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RESEARCH AND EVALUATION OF BIOMASS RESOURCES/CONVERSION/ UTILIZATION SYSTEMS (MARKET/EXPERIMENTAL ANALYSIS FOR DEVELOPMENT OF A DATA BASE FOR A FUELS FROM BIOMASS MODEL)

Volume 1. Biomass Allocation Model

Technical Progress Report for period ending September 30, 1980

By
Yong K. Ahn
Herbert T. Chen
Richard W. Helm
Eric T. Nelson
Kevin J. Shields
Richard P. Stringer

November 1980

Work Performed Under Contract No. AC02-78ET20611

Gilbert Associates, Inc.
Reading, Pennsylvania

U.S. Department of Energy

Solar Energy

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VOLUME I

BIOMASS ALLOCATION MODEL

TECHNICAL PROGRESS REPORT

FOR THE PERIOD

ENDING SEPTEMBER 30, 1980

WORK PERFORMED UNDER

DOE CONTRACT CE-AC0278ET20611
(FORMERLY CONTRACT NO. ET 78-C-02-5022)

Yong K. Ahn
Herbert T. Chen
Richard W. Helm
Eric T. Nelson
Kevin J. Shields
Richard P. Stringer (Project Manager)

of

Gilbert Associates, Inc.
Reading, Pennsylvania 19603

EXECUTIVE SUMMARY

A biomass allocation model has been developed to show the most profitable combination of biomass feedstocks, thermochemical conversion processes, and fuel products to serve the seasonal conditions in a regional market. This optimization model provides a tool for quickly calculating the most profitable biomass missions from a large number of potential biomass missions. Other components of the system serve as a convenient storage and retrieval mechanism for biomass marketing and thermochemical conversion processing data. The system can be accessed through the use of a computer terminal, or it could be adapted to a portable micro-processor. A User's Manual for the system has been included in Appendix A of the report.

The validity of any biomass allocation solution provided by the allocation model is dependent on the accuracy of the data base. The initial data base was constructed from values obtained from the literature, and, consequently, as more current thermochemical conversion processing and manufacturing costs and efficiencies become available from the process development units and commercial facilities, and as the prices and availabilities of biomass feedstocks, and selling prices and demands for the biomass derived fuels change with world economic conditions, the data base should be revised. Biomass derived fuels included in the data base are the following: medium Btu gas, low Btu gas, substitute natural gas, ammonia, methanol, electricity, gasoline, and fuel oil. The market sectors served by the fuels include: residential, electric utility, chemical (industrial), and transportation. Regional/seasonal costs and availabilities and heating values for 61 woody and non-woody biomass species are included. The study has included four regions in the United States which were selected because there was both an availability of biomass and a commercial demand for the derived fuels: Region I: NY, WV, PA; Region II: GA, AL, MS; Region III: IN, IL, IA; and Region IV: OR, WA.

Applications of the system include the following:

a. Calculating the most profitable regional and seasonal biomass missions;

b. Studying the overall impact that changes in biomass marketing conditions or processing conditions can have on the profit associated with a given biomass mission; and

c. Storing and retrieving biomass characterization, marketing, and conversion data.

BIOMASS ALLOCATION MODEL

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1.0
INTRODUCTION

1.0 INTRODUCTION

The purpose of this study was to produce a working biomass allocation optimization model based on thermochemical conversion processes and to develop an initial data base for use with the model. Optimization is the collective process of finding the set of conditions required to achieve the best results for a given situation. Computers are often used when the number of variables and constraints are so numerous and complex that it would be impractical to tackle the optimization by hand. In this project optimization has been used to produce a computer-oriented tool for the energy planner to assist him in determining the most profitable allocation of biomass resouces to produce alternative fuels. Other situations where optimization has found application because it has increased profits include scheduling an airline or fleet of moving vans, blending grades of petroleum products in a refinery, traffic flow control, and optimization in chemical process control. The model shows the most profitable combinations of biomass feedstocks, conversion processes, and fuel products to serve the conditions in a regional market sector. The computer simplifies the selection of the most profitable mission from a very large number of them.

As an indication of the large number of missions, consider the biomass mission shown in Table 1-1. The available biomass could include numerous woody and non-woody biomass resources. The fuels which these resources could be converted to would depend on the demands of the market sectors. The demands for, and the selling prices of the fuels would vary according to market sector and region. Fuel products would be derived by different thermochemical conversion processes and the costs of the products would vary according to the efficiencies, configurations of the conversion process, financing, and the costs of the biomass feedstock being reacted. For each of these processes and for each biomass, there is a manufacturing cost and process efficiency which must be considered in determining the most profitable biomass allocation.

