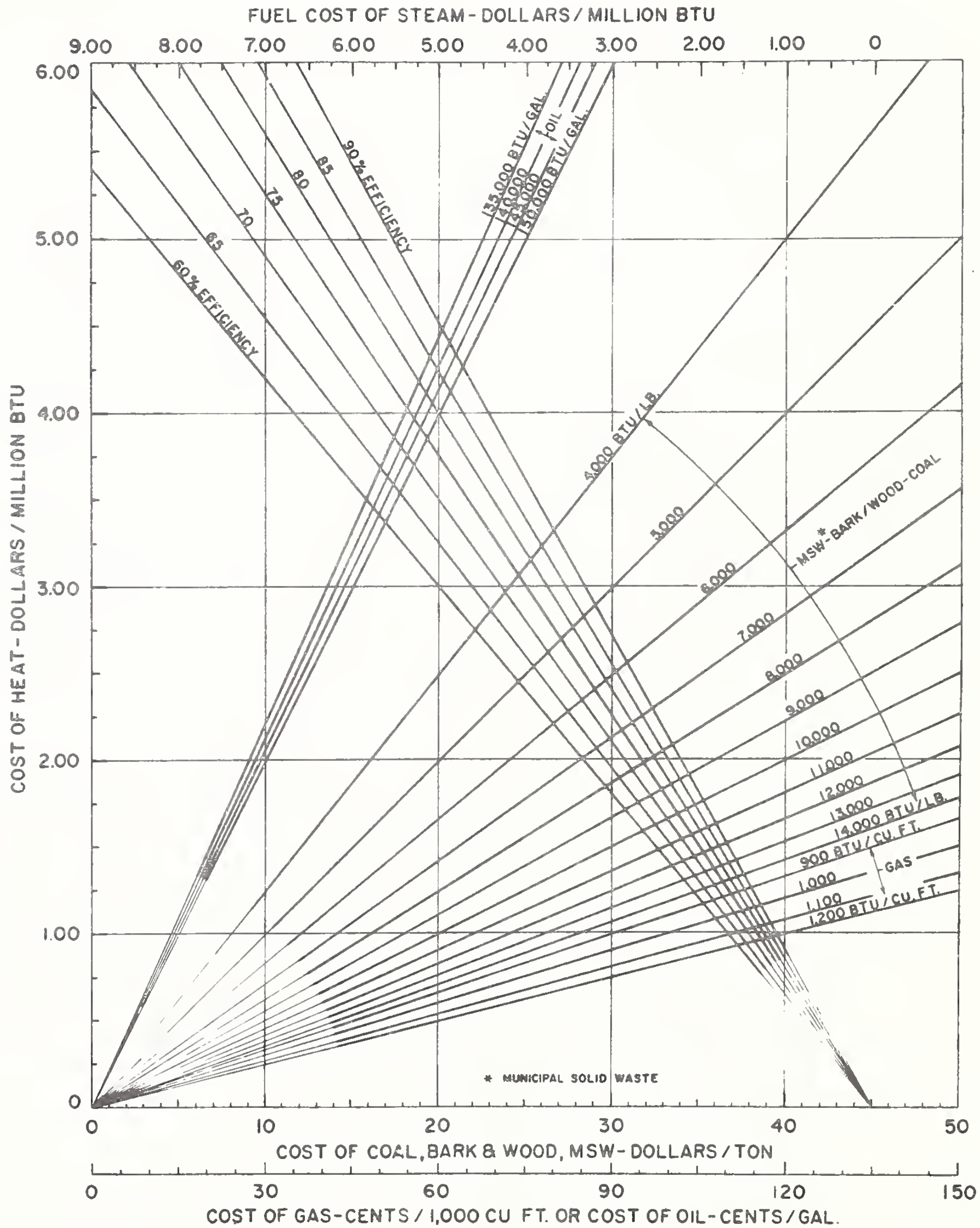
Given: Fuel is oil at 150,000 Btu/gal. Cost is 30¢/gal.

Problem: What is the cost of heat?

Solution: On lower scale at bottom of chart extend a vertical line from 30¢/gal. to the 150,000 Btu/gal. heating value line for oil. Then extend a line horizontally to the vertical scale and read the cost of heat.

Answer: $2/million Btu.

Source: USFS, Rodger Arola



The total cost differential between the purchase of new fossil versus new residue combustion systems includes capital recovery and operational cost as well as fuel cost. The capital recovery was annualized using typical industry factors (e.g., 15% simple interest and five year capital recovery). An allowance for operational cost such as combustion system chemicals, labor, and maintenance was also included.

APPROACH

The conceptual designs were sized for the power requirements of the four pulp/paper mills visited. An excess capacity of 10% was included in the designs which were costed from data collected in the combustion survey. The fuel preparation systems designs which were scaled and costed from existing equipment collected in the combustion survey included capabilities for sizing, drying, metering, etc. as required for handling specific fuels.

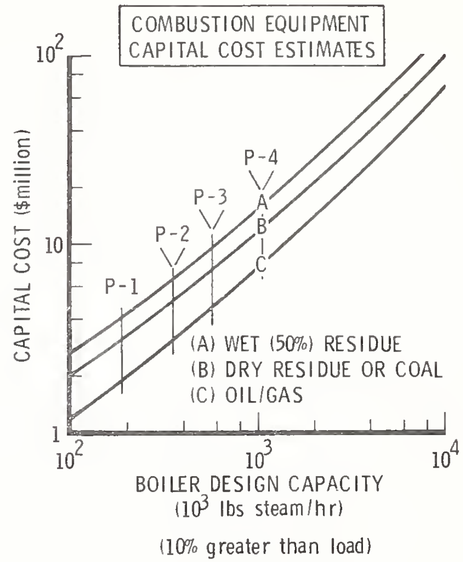
Total annualized capital recovery and operational cost of the four system options were normalized on a dollar per ton basis of as received residue. The reader should note that the normalized differential annual costs for dry residue systems exceeds those costs for wet residue systems since one half the tons of dry residue are required for equivalent heat output. Capital cost recovery for all systems studied were less than $5 per ton. If a less conservative ten year instead of five year capital recovery period was used, the maximum cost of the systems studied would be about $3 per ton.

Capital Cost

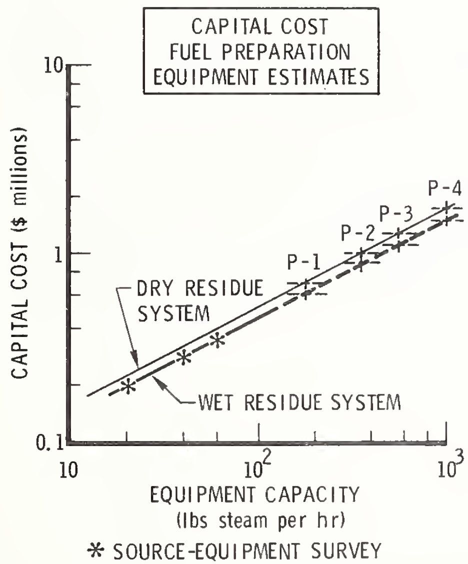
- ESTIMATES BASED ON DATA FROM COMBUSTION SURVEY
- CAPITAL RECOVERY
  - ANNUALIZED
  - 15% SIMPLE INT.
  - 5 YEAR CAPITAL RECOVERY
- ALLOWANCE FOR OTHER OPERATING COST (15% of investment)
  - CHEMICAL
  - LABOR
  - MAINTENANCE

a

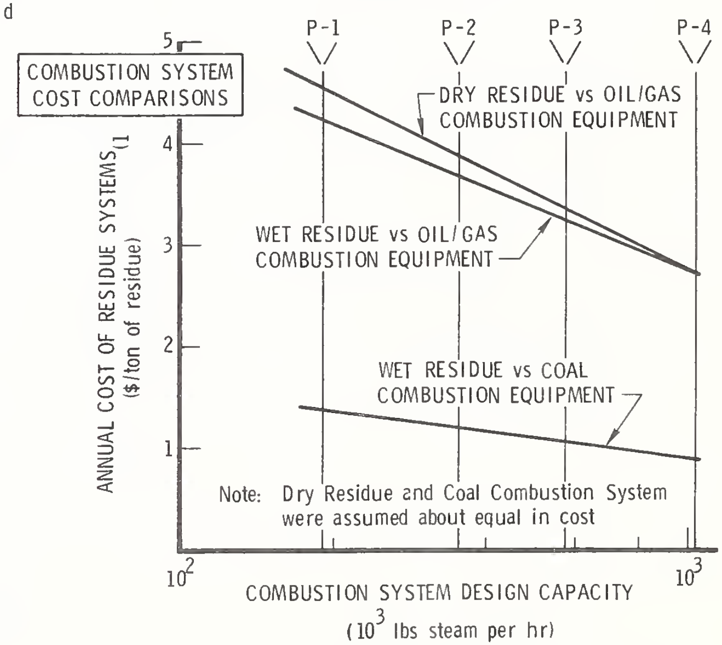
b



c



d



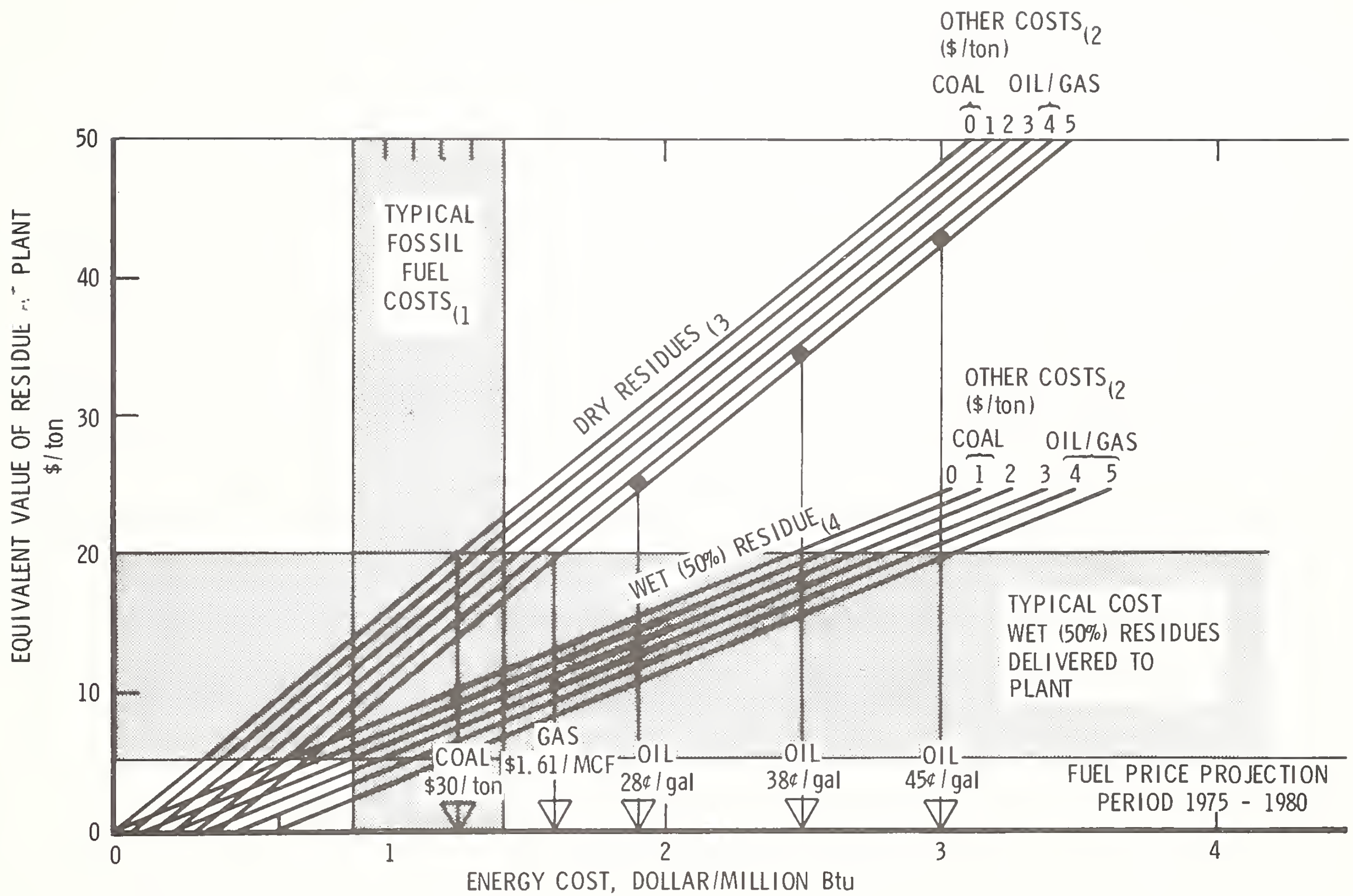
1) INCLUDES CAPITAL RECOVERY AND OPERATION

The economic analysis of residue combustion options provided an equivalent price which could be paid for residues which were delivered to the plant based on prices (current and projected) for fossil fuels. These prices were computed for both wet and dry residues with various levels of other costs (annualized capital recovery, and operating cost).