TABLE 1-1

BIOMASS MISSIONS CONSIDERED FOR THE ALLOCATION MODEL

Biomass Derived Fuel	Thermochemical Conversion Process	Market Sector: Residential	Market Sector: Electric Utility	Market Sector: Chemical (& Industrial)	Market Sector: Transportation
Med Btu Gas	Oxygen-Blown Gasification		X	X	
Low Btu Gas	Air-Blown Gasification		X	X	
Synthetic Natural Gas	Shift and Methanation of Med Btu Gas	X	X		
Ammonia	Shift and Ammonia Synthesis via Med Btu Gas			X	
Methanol	Shift and Catalytic Methanol Synthesis via Med Btu Gas		X	X	X
Electricity	Direct Combustion; Combined Cycle Plant via Low Btu Gas or Med Btu Gas, or Gas Turbine via Methanol	X	X	X	
Gasoline	Catalytic Synthesis From Methanol Derived Med Btu Gas				X
Fuel Oil	Pyrolysis of Biomass	X	X	X	X

The initial data base which has been developed to demonstrate the allocation is based on information available from previous studies. For instance, the price information for biomass resouces was derived from the SRI "Biomass System Analysis Study."[1] Non-woody and woody biomass availability figures were drived from an EPRI[2] and a SRI[3] study. Manufacturing costs for the biomass derived fuels were developed by a computer program with data from MITRE[4] and Gilbert/Commonwealth[5]. Fuel selling prices are based on published 1980 prices escalated to 1985.

Demand data for the fuels in the various market sectors was also derived from an SRI[1] study. Provisions have been made in the program to update the data base as more and better data become available.

The present study has been limited to four, 2 to 3 state regions in the United States. The regions were selected because they contained an abundance of biomass feedstock and a high demand for the converted fuel products. The concept could be expanded to include larger regions in the United States, or a much larger area such as countries in the Americas.

The biomass allocation model is expected to be used by regional or national energy planners who must make decisions concerning the optimum use of the available biomass resouces in order to satisfy the fuel needs. Another application of the model will be in training the manpower needed to work with biomass. For example, by varying the price and availability of a biomass feedstock, or the efficiency of a thermochemical conversion process, the student could examine the affect it would have on the overall allocation optimization. The model can also be used to point out areas where data is missing and where there may be a need for additonal research. Although the allocation model is now limited to thermochemical conversion processes, it could be expanded to include bioconversion technologies. For example, as the technology develops for converting hybrid poplar trees to ethanol, conversion efficiencies, ethanol selling prices, and ethanol demands and manufacturing costs could be added to the data base.

The importance of having the biomass allocation optimization model available early in the development of biomass conversion technologies is that the model can be used as a convenient tool for storing and utilizing data on the market and processing aspects of biomass.

The body of the report is divided into sections for the major tasks of the project: Chapter 2 - Market Analysis, Chapter 3 - Thermochemical Conversion Process Economics, Chapter 4 - Data Storage and Retrieval System, and Chapter 5 - Biomass Allocation Model. The Summary and Recommendations are contained in Chapter 6, and Appendix A is a "User's Guide" which presents a step-by-step guide for using the model. Volume II consists of Appendices C through E. Appendix B contains the data bases. Appendix C contains a description of the computer programming used in the project. Appendix D is the detailed results of the biomass thermochemical conversion process economic analysis, and Appendix E contains a description of the limited work which was performed in an attempt to develop thermochemical conversion efficiencies through application of process models which have been used with coal.

The work reported in Volumes III and IV was carried out under the same contract number and is devoted to characterization of biomass fuels in thermochemical conversion environments. Volume III contains the results of laboratory scale biomass characterization work performed by the Department of Chemical Engineering at West Virginia University. Volume IV contains the results of process development unit biomass characterization work performed by Environmental Energy Engineering, Inc.

2.0
MARKET ANALYSIS

2.0 MARKET ANALYSIS

2.1 OBJECTIVES

The objective of the market analysis task of this project is to develop an initial base of information concerning the market conditions for biomass feedstocks and the fuels which could be derived from these feedstocks using thermochemical conversion processes. These data bases are to be used in the computer-based biomass allocation planning aid which will be capable of generating optimum allocation of biomass feedstock to meet given market demands for biomass derived fuels.

Products of the market analysis task of the study are as follows:

A. Biomass feedstocks:

1. Costs by region and season in $/MM (million) Btu.

2. Availability by region and season in MMBtu.

B. Biomass Derived Fuels:

1. Demands by market sector in MMBtu.

2. Selling prces by market reactor in $/MMBtu.

The fuels, market sectors, and regions used in the study are as follows:

A. Biomass derived fuels:

1. Low Btu gas,
2. Medium Btu gas,

3. Fuel oil,
4. Electricity,
5. Synthetic natural gas,
6. Ammonia,
7. Methanol, and
8. Gasoline.

B. Market sectors:

1. Residential,
2. Electric Utility,
3. Chemicals, and
4. Transportation.

C. Regions:

1. Region I: New York, Pennsylvania, West Virginia;
2. Region II: Alabama, Mississippi, Georgia;
3. Region III: Ohio, Indiana, Illinois; and
4. Region IV: Washington, Oregon.