Based on current fossil energy costs of \$.85 to \$1.25/10^6 Btu as found in the site survey, wet (50%) residue may be worth \$7 to \$11/ton. Projected fossil fuel prices could raise this value up to \$25/ton over the next ten years. Other costs which include capital recovery and operations could reduce these values by as much as \$5/ton. Dry residue fuels delivered to the plant could be worth up to \$25/ton more than the residues which have 50% moisture.

Residue price estimates ranges from \$5 to \$20/per ton based on location. Higher prices were found on the Pacific Coast.

Combustion Analysis

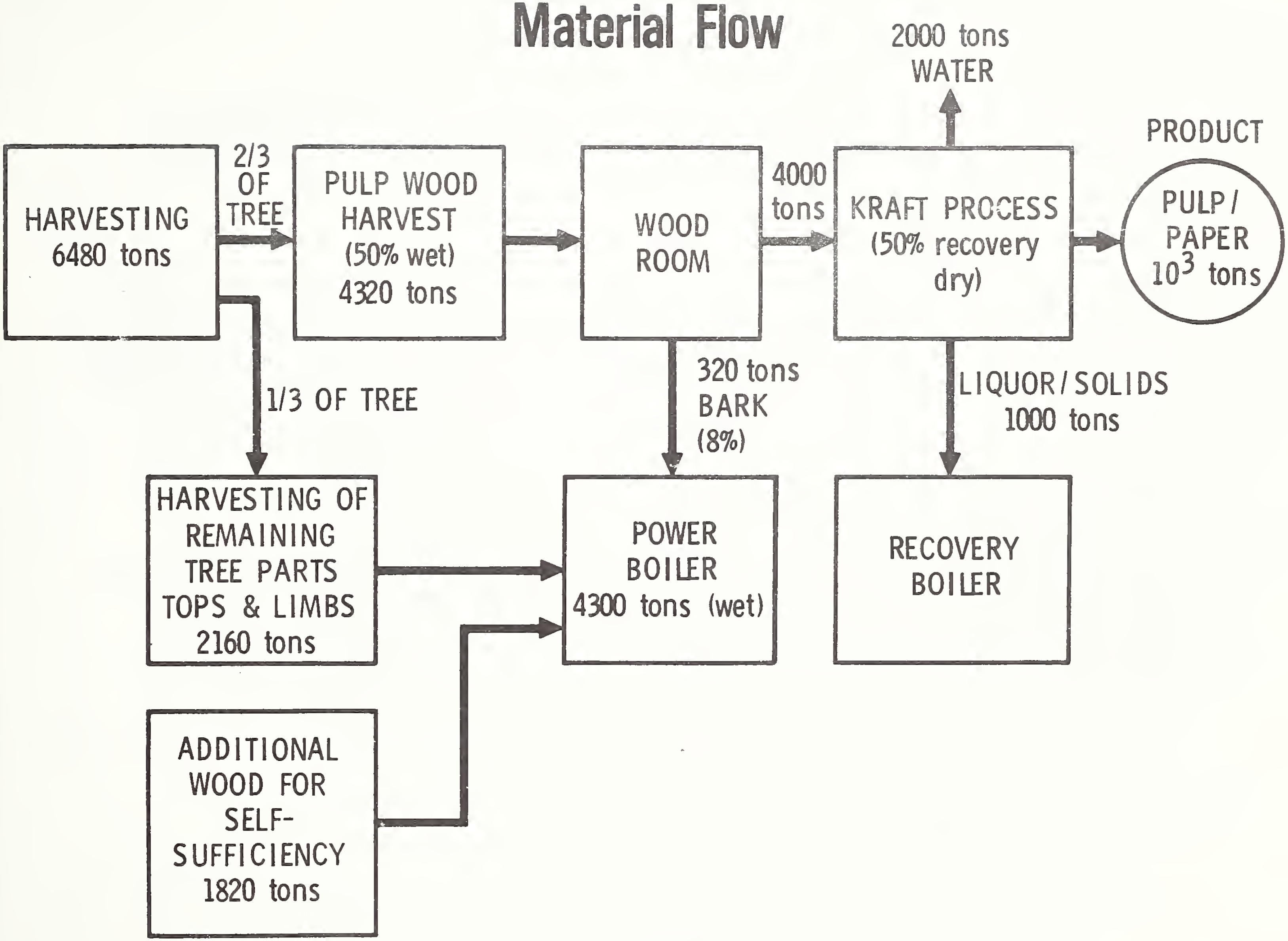


1) Site survey data
2) Other costs incl (capital recovery, emission control, chemicals, labor, maint....) compared with fossil combustion costs as noted
3) Based on 8000 Btu/lb for dry residue
4) Based on 4000 Btu/lb for wet (50%) residue

A major issue of energy self-sufficiency implementation is the availability of adequate residues for fuel. The flow of material in a typical pulp/paper plant was analyzed to obtain an estimate of the residue required.

Assuming 1000 ton/day product from the Kraft process a 50% dry recovery requires about 4000 ton/day fiber input with a 50% moisture content. The wood room which supplies 4000 ton of fiber requires about 4320 ton of pulp logs assuming about 8% bark. Typically, about 22.4×10^6 Btu/ton of output of purchased energy is consumed in the pulping process which requires about 4300 ton of 50% wet residue which is provided from 320 tons of bark from wood room, 2160 tons from utilization of the whole tree from which fiber was supplied and 1820 tons of additional residue.

Material Flow



A material flow analysis was conducted for pulp/paper mills having capacities ranging from 200 to 2000 tons/day to determine the amount of wood (fiber and residue) required to sustain pulping operations and achieve energy self-sufficiency by burning residue.

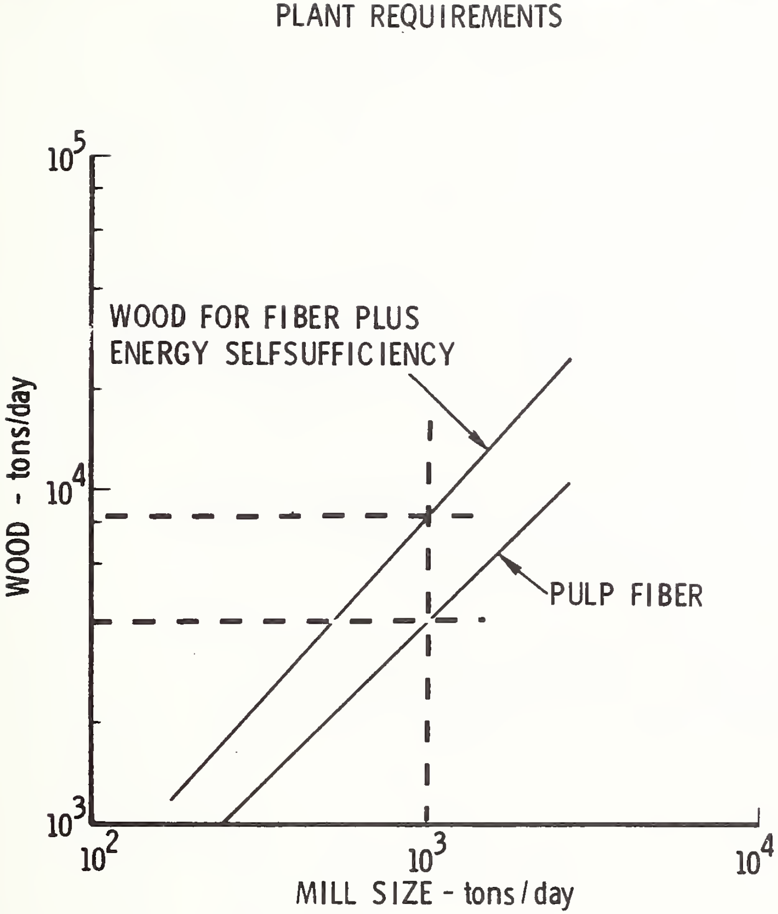
PLANT REQUIREMENTS

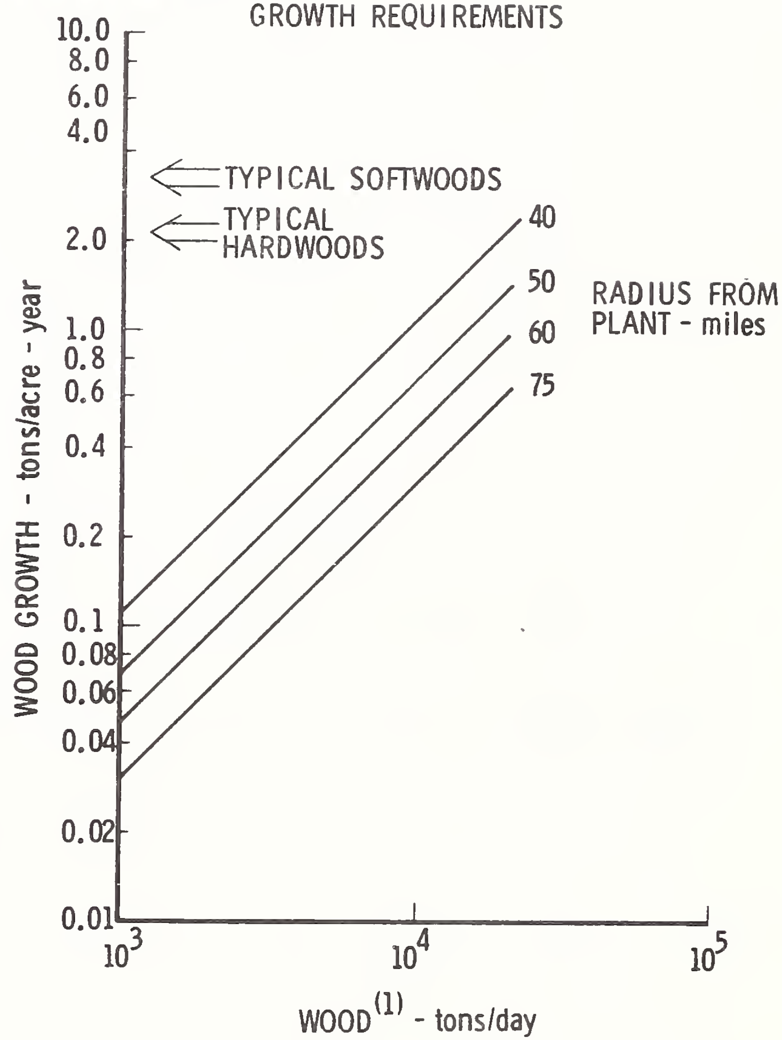
The total amount of wood required to support pulp/paper mill operations including the burning of residue for fuel is a function of mill size and assumptions made for wood moisture content, pulping efficiencies, boiler efficiencies etc. For the cases shown the wood was assumed to contain 50% moisture, pulping efficiency was 50%, residue (wood and/or bark) heating value was 4,000 Btu/lb and the boiler efficiency was assumed to be 0.65. The specific purchased energy consumption as a function of mill size was taken from data presented earlier. As can be seen from the curves, a typical mill having a capacity of 1000 ton/day would use about 8300 ton/day of wood with about 4000 ton/day used for pulp fiber.

GROWTH REQUIREMENTS

The amount of growth (wood) required per acre per year for demands of mills using the assumptions stated above can be obtained by assuming average growth on all land within selected radii from the mill. For example, if the total wood requirements were 8300 ton/day then average wood growth of approximately 0.4 ton/acre/year would be required at a collection radius of 50 miles from the plant. Typical growth rates for softwoods and hardwoods are noted.

Wood Requirements





(1) Wet Basis

The additional forest residue required over that which would be left after normal pulp wood logging is a function of the amount of pulp wood harvested and the amount of pulp fiber which is obtained from non-forest sources such as sawmills, plywood mills, etc.

For the assumptions shown;

SOFTWOOD

Assuming 25% of the pulp fiber is obtained from non-forest sources and all residue from current logging operations are used as fuel then about 2000 tons per day of additional residue would be needed to achieve energy self-sufficiency in a 1000 tons/day mill.