2.2 METHODS

2.2.1 Biomass Prices

During the first phase of the biomass resource price and availability study, a large number of existing publications were reviewed for information on the prices of wood and non-wood biomass species. Only a small amount of extremely scattered price information was found available. It was decided, therefore, that this scattered information should be correlated and smoothed in some way. Otherwise, the results from each feedstock allocation run would merely reflect the price and availability uncertainty of the input data. Several attempts were made to select price parameters based on supply and demand considerations or upon the main characteristics of each type of material. Finally, since a supply and demand model would have been beyond the scope of the present study, the final selection of parameters was based upon the current trend towards an increasing importance of the fuel value of wood.

The gasification of wood fuel offers the greatest potential for application to a variety of feedstock-to-product paths, and also offers an economic advantage when applied to existing gas and oil-fired boilers. Therefore, in selecting parameters based on fuel value, particular attention was given to the value of the biomass fuel from a gasification point of view. For this reason a correlation based primarily on fuel handleability, fuel preparcability, and heating value was provided to assess price differences between species. Since the costs to be generated for the Biomass Allocation System are to be used for planning purposes, it was decided to project prices for the year 1985. These data provide a reasonable period for construction using today's conversion technologies.

Although much price uncertainty exists at this time, the primary objective of the present study is not to generate specific recommendations, but rather to build a planning tool for future use. Therefore, three approaches were used and are listed as follow:

a. Initial prices for the individual feedstocks were aggregated to four general types - softwood, hardwood, low moisture (cellulosic) material, and high mosture material.

b. Provision was made to modify the price of each species on the basis of its fuel value.

c. A data base update program was provided so that the initial price estimates can be replaced with more reliable information during or after completion of the present study.

Approaches 1 and 2 are needed because this study is being made during the period that biomass materials are being priced by two value comparisions, as a fuel and as an industrial raw material. In order to generate cost estimates during this period both approaches have been combined into a single algebraic relationship. In recogition of the fact that approaches 1 and 2 must eventually be replaced by averages of actual prices, the third approach is available and may be used to add improved cost estimated at any time.

In light of these facts and after completing a review of the existing literature, the cost data for wood and agricultural residues was found to be so scattered that some approach had to be developed for establishing an initial data base other than the direct entry of published data on punched cards. The general approach which was developed may be represented by the following relationship:

$$C = a\ f(H,P)\ RAS\ (B/8600)^2$$

where, C = feedstock cost ($/MMBtu)

R = a cost factor (currently between 0.94 and 1.12) which is based on regional labor rates.

A = a cost factor (currently between 0.95 and 1.1) which depends upon regional availability

S = a cost factor (currently between 0.95 and 1.1) which depends upon seasonal availability)

H = a handleability index which can take on integer values between 1 (poor) and 5 (good)

P = a preparability index which can take an integer values between 1 and 5

B = the feedstock heating value in Btu/lb on a dry basis

f(H,P) = an empirical function of H and P

Initially a relationship was used in which the value of "a" (an average cost) was assumed in order to generate an initial data base. This work was carried out primarily to develop the necessary computer programs and data files.

The approach was then evaluated on the basis of the results obtained; a telephone survey was carried out on current prices for a specific material (green pulpwood chips delivered); and the general approach was reviewed with representatives of the U.S. Department of Agriculture, Forest Service. A partial list of the organizations contacted follows:

- U.S. Department of Agriculture
  Forest Service
  Washington, D.C.

- New York State Department of Environmental Conservation
  Division of Lands and Forests
  Albany, New York

- Mississippi Forestry Commission
  Jackson, Mississippi

- Georgia Forestry Commission
  Macon, Georgia

- o Indiana Division of Forestry
  Indianapolis, Indiana

- o Illinois Division of Forestry
  Springfield, Illinois

- o Washington Department of Natural Resources
  Olympia, Washington

As a result of the survey, the general concensus was that development of a cost figure for each material would not be practical at this time, and that costs should be aggregated for specific types of materials and specific regions. The average cost for softwood and hardwood chips was found to be $18 and $15 per ton, respectively. Therefore the following average prices used by SRI[(3)] were deemed acceptable:

Material	Base Price (1979 dollars) ($/dry ton)
Softwood	$19
Hardwood	$15
Low Moisture	$25
High Moisture	$35

Although the SRI prices are noted in 1977 dollars, there appeared to be no point in converting them to 1980 dollars because of the fact that the actual wood prices were slightly lower than those assumed by SRI for 1977.

The purpose of the function f(H,P) is to introduce cost factors which can be estimated on an engineering economic basis and can account for the differences in handleability and prepareability of the feedstock in question. Based on engineering judgement, the function $f(H,P) = 0.267\ H^{0.2}P$ has been assumed. This means that a material which would be difficult to handle (H = 1) and difficult to prepare (P = 1) would (from a fuel value point of view) be expected to be available at 26.7 percent of the cost of an average material, with H = 3 and P = 3 (for which f(H,P) = 1.0). Similarly, an ideal material may require no preparation and may have such excellent characteristics that a fuel price 84 percent greater than average would yield an acceptable return on the investment. For such a fuel H and P would both have an index of 5.

In addition to the index for H, it has been assumed that each biomass feedstock will be a function of its heating value. At the present time this index has been assumed to be 2.0, therefore the expression as programmed is:

$$C = 0.267 \text{ a } H^{0.2} \text{ PRAS } (B/8600)^2 \text{ \$/ton}$$

where, a = the base price for the type of material under consideration in late 1979 dollars.

In the absence of suitable characterization information, values of H = 3 and P = 3 were assumed. Also, as an initial assumption, the values for R, A, and S have been assumed to be as shown in Table 2-1. It should be noted that none of these factors cause the base price to change significantly; consequently, a high level of price aggregation has been retained in the initial data base.

TABLE 2-1
COST FACTORS APPLIED TO THE BASE FUEL COSTS

Regional Availability (%)	A	Region Number	R	Seasonal Availability (%)	S
< 5	1.1	1	1.12	<10	1.1
<10	1.05	2	0.98	<25	1.05
<25	1.0	3	0.92	<50	1.0
≥25	0.95	4	0.94	≥50	0.95

The historical price increase for woodpulp between 1967 and 1976 has been five to eight percent (approximately 6.5 percent) relative to other products. However, in view of the increasing competition which is developing a relative percentage increase 35 percent greater than this (i.e., 8.7 percent) has been assumed in calculating the costs for 1985.

For more detailed information on the generation of the initial data base, reference should be made to the descriptions of the DATGEN and FPSTOR programs in Appendix C. The actual input parameters are listed in Appendix B.

2.2.2 Biomass Availability

Of the energy supply and demand studies available, the work carried out by SRI International was determined to be most readily applicable to the present study.[3]

Since the biomass supply and demand situation will vary with time, it was necessary to select a specific year for use in building the required supply and demand data base. The year 1985 was selected in order to provide for a reasonable construction and planning period prior to use of available technology.

Because of the fact that the objective of the study is to generate a data base for specific species, it was necessary to select a procedure for allocating the supply amounts derived from the SRI study to those specific species.

Of the scenarios available from the SRI study, the optimistic scenario was selected in view of the fact that the introduction of tax incentives and the use of publicly owned forest acreage would appear to be probable in order to help achieve the President's goal for the greater utilization of solar energy.

Given these guidelines, the availability of the wood species was estimated from the results of the SRI study and from information published by the Forest Service of the U.S. Department of Agriculture.[6,7] Initial non-wood biomass availabilities were also estimated in a similar manner from the results of the SRI study and from information published in an EPRI study[2].

If, in the course of this study or subsequent studies, it is determined that the initial data base should be updated, then the procedure should be to revise the card deck which is used to generate the initial data base. In this way a reasonably smooth set of input data can be maintained in the system at all times.

In the case of the feedstock availability data, no input data smoothing was carried out during this study. Such smoothing as was performed is inherent in the input data as a result of the editing work carried out by the Rocky Mountain Forest and Range Experiment Station's Resources Evaluation Techniques Program Staff, and the fact that the SRI supply and demand estimates were obtained from an economic model.

<u>Non-Wood</u> (Availability)

The initial data base for the availability of non-wood species was based upon two sources -- the SRI International Study[3] and the EPRI study[2]. The total projected availability of the non-wood species was obtained from the SRI study, whereas the EPRI study was used to obtain relative availabilities.

The availability information by region was obtained from the SRI study in two steps, and the relative availability information by species and season was obtained from the EPRI study in four steps as follows. For a description of how total availabilities and projected availabilities are used by the computer program see Appendix C (Program Description).

Total Availabilities

Step 1: List the non-wood availabilities as published in the SRI report. This information is shown in Table 2-2.

Step 2: Allocate the Table 2-2 availabilities to states on a basis of their published forest and crop acres so that they can be reallocated to GAI regions. This information, which is shown in Table 2-3, was used as availability input data for the computer program.

Relative Availabilities

Step 1: List the non-wood availabilities as published in the EPRI report. These data are shown in Table 2-4. This table has been named RB (J, IR).