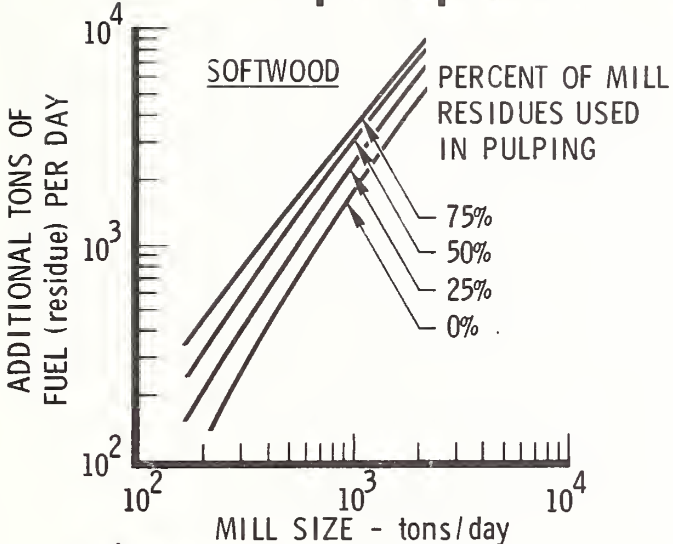
HARDWOOD

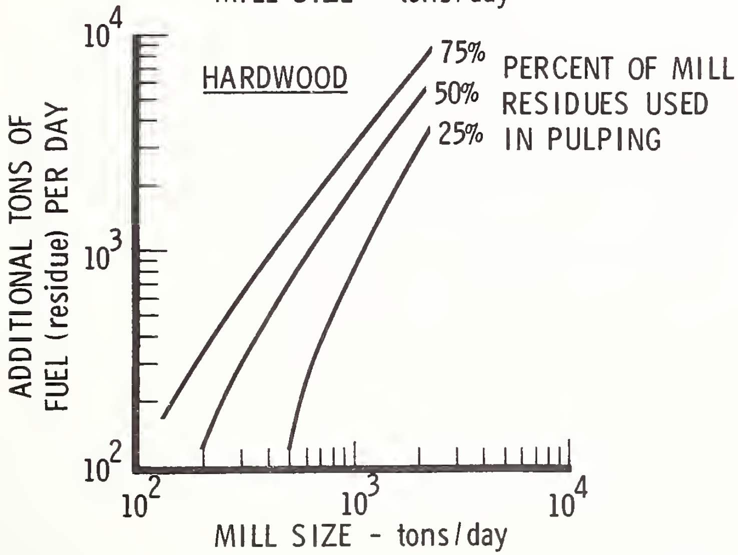
With the same assumption as above - about 900 tons per day of additional residue would be needed to achieve energy self-sufficiency in a 1000 ton/day mill.

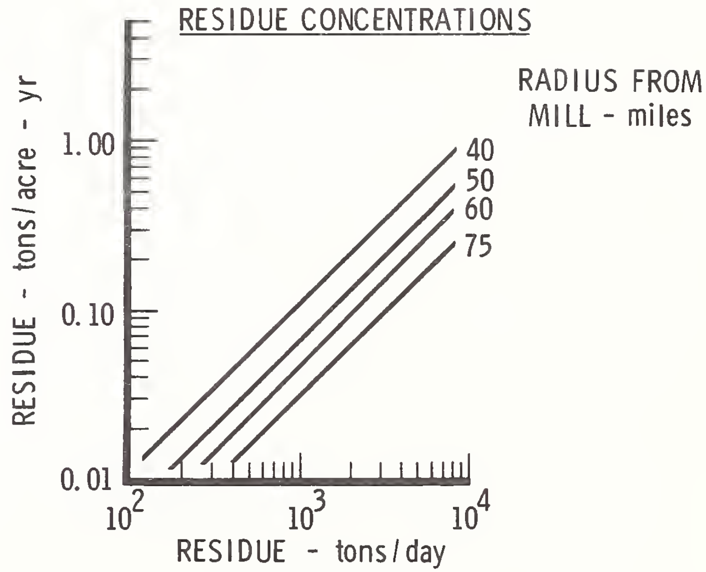
RESIDUE CONCENTRATIONS

The residue concentrations required to meet the additional demand for fuel would average -.12 and 0.07 tons/acre/year respectively for the above cases if the residue was collected within a 50 mile radius from the mill.

Additional Residue (fuel) Requirements for Pulp/Paper Plant Energy Self-Sufficiency







ASSUMPTIONS

(1) SOFTWOOD - 50% YIELD IN PULPING PROCESS - 33% OF TREE IS RESIDUE

(2) HARDWOOD - 50% YIELD IN PULPING PROCESS - 50% OF TREE IS RESIDUE

(3) PULP MIXTURE MADE UP OF PULP LOGS AND PLANT RESIDUE IN PERCENTAGE NOTED

(4) ALL RESIDUE AND BARK FROM PULP LOGGING OPERATIONS IS USED AS FUEL

(5) FUEL AT 4,000 btu/lb AND 0.65 BOILER EFFICIENCY

The feasibility study quantified the forest industries energy problem and evaluated some possible solutions using residue fuels. The pulp/paper sector as the largest user of energy within the forest industry presents the greatest opportunities for achieving energy self-sufficiency. The economics of converting from fossil to residue fuels are becoming more attractive as prices continue to increase. The residue requirements to support energy self-sufficiency were identified for typical mills and was found that a large portion of their fuel needs could be met by whole tree utilization. Current combustion technology appears capable of meeting the energy demands using available residues, however significant improvement opportunities exist for making the concept more economically attractive by improving the fuel properties of the residue (principally through drying).

IMPROVEMENT OPPORTUNITIES

Improvement can be accomplished in any or all of the major elements of a residue utilization system. Some of these improvements will have less technical risk and some larger economic impact for a given R&D expenditure. Based on information obtained during the feasibility study, the greatest payoff in improving the residue combustion process technically and economically lies in the fuel preparation area.

Conclusions

- FEASIBILITY OF INCREASING ENERGY SELF-SUFFICIENCY
  - PULP/PAPER - KEY INDUSTRY
  - WHOLE TREE UTILIZATION CAN PROVIDE SUBSTANTIAL FUEL
  - RESIDUE VALUES BECOMING COMPETITIVE WITH FOSSIL FUEL
  - REMOVAL OF MOISTURE FROM RESIDUE FUELS ENHANCE THEIR VALUE
- SYSTEM IMPROVEMENT OPPORTUNITIES*
  - REFINEMENT/PREPARATION OF RESIDUE FUEL
  - RESIDUE COLLECTION/TRANSPORT
  - COMBUSTOR DESIGN IMPROVEMENT

*RANKED FOR EXPECTED PAYOFF

A study of the economics of producing chemicals from wood waste was undertaken as part of the feasibility study. Data are taken from an engineering study by Raphael Katzen Associates.

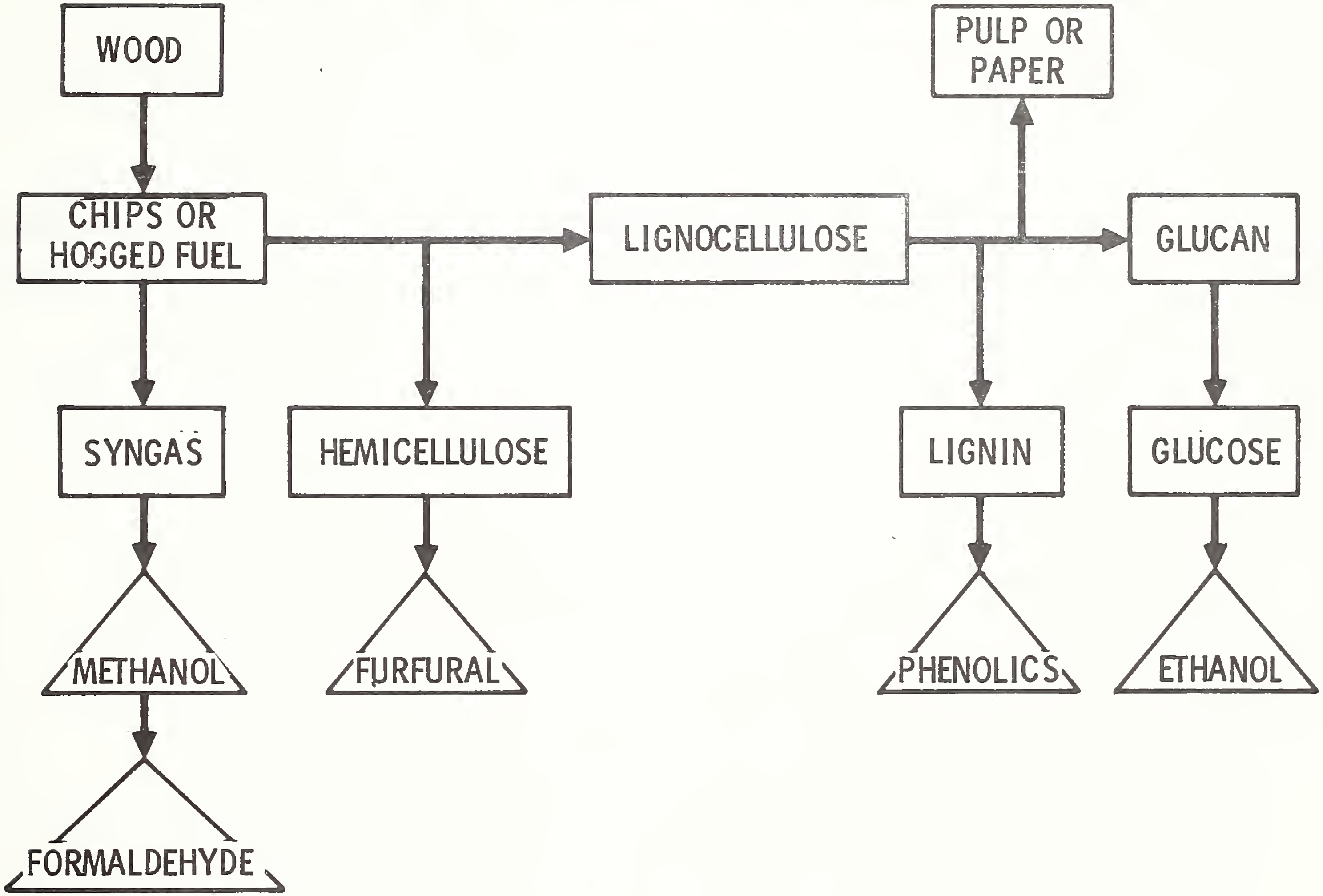
OBJECTIVES

- To outline chemical processes based on known process and engineering technology for producing methanol, ethanol, formaldehyde, furfural, and phenols from wood waste.
- To estimate investment and operating costs for these plants.
- To compare these economics with those for production of the same chemicals from more conventional raw materials.
- To recommend possible areas for future research and development.

SCOPE

The chemical conversions processes considered included, methyl alcohol, formaldehyde, ethyl alcohol, phenol, and multi product schemes.

Chemicals from Wood and Wood Waste



The major usage for methanol is conversion into formaldehyde, a constituent of synthetic resins for the manufacture of plywood, chipboard and plastics. These resins are generally urea-formaldehyde and phenol-formaldehyde compositions.

METHANOL PRODUCTION, CAPACITY AND USES

NEW USE - AS GASOLINE ADDITIVE

U. S. Gasoline Consumption:
1973 - 115,000 MM GPY

Methanol Required
at 10% addition - 11,500 MM GPY

Present U. S. Capacity - 1,242 MM GPY

Methanol Capacity Required
10 Times Present Capacity

Methanol Plants

Capacity MMGPY	Number Plants	Total MMGPY
22	1	22
50	3	150
80	1	80
100	4	400
160	1	160
200	1	200
230	1	230
Total U. S. Capacity		1,242

Production and Uses

	%	MMGPY
Formaldehyde	45	486
Solvents	10	108
DMT (Dimethyl Terephthalate)	7	76
Plastics	8	86
Export	5	54
Miscellaneous	25	270
Total U. S. Production 1974[1]		1,080

[1] Chemical Marketing Reporter

Today methanol is made from natural gas by conversion of methane into syngas containing hydrogen and carbon monoxide. Natural gas generally contains over 95% methane. It takes 115 cu ft of natural gas, or 4.9 pounds, to make one gallon of methanol.