Step 2: List the regional availabilities as published in the EPRI report. This information is shown in Table 2-5. For computational purposes this table has been called RM (IS, IR).

Step 3: Calculate the relative availability of each species.

Step 4: having obtained the relative availabilities in the form of Table 2-6, they were then converted into the form expected by the allocation program. This was accomplished by splitting Table 2-6 into a table of percentage availabilties by season as shown in Table 2-7 and also into relative availabilities by region as shown in Table 2-8.

TABLE 2-2

AVAILABLE NON-WOOD BASED ON THE SRI STUDY

SRI Region	Forest & Crop (10^6 acres)	Low Moisture (10^6 tons)	High Moisture (10^6 tons)
1 (North East)	34.7	0	0
2 (Middle Atlantic)	46.3	0	0
3 (South Atlantic)	131.0	0	5
4 (East South Central)	91.6	11	8
5 (East North Central)	117.4	13	26
6 (West South Central)	112.7	27	6
7 (West North Central)	202.3	78	20
8 (Pacific)	86.1	14	8
9 (Mountain)	97.1	27	5

TABLE 2-3

AVAILABLE NON-WOOD ALLOCATED TO GAI REGIONS

State	GAI Region	Forest & Crops (10^6 acres)	Low Moisture (10^6 tons)	High Moisture (10^6 tons)
New York		20.3	0	0
Pennsylvania	1	23.0	0	0
West Virginia		12.9	0	0
Georgia		31.5	0	1.2
Alabama	2	26.9	3.2	2.3
Mississippi		23.5	2.8	2.0
Illinois		27.5	3.0	6.0
Indiana	3	17.2	1.9	3.8
Iowa		28.8	11.1	2.8
Oregon	4	28.6	5.0	2.9
Washington		26.5	4.3	2.5

TABLE 2-4

REGIONAL AVAILABILITIES OF NON-WOOD SPECIES FROM THE EPRI STUDY

Number (J)	Name	Region Number (IR)				
		1	2	3a	3b	4
1	Wheat	285.2	33.5	285.2	77.3	554.3
2	Grain Corn	657.4	78.8	657.4	561.4	22.1
3	Soybeans	456.8	190.3	456.8	393.4	0.0
4	Oats	97.1	7.0	97.1	169.4	14.9
5	Potatoes	78.5	10.1	8.5	30.4	178.3
6	Barley	18.7	3.3	18.7	97.1	165.5
7	Sugarbeet Field	17.9	0.0	17.9	49.5	138.1
8	Grain Sorghum	1.7	2.5	1.7	66.9	11.7
9	Rice Straw	0.0	6.4	0.0	0.7	29.0
10	Sugarcane Field	0.0	30.7	0.0	0.0	0.0
11	Cotton	0.0	9.9	0.0	1.0	14.0
12	Peanuts	2.0	27.1	2.7	0.0	0.2
13	Bagasse	0.0	9.8	0.0	0.0	0.0
14	Rye	5.2	2.3	5.2	8.2	0.7
15	Seed Grasses	0.3	0.2	0.3	1.9	6.7
16	Rice Hulls	0.0	0.2	0.0	0.0	0.8
17	Sugarbeet Pulp	0.0	0.0	0.0	0.0	0.0

Note: 3a and 3b are sub-regions of Region 3. They were tabulated in this way to facilitate conversion from EPRI to GAI regions.

TABLE 2-5

SEASONAL AVAILABILITIES OF NON-WOOD SPECIES

FROM THE EPRI REPORT

Region	Spring	Summer	Autumn	Winter
1	0.0	48.7	47.7	0.0
2	16.8	41.3	135.9	0.0
3a	0.3	304.8	600.8	0.0
3b	0.0	39.3	438.3	0.0
4	0.0	243.7	68.6	0.0

TABLE 2-6

RELATIVE AVAILABILITIES IN 10^6 TONS OF NON-WOOD SPECIES BY REGION AND SEASON

Region Number 1 - NY, PA, WV

	Spring	Summer	Autumn	Winter
Wheat	0.0	0.57	0.58	0.0
Grain Corn	0.0	1.32	1.29	0.0
Soybeans	0.0	0.91	0.90	0.0
Oats	0.0	0.19	0.19	0.0
Potatoes	0.0	0.16	0.15	0.0
Barley	0.0	0.04	0.04	0.0
Sugarbeet - Field	0.0	0.04	0.04	0.0
Grain Sorghum	0.0	0.0	0.0	0.0
Rice - Straw	0.0	0.0	0.0	0.0
Sugarcane - Field	0.0	0.0	0.0	0.0
Cotton	0.0	0.0	0.0	0.0
Peanuts	0.0	0.01	0.01	0.0
Bagasse	0.0	0.0	0.0	0.0
Rye	0.0	0.01	0.01	0.0
Seed - Grasses	0.0	0.0	0.0	0.0
Rice - Hulls	0.0	0.0	0.0	0.0
Sugarbeet - Pulp	0.0	0.0	0.0	0.0

Region Number 2 - GA, AL, MISS

	Spring	Summer	Autumn	Winter
Wheat	0.09	0.22	0.68	0.0
Grain Corn	0.21	0.53	1.60	0.0
Soybeans	0.52	1.27	3.88	0.0
Oats	0.02	0.05	0.14	0.0
Potatoes	0.03	0.07	0.21	0.0
Barley	0.01	0.02	0.07	0.0
Sugarbeet - Field	0.0	0.0	0.0	0.0
Grain Sorghum	0.01	0.02	0.05	0.0
Rice - Straw	0.02	0.05	0.15	0.0
Sugarcane - Field	0.08	0.21	0.63	0.0
Cotton	0.03	0.07	0.20	0.0
Peanuts	0.07	0.18	0.55	0.0
Bagasse	0.02	0.06	0.18	0.0
Rye	0.01	0.02	0.05	0.0
Seed - Grasses	0.0	0.0	0.0	0.0
Rice - Hulls	0.0	0.0	0.0	0.0
Sugarbeet - Pulp	0.0	0.0	0.0	0.0

TABLE 2-6 (Cont'd)

Region Number 3a - (Illinois & Indiana)

	Spring	Summer	Autumn	Winter
Wheat	0.0	3.57	7.04	0.0
Grain Corn	0.01	8.24	16.24	0.0
Soybeans	0.01	5.72	11.28	0.0
Oats	0.0	1.22	2.40	0.0
Potatoes	0.0	0.98	1.94	0.0
Barley	0.0	0.23	0.46	0.0
Sugarbeet - Field	0.0	0.22	0.44	0.0
Grain Sorghum	0.0	0.02	0.04	0.0
Rice - Straw	0.0	0.0	0.0	0.0
Sugarcane - Field	0.0	0.0	0.0	0.0
Cotton	0.0	0.0	0.0	0.0
Peanuts	0.0	0.03	0.07	0.0
Bagasse	0.0	0.0	0.0	0.0
Rye	0.0	0.07	0.13	0.0
Seed - Grasses	0.0	0.0	0.01	0.0
Rice - Hulls	0.0	0.0	0.0	0.0
Sugarbeet - Pulp	0.0	0.0	0.0	0.0

Region Number 3b - (Ohio)

	Spring	Summer	Autumn	Winter
Wheat	0.0	1.02	11.36	0.0
Grain Corn	0.0	0.65	7.27	0.0
Soybeans	0.0	0.46	5.09	0.0
Oats	0.0	0.20	2.19	0.0
Potatoes	0.0	0.04	0.39	0.0
Barley	0.0	0.11	1.26	0.0
Sugarbeet - Field	0.0	0.06	0.64	0.0
Grain Sorghum	0.0	0.08	0.87	0.0
Rice - Straw	0.0	0.0	0.01	0.0
Sugarcane - Field	0.0	0.0	0.0	0.0
Cotton	0.0	0.0	0.01	0.0
Peanuts	0.0	0.0	0.0	0.0
Bagasse	0.0	0.0	0.0	0.0
Rye	0.0	0.01	0.11	0.0
Seed - Grasses	0.0	0.0	0.02	0.0
Rice - Hulls	0.0	0.0	0.0	0.0
Sugarbeet - Pulp	0.0	0.0	0.0	0.0

TABLE 2-6 (Cont'd)

Region Number 4 - (Wash, Ora.)

	Spring	Summer	Autumn	Winter
Wheat	0.0	7.95	2.24	0.0
Grain Corn	0.0	0.32	0.09	0.0
Soybeans	0.0	0.0	0.0	0.0
Oats	0.0	0.21	0.06	0.0
Potatoes	0.0	2.56	0.72	0.0
Barley	0.0	2.37	0.67	0.0
Sugarbeet - Field	0.0	1.94	0.55	0.0
Grain Sorghum	0.0	0.17	0.05	0.0
Rice - Straw	0.0	0.48	0.13	0.0
Sugarcane - Field	0.0	0.0	0.0	0.0
Cotton	0.0	0.20	0.06	0.0
Peanuts	0.0	0.0	0.0	0.0
Bagasse	0.0	0.0	0.0	0.0
Rye	0.0	0.01	0.0	0.0
Seed - Grasses	0.0	0.09	0.03	0.0
Rice - Hulls	0.0	0.01	0.0	0.0
Sugarbeet - Pulp	0.0	0.0	0.0	0.0