Methanol Synthesis from Natural Gas

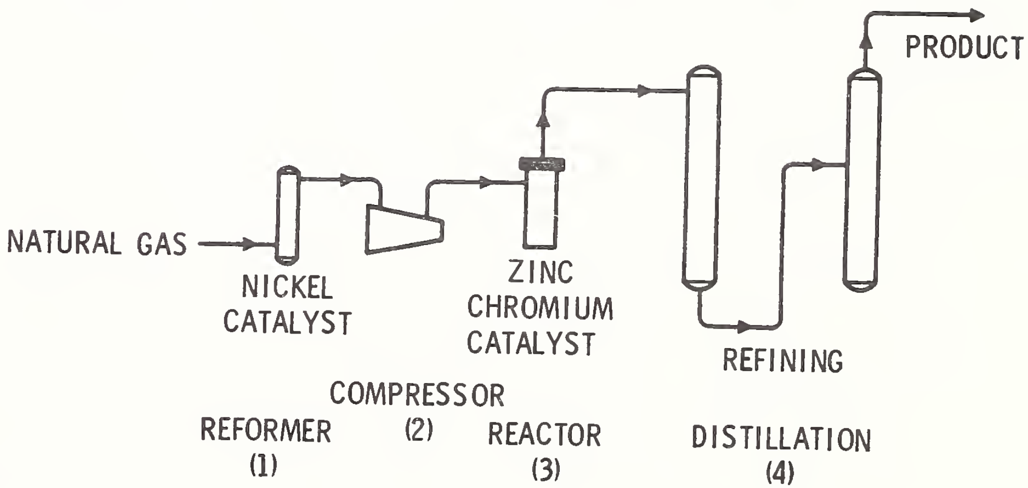
PROCESS STEPS

(1) REFORM NATURAL GAS TO SYNGAS

(2) COMPRESS SYNGAS TO 1500-3000 psig

(3) CONVERT SYNGAS TO METHANOL

(4) REFINE CRUDE METHANOL INTO SPECIFICATION GRADE PRODUCT



The most promising reactor-gasifiers for wood gasification are the Moore-Canada and the Union Carbide Purox units. These two systems have undergone extensive development.

Further experimental testing of these systems is required to optimize them to yield a crude syngas with a high percentage of hydrogen and carbon monoxide and a low percentage of carbon dioxide and hydrocarbons. It is expected that the efficiency of these units can be improved in this regard.

TYPES OF REACTOR-GASIFIERS

METHANOL FROM WOOD WASTE		Moore Semi-Works	Moore[1] Full Scale	UCC Purox	Batelle Pilot	Thermex Semi-Works
Operating factors for a methanol plant based on data from Moore-Canada and Union Carbide's Purox process	Type Reactor (bed)	Moving	Moving	Moving	Moving	Fluidized
	Feed	Wood Waste	Wood Waste	Garbage	Wood	Wood Waste
	Form of Feed	Hogged	Hogged	Hogged	Chips	Hammer Milled
	Air/Oxygen	Air	Air	Oxygen	Air	Air
	Feed Rate - lb/hr OD	1,500	5,000	14,000	1,600	4,000
	Diameter-ft	5'6"	9'6"	12'0"	3'0"	8'0"
	Mass Velocity lb/hr ft^2	63	70.5	123	140	80
	Aspect Ratio L/D	No data available				
	Temp. at Bottom, ^{o}F	2,200	2,200	3,000	--	--
	Form Ash	Granular	Granular	Molten		

[1] In operation late 1975

Methanol from wood waste is a complex operation. A 10 day supply of wood waste requires 10 acres storage area and considerable mechanical equipment for material handling. Crude gas from the reactor-gasifiers requires several process steps to clean the gas, to remove the hydrocarbons and nitrogen, and to convert part of the carbon monoxide to obtain the correct ratio of hydrogen and carbon monoxide for synthesis.

Methanol Synthesis from Wood Waste

PROCESS STEPS

(1) PARTIAL OXIDATION OF WOOD WASTE

(2) CLEAN AND COOL CRUDE GAS

(3) COMPRESS TO 100 psig

(4) REMOVE CARBON DIXOIDE

(5) REMOVE RESIDUAL CARBON DIOXIDE

(6) REMOVE NITROGEN AND HYDROCARBONS

(7) COMPRESS TO 400 psig

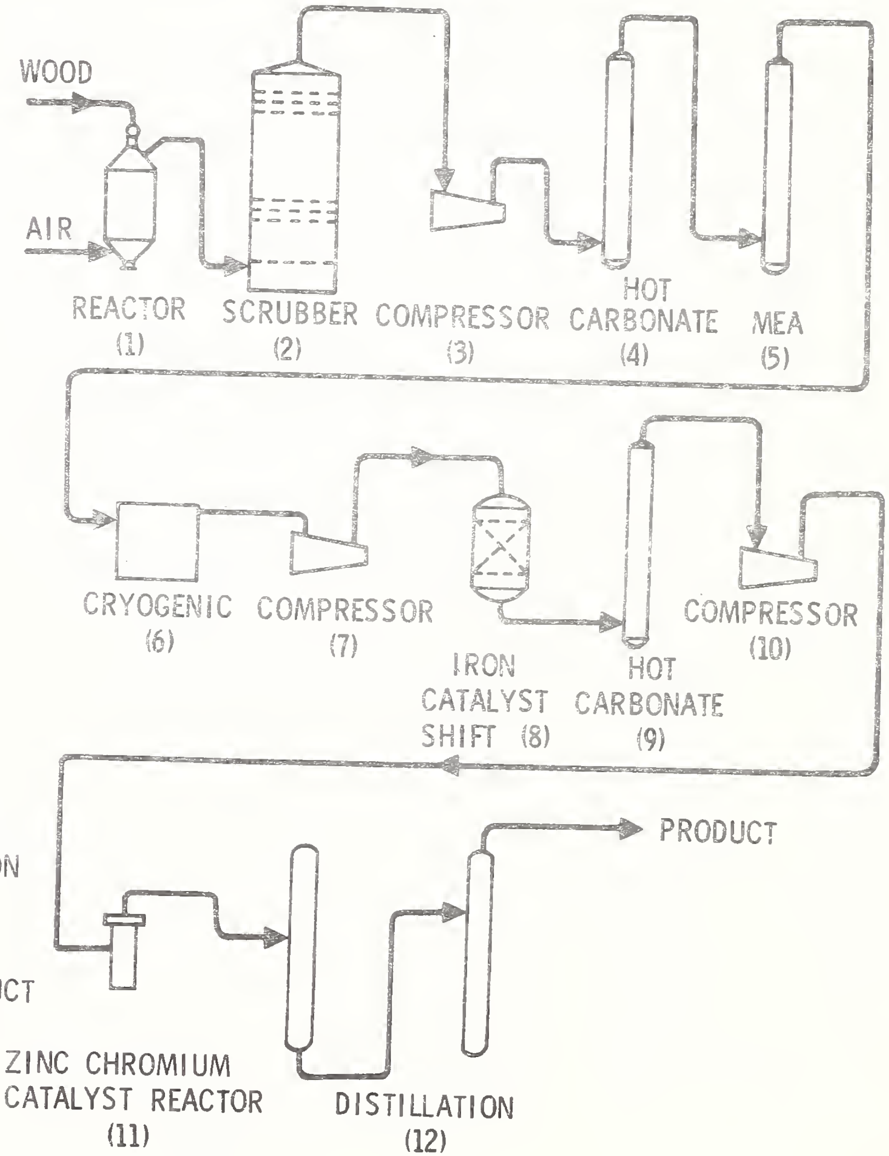
(8) SHIFT GAS TO TWO PARTS HYDROGEN AND ONE PART CARBON MONOXIDE

(9) REMOVE CARBON DIOXIDE FORMED IN SHIFT

(10) COMPRESS TO 2500 psig

(11) CONVERT HYDROGEN AND CARBON MONOXIDE INTO METHANOL

(12) REFINE CRUDE METHANOL INTO SPECIFICATION GRADE PRODUCT



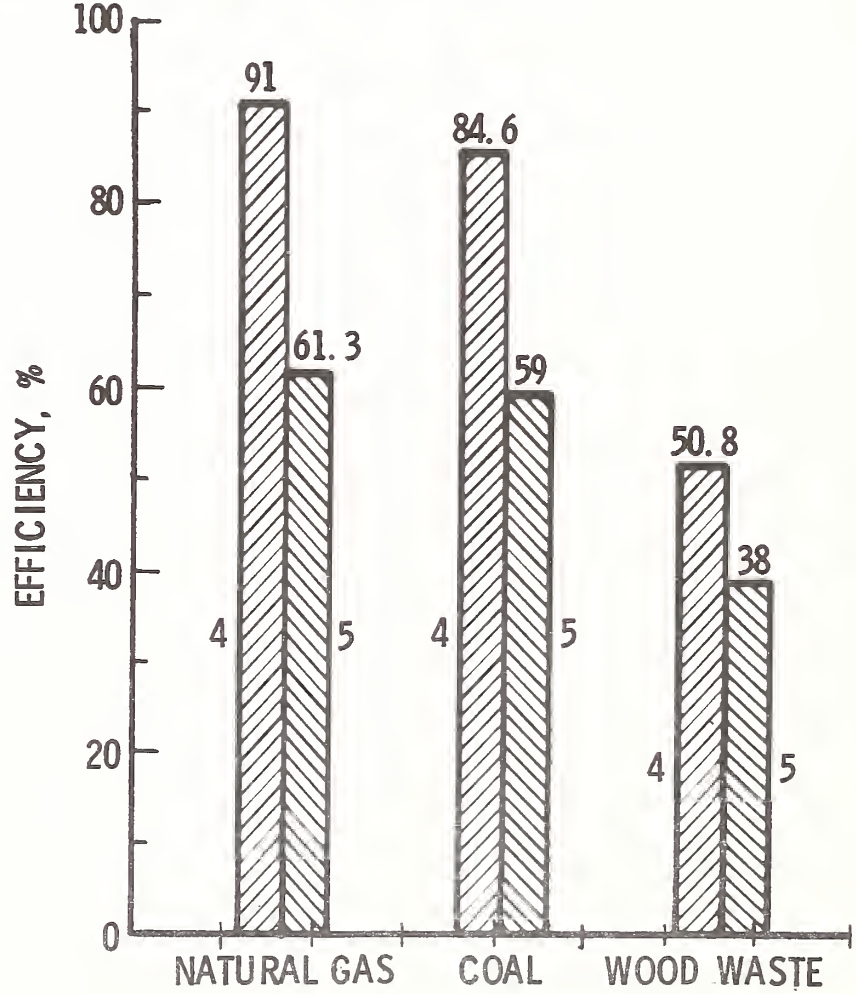
Reforming of methane into syngas requires energy in the form of heat because the reaction is endothermic. This reaction requires about 15% of total feed energy input. About 15% additional energy is required to drive the multiple-stage compressor trains.

Coal conversion to syngas has a greater efficiency than wood waste because the former has a higher carbon content and a lower oxygen content than wood.

Methanol Synthesis Conversion Efficiency

NATURAL GAS, COAL, AND WOOD WASTE

1. NATURAL GAS - HEATING VALUE
   1,000 Btu / cu ft
2. COAL - NEW MEXICO COAL WITH
   19% ASH CONTENT, HEATING VALUE
   8,660 Btu / lb
3. WOOD WASTE - DOUGLAS FIR WITH
   25% BARK CONTENT, HEAT VALUE
   9,000 Btu / lb
4. PROCESS EFFICIENCY - HEAT VALUE
   OF METHANOL AS A PERCENT OF
   HEATING VALUE OF PROCESS FEED
5. PLANT EFFICIENCY - HEAT VALUE
   OF METHANOL AS A PERCENT OF
   TOTAL ENERGY INPUT INTO PLANT



Raw material input for the three types of methanol synthesis plants are as follows:

	50 MM GPY	200 MM GPY
Natural Gas	16.3 MM cfd	65.2 MM cfd
Coal	1,380 T/D	5,520 T/D
Wood Waste	1,480 T/D	5,920 T/D

Methanol Synthesis Plant Investment

50 MM GPY AND 200 MM GPY FACILITIES

INVESTMENT ESTIMATE

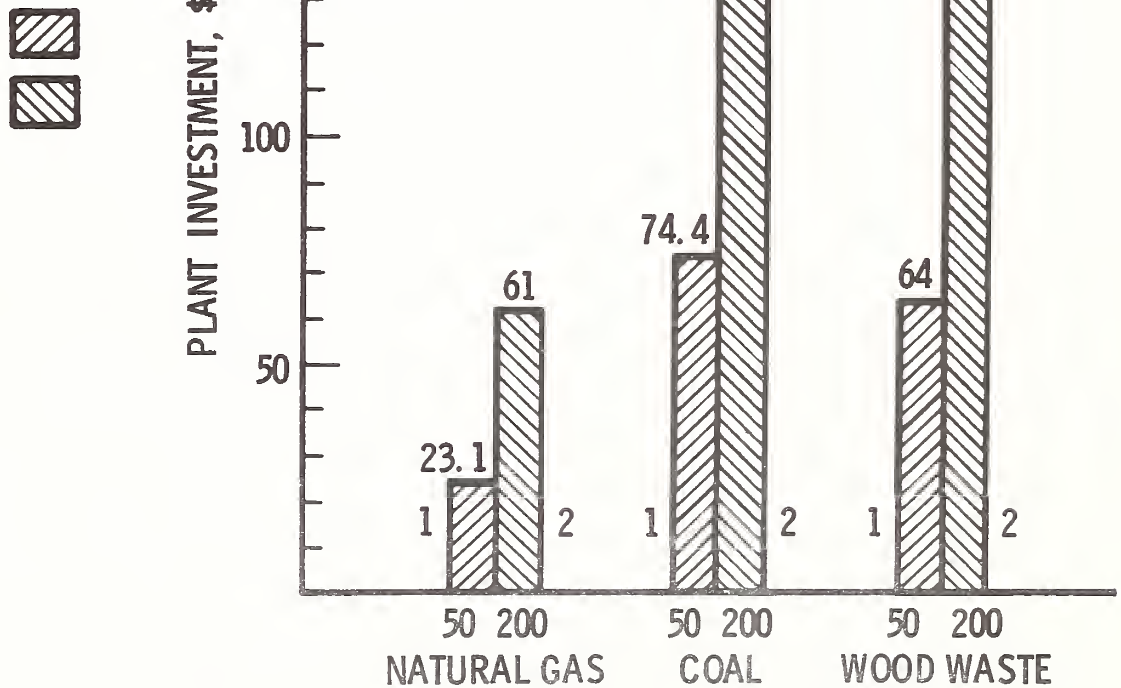
BASED ON 1975 COSTS

INCLUDES 25% CONTINGENCY

NO ESCALATION INCLUDED

1 50 MM GPY FACILITY

2 200 MM GPY FACILITY



To determine production cost of synthetic methanol, profit is deducted. Profit for the three processes is as follows (before taxes):

	Cents Per Gallon	
	50 MM GPY	200 MM GPY
Natural Gas	9.2	6.1
Coal	29.6	17.8
Wood Waste	25.6	16.9

Methanol Synthesis – Selling Price

50 MM AND 200 MM GPY FACILITIES

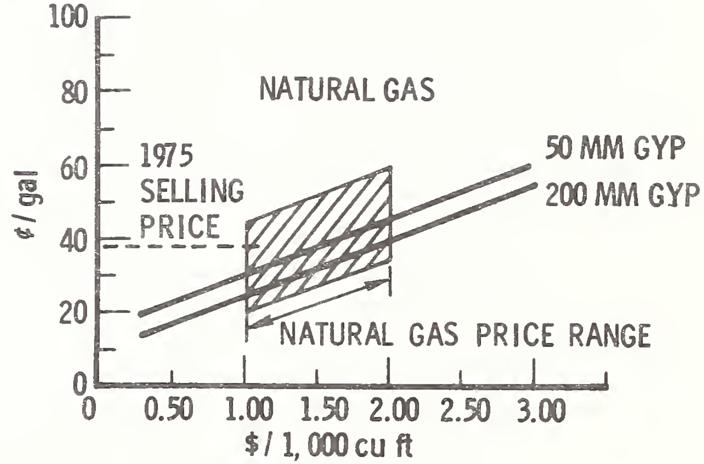
PRODUCTION COSTS	% INVESTMENT
DEPRECIATION	8
MAINTENANCE	4
TAXES AND INSURANCE	2

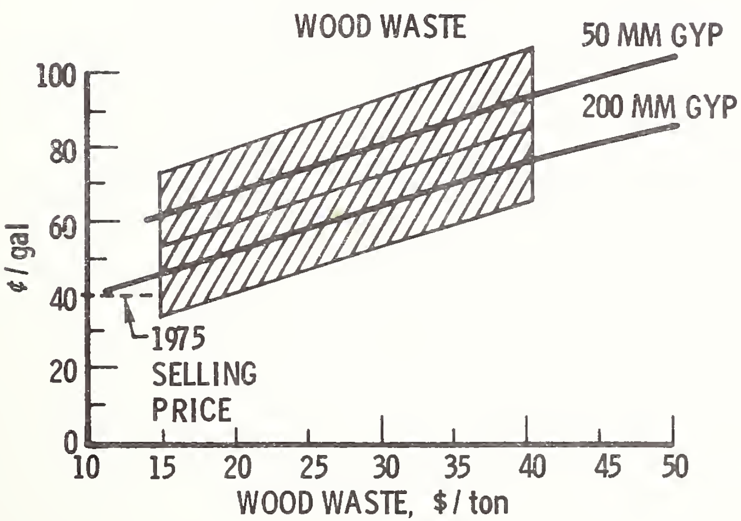
LABOR

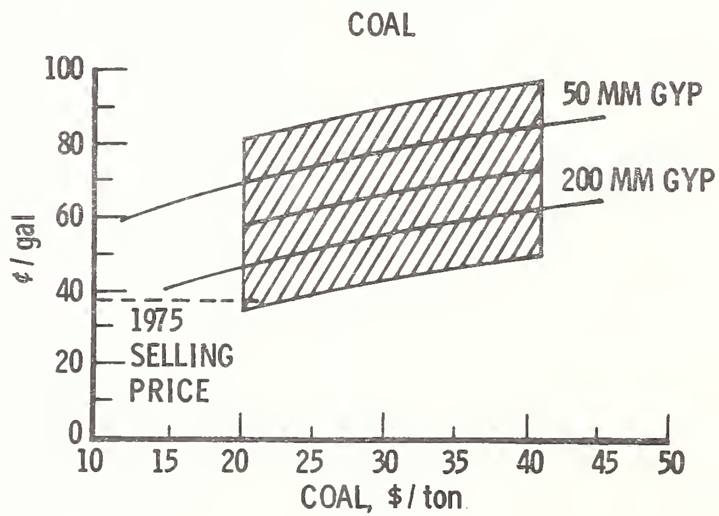
OPERATOR	\$20,000/yr
FOREMEN	25,000/yr
MANAGEMENT	30,000/yr

OVERHEAD 100% OF LABOR

PROFIT 20% OF INVESTMENT (10% after taxes)







COMPARATIVE ENERGY RECOVERY FROM WOOD

Compound	Yield/T OD[1]	Product Heat Value Btu	Total Potential Heat Value MM Btu/T OD
Wood Direct Burning	2,000 lb	8,500/lb	17.0
Charcoal	670 lb	12,500/lb	8.38
Oil	370 lb[2]	14,380/lb	5.32
Methanol	647 lb	9,788/lb	6.33

[1]T OD = tons, oven-dry

[2]1.25 bbl or 52.5 gal based on 7 lb/gal and 42 gal/bbl

Formaldehyde is an unstable chemical compound unless inhibited. It serves the chemical industry in synthetic resin formulation and as an intermediate for synthesis of other chemical products.

FORMALDEHYDE PRODUCTION, CAPACITY, AND USES

Formaldehyde Producers [1]

Capacity Range MM lb/yr 100% Basis	37% Solution Basis	Number of Producers	Total Capacity MM lb/yr 100% Basis	37% Sol'n Basis
500-630	1300-1700	3	1637	4425
250-320	680-850	3	835	2260
100-115	270-310	3	317	855
40-60	100-160	3	150	405
0-40	0-100	6	163	440
TOTALS		18	3102	8385

Formaldehyde Uses [1]

Use	Percent	MM lb/hr [2]
Urea-Formaldehyde Resins	25	1450
Phenolic Resins	21	1218
Polyacetal Resins	8	464
Pentaerythritol	7	406
Hexamine	5	290
Miscellaneous	34	1492
TOTAL	100	5800

1 Chemical Marketing Reporter, March 10, 1975
2 37% Solution Basis

Efficiency of methanol conversion to formaldehyde is as follows:

	7% MeOH	1% MeOH
lb/MeOH converted to formalhyde/ lb MeOH feed	77.3	88.3
lb MeOH converted to formaldehyde/ lb MeOH consumed	89.7	89.9

Formaldehyde from Methanol

PROCESS STEPS

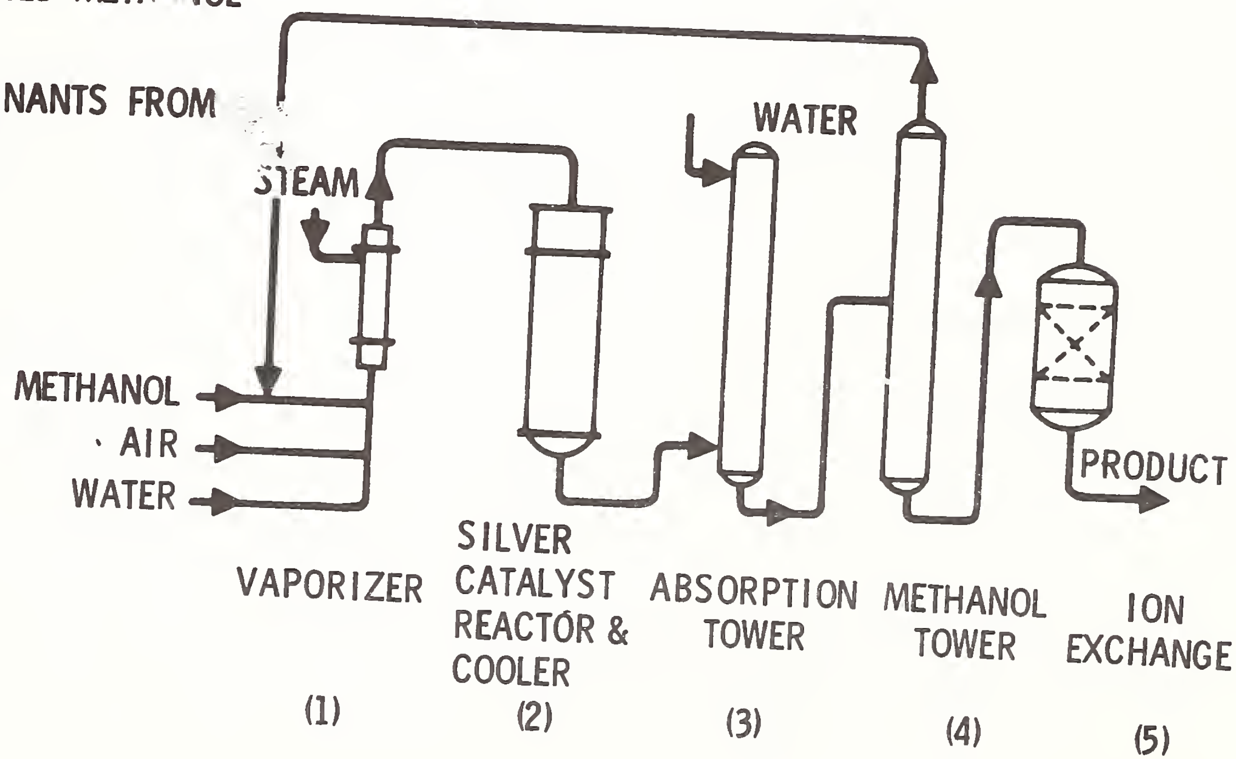
(1) VAPORIZE METHANOL AND WATER

(2) REACT VAPORS CATALYTICALLY TO FORM FORMALDEHYDE

(3) ABSORB FORMALDEHYDE IN WATER

(4) RECOVER UNREACTED METHANOL AND RECYCLE

(5) REMOVE CONTAMINANTS FROM FORMALDEHYDE



Production costs for formaldehyde are obtained by deducting a profit (before taxes) of 1.1¢/lb for the 100 MM lb/yr facility and 1.8¢/lb for the 10 MM lb/yr plant.