TABLE 2-7

SEASONAL AVAILABILITIES OF NON-WOOD SPECIES FOR GAI REGION 3

Species		Percentage Available			
No.	Name	Spring	Summer	Autumn	Winter
45	Wheat	0	20	80	0
46	Grain Corn	0	26	73	0
47	Soybeans	0	26	73	0
48	Oats	0	23	77	0
49	Potatoes	0	30	70	0
50	Barley	0	17	83	0
51	Sugarbeet Field	0	21	79	0
52	Grain Sorghum	0	10	90	0
53	Rice Straw	0	0	100	0
54	Sugarcane Field	0	0	100	0
55	Cotton	0	0	100	0
56	Peanuts	0	30	70	0
57	Bagasse	0	0	100	0
58	Rye	0	25	75	0
59	Seed Grasses	0	0	100	0
60	Rice Hulls	0	0	100	0
61	Sugarbeet Pulp	0	0	100	0

TABLE 2-8

RELATIVE AVAILABILITY OF NON-WOOD SPECIES

Species			Relative Availability			
No.	Name	Type[1]	Region 1	Region 2	Region 3	Region 4
45	Wheat	L	1.13	0.99	22.99	10.19
46	Grain Corn	H	2.61	2.34	32.41	0.41
47	Soybeans	L	1.81	5.67	22.56	0.00
48	Oats	L	0.38	0.21	6.01	0.27
49	Potatoes	H	0.31	0.31	3.35	3.28
50	Barley	L	0.08	0.10	2.06	3.04
51	Sugarbeet (Field)	H	0.08	0.00	1.36	2.49
52	Grain Sorghum	H	0.00	0.08	1.01	0.22
53	Rice Straw	L	0.00	0.22	0.01	0.61
54	Sugarcane (Field)	H	0.00	0.92	0.00	0.00
55	Cotton	H	0.00	0.30	0.01	0.26
57	Bagasse	L	0.00	0.26	0.00	0.00
58	Rye	L	0.02	0.08	0.32	0.01
59	Seed Grasses	L	0.00	0.00	0.03	0.12
60	Rice Hulls	L	0.00	0.00	0.00	0.01
61	Sugarbeet Pulp	L	0.00	0.00	0.00	0.00

Note (1): Denotes high or low moisture material

In order to perform the necessary allocations a FORTRAN computer program was written to perform the following steps:

a. The regional data and species data tables from the EPRI study were named, as follows:

RM (IS, IR) - regional availability by season and region

RT (J, IR) - species availability data in 10^6 tons

RB (J, IR) - species availability data in 10^{12} Btu

b. The energy amounts contained in RM (IS, IR) were allocated using the energy amounts in RB (J, IR). That is:

Energy in crop J for a given season and region

$$= RM(IS, IR) \cdot \frac{RB(J, IR)}{\sum_{J=1}^{17} RB(J, IR)}$$

c. Finally, the Btu values were used to convert the resulting energies to biomass availabilities in millions of dry tons using the heating values shown in Table 2-7. The results are shown in Table 2-9.

<u>Wood (Availability)</u>

The initial data base for the wood species availabilities was obtained from the SRI Study[3] and from data provided by the U.S. Forest Service[7].

TABLE 2-9

HEATING VALUES OF NON-WOOD SPECIES

No.	Species Name	Heating Value Btu/lb
45	Wheat	7500
46	Grain Corn	7500
47	Soybeans	7500
48	Oats	7500
49	Potatoes	7500
50	Barley	7500
51	Sugarbeet (Field)	7500
52	Grain Sorghum	7500
53	Rice Straw	6550
54	Sugarcane (Field)	7500
55	Cotton	7500
56	Peanuts	7500
57	Bagasse	8300
58	Rye	7500
59	Seed Grasses	8000
60	Rice Hulls	7000
61	Sugarbeet Pulp	7500

The amounts for GAI regions were derived from the SRI study by first allocating each SRI regional amount (shown in Table 2-10) to the states contained in that region on the basis of the areas of commercial forest land and crop land reported[6] for those states. Then the amounts shown in Table 2-11 were obtained by summing the contributions to the GAI region from each state in that region.

Having obtained Table 2-11 containing total availabilities from the SRI study, the U.S. Forest Service Data were used to arrive at an estimate of relative availabilities for each species. The results, which are shown in Table 2-12, were entered into the computer system on punched cards (see Appendix B 2.1) where they were used in the following manner. For a given region the total amount was calculated. Then, the fraction corresponding to each species was multiplied by the corresponding amount contained in Table 2-11 and the heating value in order to arrive at an estimate of the energy available from each species in MMBtu per year. A similar approach was employed to develop initial availabilities for the non-wood species.

The purpose of this analysis is to generate feedstock availability input cards for the program DATGEN which is described in the Appendix C.

Table 2-12 also contains an initial set of heating values for the wood species. Any species for which no published heating value exists was assigned the value of 8600 Btu per lb.