Formaldehyde – Selling Price

10 MM AND 100 MM lb/yr FACILITIES

PRODUCTION COSTS

INVESTMENT	100 MM lb/yr	\$5.30 MM
	10 MM lb/yr	\$0.90 MM

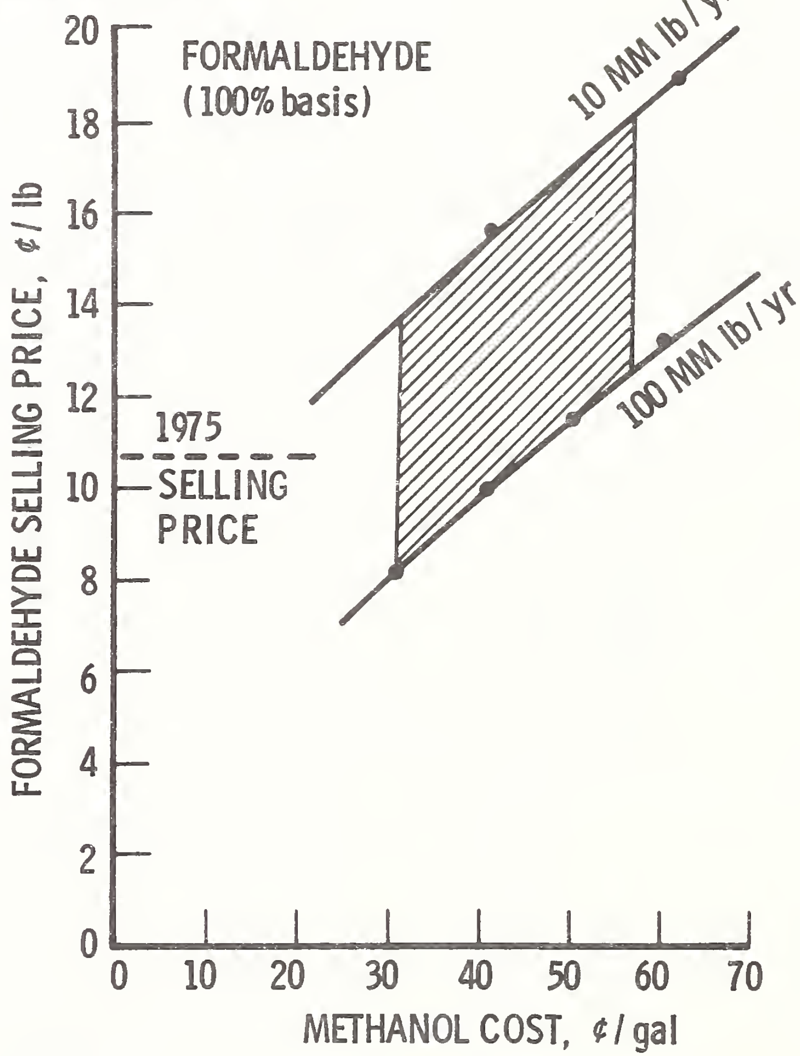
	% INVESTMENT
DEPRECIATION	8
MAINTENANCE	4
TAXES AND INSURANCE	2

LABOR

OPERATORS	\$20,000/yr
FOREMEN	25,000/yr

OVERHEAD 100% OF LABOR

PROFIT 20% OF INVESTMENT (10% after taxes)



Ethanol as a chemical finds use as a starting feedstock for synthesis of drugs and medicines. It is also used as a raw material for ethers, glycols, and ethylamines.

Capacity[1]		GPY 190 Proof
Synthetic Ethanol		361,000,000
Production 1974[2]		
Synthetic - Industrial		257,000,000
Fermentation - Industrial		88,300,000
Fermentation - Beverage		118,000,000
		463,300,000
Industrial Ethanol Usage	**Percent**	
Chemical Manufacture	26	89,780,000
Toiletries and Cosmetics	20	69,060,000
Acetaldehyde	14	48,340,000
Industrial Solvents	12	41,440,000
Detergents	10	34,530,000
Miscellaneous	18	62,150,000
		345,300,000

Synthetic Ethanol Plants

Petrochemical Plants - Size Range 25 to 120 MM GPY
Number Plants - 6

[1] Chemical Marketing Reporter
[2] U.S. Alcohol, Tobacco and Firearms Information for fiscal July - June 1974-75

Enzyme conversion of cellulose into glucose requires 25 lb enzyme/Ton O.D. wood estimated by Natick Laboratory to cost $125, or the equivalent of $8/gal ethanol, 190 pr. (TVA yield). At present the recovery and recycle of spent Enzyme has not been developed. In addition, energy to ballmill wood into a flour-like material to break down the crystalline form of the cellulose ranges from 500 hp-hr to 2,000 hp-hr/Ton O.D. At 500 hp-hr electrical cost is $8/Ton O.D. at $0.02/kw hr or $0.50 per gallon ethanol, 190 proof. Current selling price of industrial ethanol is about $1.00 per gallon.

1 PROCESS	2 WOOD lb	3 RAW MATERIAL TYPE	4 GLUCOSE YIELD lb	5 ETHANOL YIELD-GAL 190 PROOF
Enzymes	2,000	TVA wood waste-ball milled	198	16.4
Enzymes	2,000	Hercules Pine Chips-ball milled	490	40.7
Enzymes	2,000	Gov't Documents ball milled	1,146	95.2
Acid Hydrolysis	2,000	Douglas Fir - Bark Free-hogged	785	65.0
Acid Hydrolysis	2,000	Douglas Fir -with 25% bark-hogged	590	49.0

Synthetic ethanol today is made by the direct hydration of ethylene and water. This reaction is carried out at about 1,000 psi and 500°F in the presence of a phosphoric acid catalyst. Ethylene, a building block for the petrochemical industry is made by the cracking of ethane and propane, or naphtha, natural gas and petroleum fractions, respectively.

Synthetic Ethanol from Ethylene

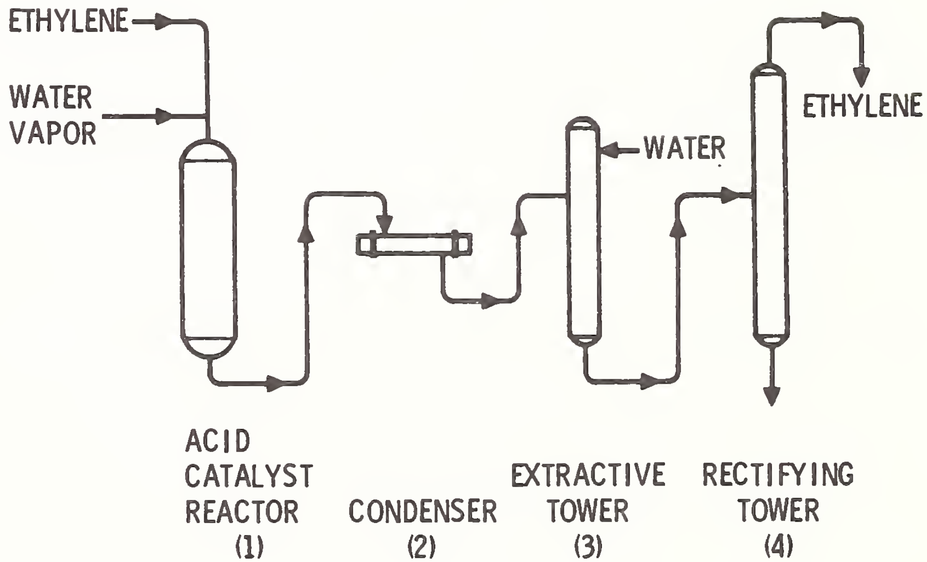
PROCESS STAGES

(1) ETHYLENE AND STEAM AT HIGH TEMPERATURE AND PRESSURE IN PRESENCE OF ACID CATALYST COMBINE INTO ETHANOL

(2) ETHANOL VAPOR CONDENSED TO FORM CRUDE PRODUCT

(3) PURIFY CRUDE DILUTE ETHANOL

(4) CONCENTRATE DILUTE ETHANOL TO 190 PROOF STRENGTH



CHEMISTRY

$$C_2H_4 + H_2O \xrightarrow{CAT.} C_2H_5OH$$

ETHYLENE WATER ETHANOL

Conversion of wood or wood waste into sugar requires hydrolysis in the presence of a dilute mineral acid catalyst at temperatures up to 385°F and a pressure of 225 psig. After recovery of the sugars, the 6 carbon sugars can be fermented by yeast into ethanol. By means of a second mineral acid hydrolysis step, the remaining 5 carbon sugars can be converted into furfural.

Ethanol from Waste Wood

PROCESS STEPS

(1) CELLULOSE CONVERTED TO SUGAR BY ACID HYDROLYSIS UNDER HIGH PRESSURE AND TEMPERATURE

(2) SUGAR SOLUTION FLASHED

(3) FURFURAL IN FLASH CONDENSATE RECOVERED

(4) SUGAR SOLUTION NEUTRALIZED

(5) CALCIUM SULFATE SEPARATED

(6) SUGARS (6 carbon type) FERMENTED TO ETHANOL AND CARBON DIOXIDE

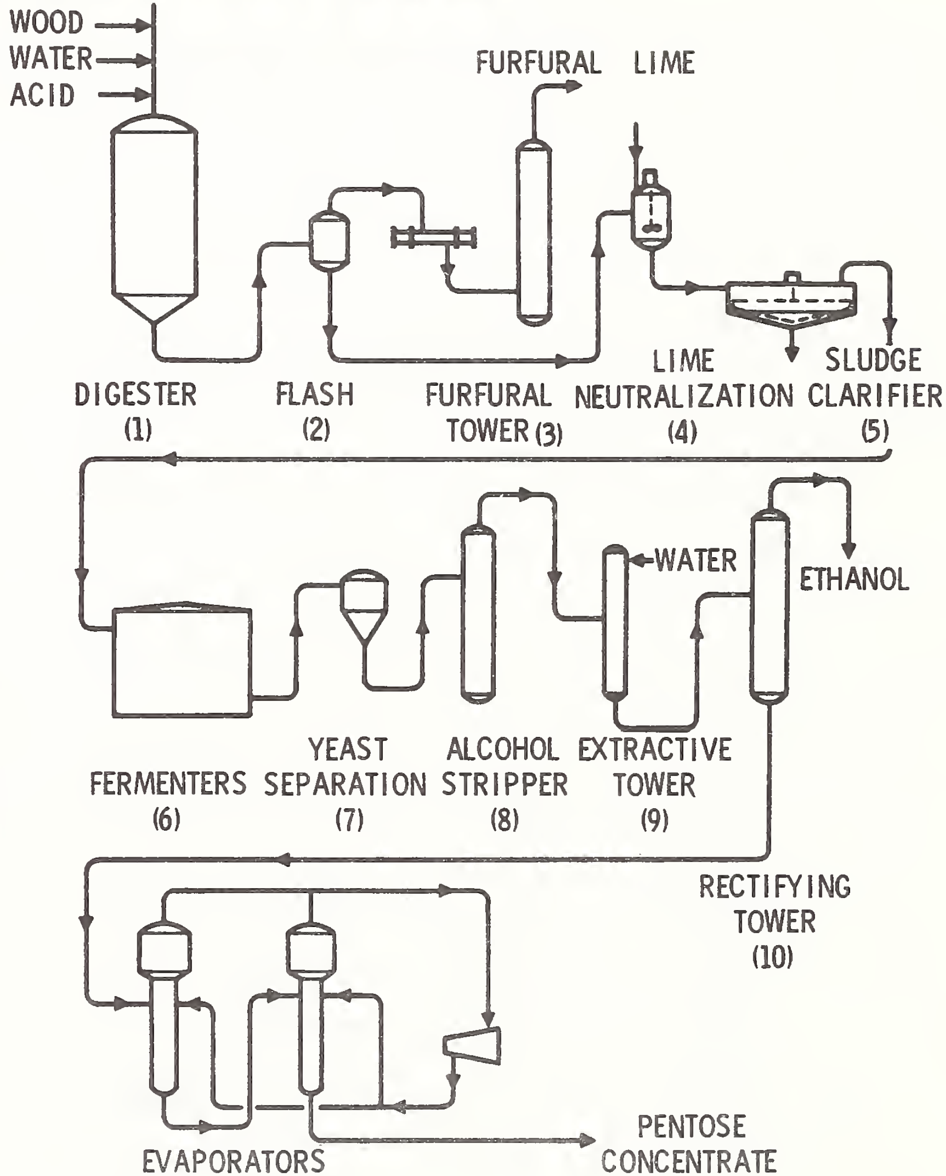
(7) YEAST SEPARATED FOR RE-USE

(8) ETHANOL STRIPPED FROM DILUTE LIQUOR

(9) CONTAMINANTS EXTRACTED FROM ETHANOL

(10) ETHANOL CONCENTRATED TO 190 PROOF

(11) SUGARS (5 carbon type) CONCENTRATED



The complexity of the wood waste process to produce sugars and ethanol is reflected in high investment requirements.

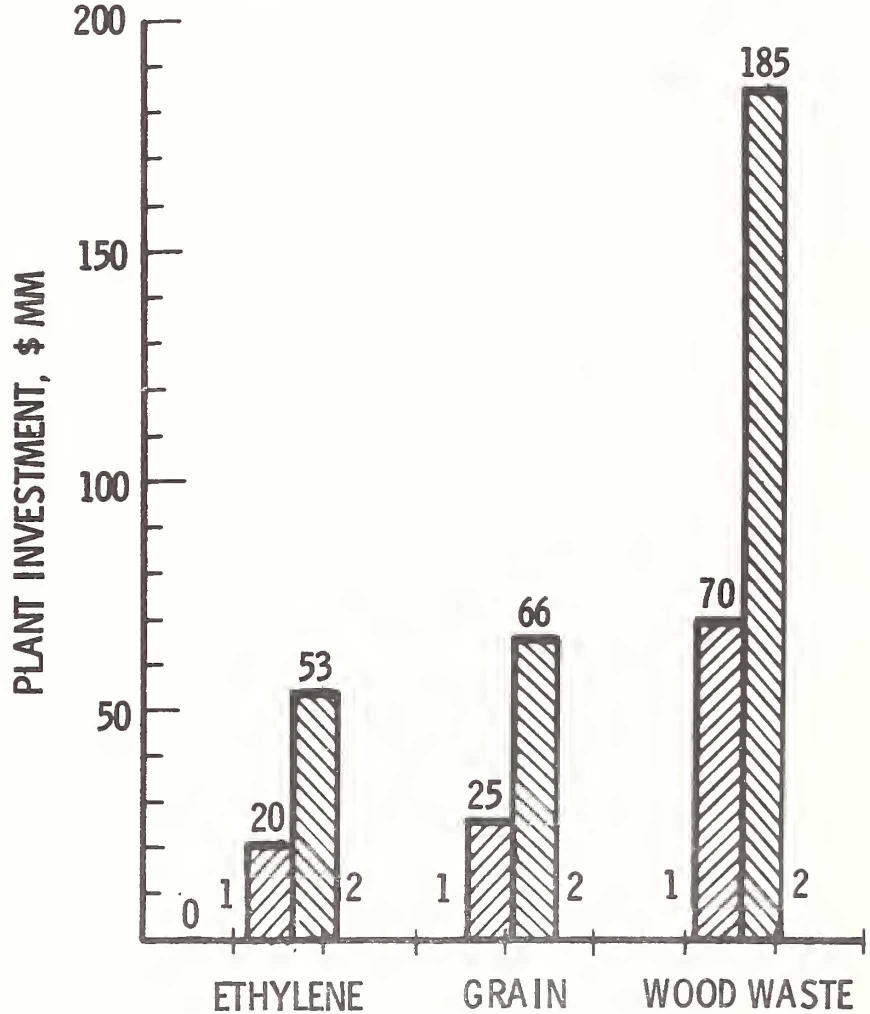
Ethanol Plant Investment

25 MM GPY AND 100 GPY (190 proof) FACILITIES

INVESTMENT ESTIMATE

- BASED ON 1975 COSTS
- INCLUDED 25% CONTINGENCY
- NO ESCALATION INCLUDED

1. 25 MM GPY FACILITY
2. 100 MM GPY FACILITY



Production costs for ethanol can be determined by deducting the following unit profit (before taxes):

	Cents Per Gallon, 190° Pr	
	25 MM GPY	100 MM GPY
Ethylene	8.1	5.3
Grain	20.0	13.2
Wood Waste	56.0	37.0

Ethanol – Selling Price

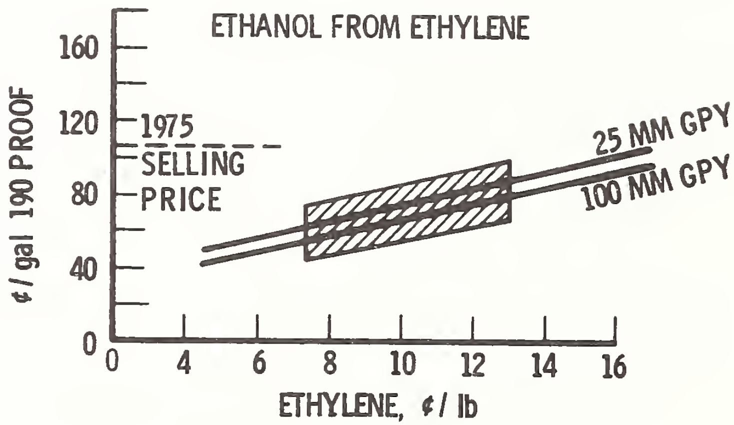
25 MM AND 100 MM GPY (190 proof) FACILITIES

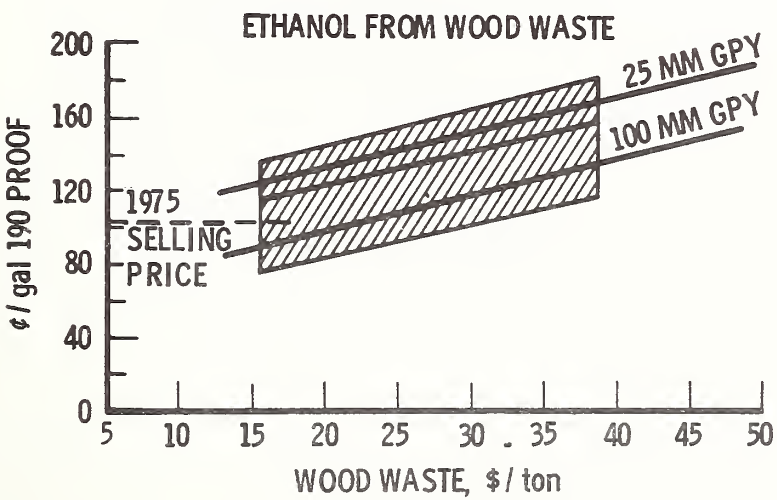
PRODUCTION COSTS	% INVESTMENT
DEPRECIATION	8
MAINTENANCE	4
TAXES AND INSURANCE	2

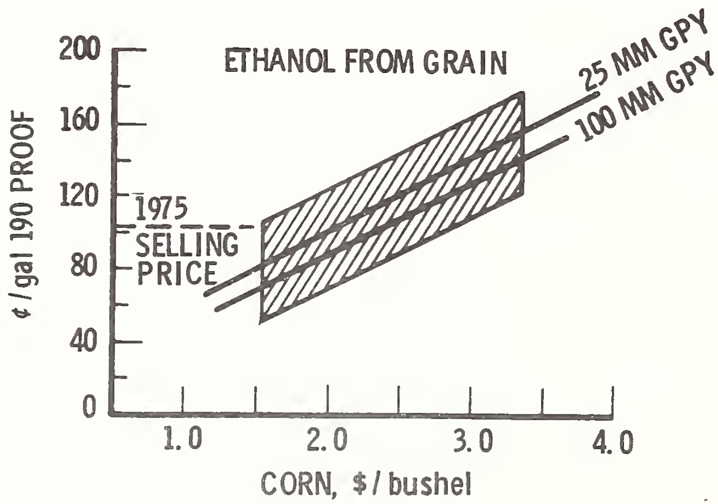
LABOR	
OPERATORS	$20,000/yr
FOREMEN	25,000/yr
MANAGEMENT	30,000/yr

OVERHEAD — 100% OF LABOR

PROFIT — 20% OF INVESTMENT (10% after taxes)







A molasses-like product for animal feed can be produced from wood waste by acid hydrolysis. A concentrate of about 65% sugar content can be made at a selling price of from 8-10¢/lb (dry basis) which compares with 14¢/lb for raw sugar and 7¢/lb for molasses. The sugars from wood waste contain a combination of 6 and 5 carbon sugars. Raw sugar from cane contains about 98% C_{12} disaccharides.

To determine production cost for the raw sugar, a profit of 3.5¢/lb (before taxes) is deducted.

Sugars from Waste Wood

ACID HYDROLYSIS PROCESS

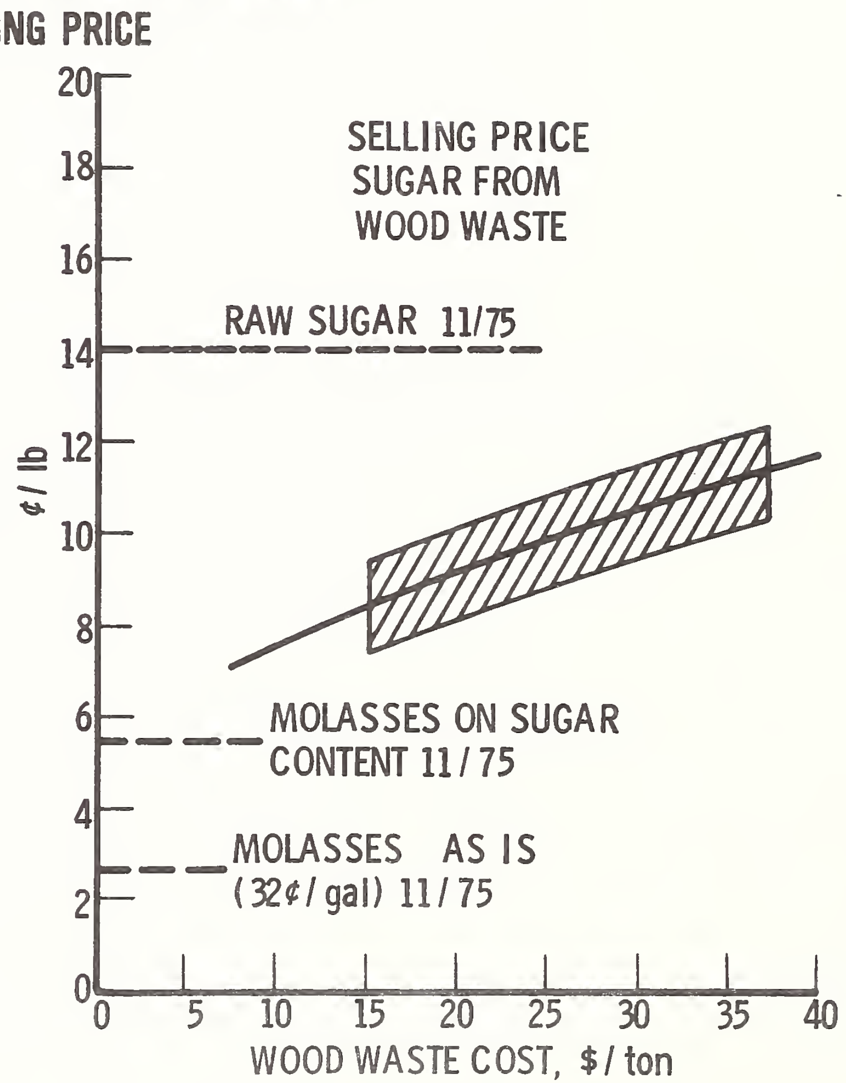
INVESTMENT ESTIMATE - $60 MM

WOOD WASTE - 1480 T/D O. D. (softwood)

PRODUCTION - 516 T/D SUGARS (100% sugar basis)

PRODUCT -
- CONCENTRATED TO 65% SOLIDS CONTENT
- SUGARS CONTAIN 90% HEXOSES (C_6) AND 10% PENTOSES (C_5)

SELLING PRICE INCLUDES -
- FIXED COSTS - 14% OF INVESTMENT
- LABOR
- CHEMICALS
- PROFIT - 20% OF INVESTMENT (10% after taxes)



A considerable amount of furfural is hydrogenated to furfuryl alcohol, which is added to urea-formaldehyde resins in applications for foundry core binders and special adhesives.

Furfural also is used in the extraction of butadiene and wood rosin refining.

FURFURAL PRODUCTION AND USES - 1975

Furfural Production[1]	MM lb/yr
U.S.A.	186
Europe (Western)	77
Asia Australia	36
South Africa	20
Latin America and Dominican Republic	56
Total	375

Raw Materials

Corn Cobs
Bagasse
Oat Hulls
Rice Hulls

Furfural Uses[2]	Percent
Chemical Intermediates	55
Lube Oil Refining	25
Solvents	20
	100

[1] Forest Products Laboratory April 1975

[2] Chemical Week 4/2/55

Furfural is a 5 carbon heterocyclic organic compound made only from C_5 carbohydrates. No practical synthesis route is known.

A wood waste furfural plant requires about 33% of the residue for plant energy uses. The remaining residue represents a potential source of other chemicals or can be credited for its heat value.

Furfural from Wood Waste (hardwood)

PROCESS STEPS

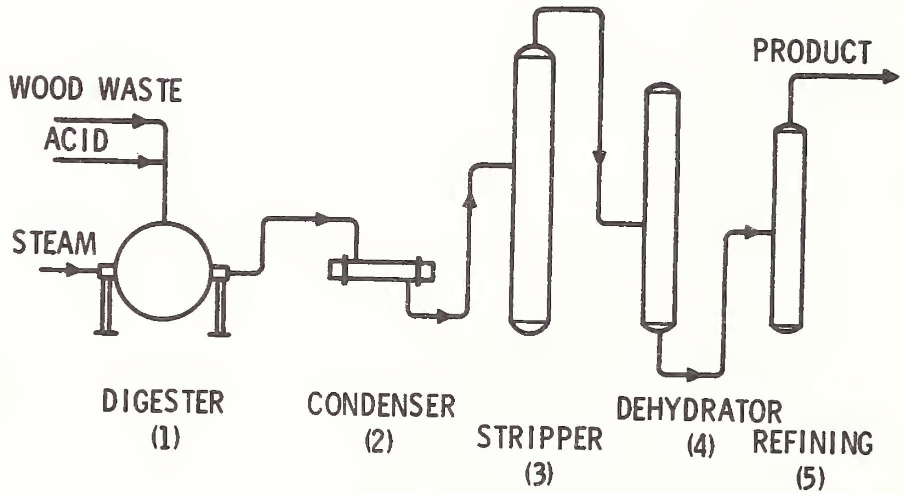
(1) HYDROLYZE PENTOSANS IN WOOD WASTE INTO FURFURAL

(2) CONDENSE FURFURAL AND STEAM VAPOR

(3) STRIP FURFURAL FROM CRUDE FURFURAL FEED

(4) DEHYDRATE FURFURAL

(5) REFINE FURFURAL



Furfural production cost is obtained by subtracting 6.5¢/lb of profit (before taxes).

Furfural from Waste Wood (hardwood) – Selling Price

40 MM lb/yr FACILITY

BASIS OF ESTIMATE

WOOD WASTE (hardwood)	760 T/D O.D.
INVESTMENT ESTIMATE	$27.7 MM
PENTOSE IN WOOD WASTE	18%

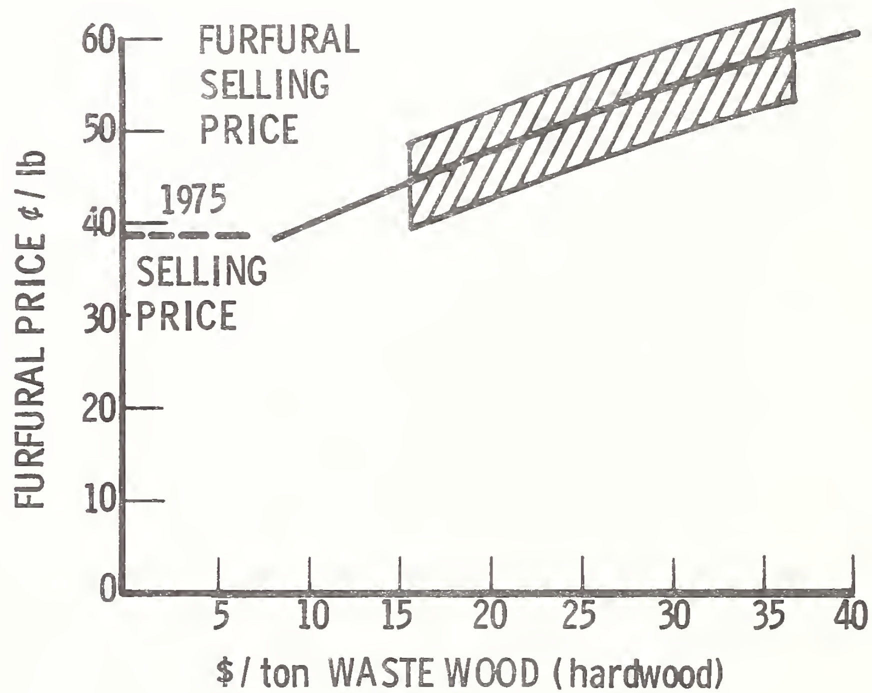
PRODUCTION COSTS	% INVESTMENT
DEPRECIATION	8
MAINTENANCE	4
TAXES AND INSURANCE	2

LABOR

OPERATORS	$20,000/yr
FOREMEN	25,000/yr
MANAGEMENT	30,000/yr

OVERHEAD 100% OF LABOR

PROFIT 20% OF INVESTMENT (10% after taxes)



Phenol, hydroxybenzene, is made synthetically from petrochemical feedstocks. Phenolic resins consume the largest share of phenol production. Plywood bonding is a major outlet for phenolic resins. Another large end use is in the manufacture of bisphenol A, used in the manufacture of polycarbonate and epoxy resins.

PHENOL PRODUCTION, CAPACITY AND USES

Phenol Plants - Synthetic

Capacity MM lb/yr	Companies	Total MM lb/yr
50	4	200
100	2	200
150	2	300
200	2	400
250	1	250
400	2	800
550	1	550
	Total U.S. Capacity	2,700

Production and Uses

	%	MM lb/yr
Phenolic Resins	46	1,100
Caprolactam (synthetic fibers)	16	390
Bisphenol-A (synthetic resins)	14	340
Adipic Acid (synthetic fibers)	3	70
Exports	3.5	80
Other	17.5	420
	Total U.S. Production 1974[1]	2,400

[1]Chemical Marketing Reporter

Yield of furfural from a multi-product plant may be somewhat high compared with a single product plant.

Feasibility of a multi-product plant is dependent on a hardwood waste supply of 1,500 T/D O.D., a relatively large quantity.

Multiple Product Waste Hardwood Facility Ethanol, Furfural, and Phenol

BASIS OF PROJECTION

WOOD WASTE (hardwood)	1500 T/D O. D.
INVESTMENT ESTIMATE	$100 MM
PHENOL RECOVERY	20% OF LIGNIN IN RESIDUE
FURFURAL RECOVERY	7.2% OF WOOD WASTE

ETHANOL	25 MM GPY 190 PROOF
FURFURAL	75 MM lb/yr
PHENOL	52 MM lb/yr

PRODUCTION COSTS	% INVESTMENT
DEPRECIATION	8
MAINTENANCE	4
TAXES AND INSURANCE	2

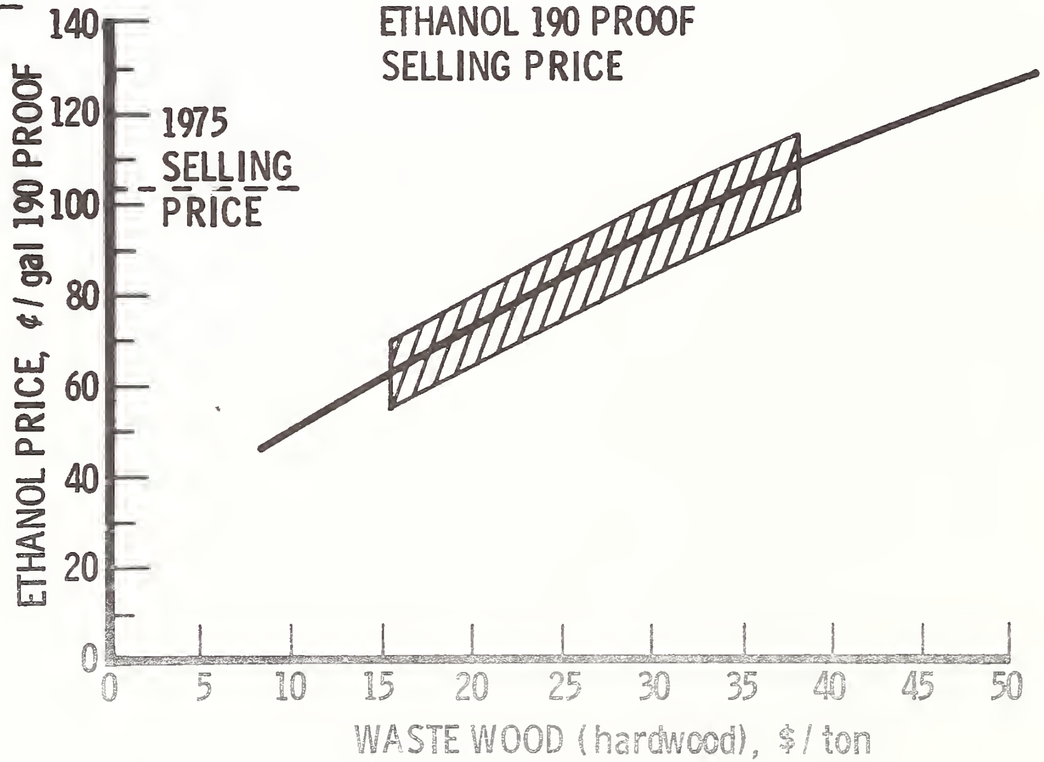
LABOR

OPERATORS	$20,000/yr
FOREMEN	25,000/yr
MANAGEMENT	30,000/yr

OVERHEAD 100% OF LABOR

PROFIT 20% OF INVESTMENT (10% after taxes)

CREDIT	1975 SELLING PRICE
FURFURAL AT 80% OF	$0.37
PHENOL AT 80% OF	$0.27



Yield of furfural from a multi-product plant may be somewhat high compared with a single product plant.

Feasibility of a multi-product plant is dependent on a hardwood waste supply of 1,500 T/D O.D., a relatively large quantity.

Multiple Product Waste Softwood Facility
Ethanol, Furfural, and Phenol

ETHANOL	25 MM GPY
FURFURAL	27 MM lb / yr
PHENOL	52 MM lb / yr

BASIS OF PROJECTION

WASTE SOFTWOOD	1500 T/ D O. D.
INVESTMENT ESTIMATE	$100 MM
PHENOL RECOVERY	20% OF LIGNIN IN RESIDUE
FURFUAL RECOVERY	2.6% OF WOOD WASTE

PRODUCTION COSTS	% INVESTMENT
DEPRECIATION	8
MAINTENANCE	4
TAXES AND INSURANCE	2

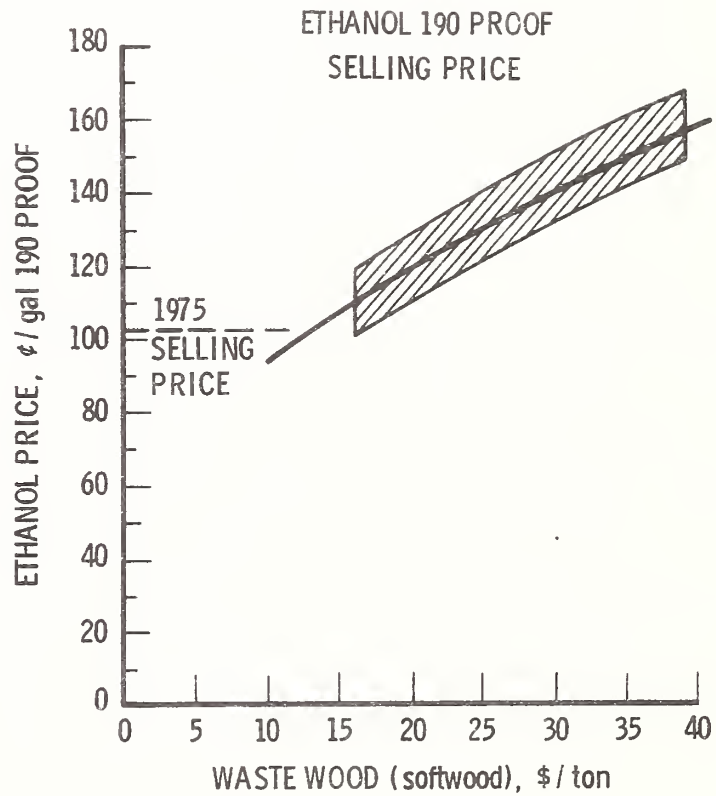
LABOR

OPERATORS	$20,000/yr
FOREMEN	25,000/yr
MANAGEMENT	30,000/yr

OVERHEAD 100% OF LABOR

PROFIT 20% OF INVESTMENT (10% after taxes)

CREDIT	1975 SELLING PRICE
FURFUAL AT 80% OF	$0.37
PHENOL AT 80% OF	$0.27



Conversions of Applicable Units Used in this Study

MULTIPLY	BY	TO OBTAIN
AREA		
ACRES	4047	SQUARE METERS
SQUARE FEET	0.0929	SQUARE METERS
LENGTH		
FEET	0.3048	METERS
MILES	1.609	KILOMETERS
VOLUME		
CUBIC FEET	0.0283	CUBIC METERS
GALLONS	3.785	LITERS
BARRELS	42	GALLONS (oil)
WEIGHT		
GRAINS	0.0648	GRAMS
TON (short)	0.9072	TON (metric)
lbs	453.6	GRAMS
ENERGY		
BTU	0.252	KILOGRAM CALORIES
kWh	860	KILOGRAM CALORIES
PRESSURE		
POUNDS PER SQUARE INCH	703.1	KILOGRAMS PER SQUARE METER
TEMPERATURE		
°C = 5/9 (F - 32)		

GPO 906-106