The results of this analysis (in card image form) are shown in Appendix B.

TABLE 2-10

AVAILABLE BIOMASS BASED ON THE SRI STUDY

SRI Region	Forest & Crop (10^6 acres)	Wood Species (10^6 tons)
1 (North East)	34.7	31
2 (Middle Atlantic)	46.3	2
3 (South Atlantic)	131.0	26
4 (East South Central)	91.6	35
5 (East North Central)	117.4	3
6 (West South Central)	112.7	14
7 (West North Central)	202.3	2
8 (Pacific)	86.1	56
9 (Mountain)	97.1	2

TABLE 2-11

AVAILABLE BIOMASS ALLOCATED GAI REGIONS

State	GAI Region	Forest & Crop (10^6 tons)	Wood Species (10^6 tons)
New York		20.3	0.9
Pennsylvania	1	23.0	1.0
West Virginia		12.9	2.6
Georgia		31.5	6.2
Alabama	2	26.9	10.3
Mississippi		23.5	9.0
Illinois		27.5	0.7
Indiana	3	17.2	0.4
Iowa		28.8	1.4
Oregon		28.6	20.2
Washington	4	26.5	17.2

TABLE 2-12

RELATIVE WOOD SPECIES AVAILABILITIES AND INITIAL HEATING VALUES

NBR	FEEDSTOCK NAME	REGIONAL AMOUNTS (1,000 CUBIC FEET) 1	2	3	4	HEATING VALUE (Btu/lb)
1	OAKS, WHITE (S,E)	3622	2301	1167	0	8600
2	OAKS, WHITE (O,E)	4318	2104	209	0	8600
3	OAKS, RED (S,E)	5444	937	529	0	8600
4	OAKS, RED (O,E)	3285	631	799	0	8600
5	HICKORY (E)	2165	2485	798	0	8600
6	BIRCH, YELLOW (E)	836	0	0	0	8600
7	MAPLE, HARD (E)	4703	29	414	0	7990
8	MAPLE, SOFT (E)	6252	872	408	0	8600
9	BEECH (E)	2396	193	141	0	8600
10	SWEETGUM (E)	0	4630	101	0	8600
11	TUPELO/B. GUM (E)	245	3591	42	0	8600
12	ASH (E)	1775	725	400	0	8600
13	BASSWOOD (E)	1010	58	103	0	8600
14	POPLAR, YELLOW (E)	2209	1893	212	0	8150
15	COTTONWOOD/ASP.	1139	150	280	352	8050
16	WALNUT BLACK (E)	164	21	140	0	8600
17	CHERRY, BLACK (E)	2846	92	65	0	8600
18	HARDWOODS (O,E)	3183	2601	1043	0	8050
19	ALDER, RED (W)	0	0	0	6997	8600
20	OAK (W)	0	0	0	52	8170
21	HARDWOODS (O,W)	0	0	0	3048	8600
22	LONGLEAF/SP (E)	0	9425	0	0	8600
23	SHORTLEAF/LOB (E)	0	25129	33	0	8600
24	PINE, YELLOW (O,E)	798	1743	35	0	8600
25	PINE, R/W (E)	1649	188	0	0	8600
26	PINE, JACK (E)	0	0	0	0	8800
27	SPRUCE/B. FIR (E)	925	0	0	0	8600
28	HEMLOCK (E)	2348	19	0	0	8600
29	HEMLOCK (W)	0	0	0	24265	8600
30	SOFTWOOD (O,E)	202	169	34	0	8600
31	PONDERSA/J. PINE	0	0	0	12633	8150
32	FIR, DOUGLAS (W)	0	0	0	60073	8600
33	FIRS, TRUE (W)	0	0	0	16925	8600
34	CYPRUS (E)	0	1046	14	0	8600
35	PINE, SUGAR (W)	0	0	0	0	8600
36	PINE, WHITE (W)	0	0	0	880	8600
37	REDWOOD (W)	0	0	0	91	8890
38	SPRUCE, SITKA (W)	0	0	0	1466	8410
39	ENGELMANN (+O,W)	0	0	0	1273	8790
40	LARCH (W)	0	0	0	2568	8600
41	CEDAR, RED (W)	0	0	0	4795	8600
42	CEDAR, INCENSE (W)	0	0	0	648	8210
43	PINE, LODGE POLE (W)	0	0	0	5640	8600
44	SOFTWOOD (O,W)	0	0	0	503	8600

2.2.3 Product Fuels

Demand (Product Fuel)

The total demand in quadrillion (10^{15}) Btu's for each biomass derived fuel product was derived directly from the SRI[1] study, and the percentage of the total demand which can be expected to be satisfied by biomass was based on 80 percent of the regional and seasonal supply and output as a parameter which the user may easily change.

Having obtained an initial date base in this way, a computer program was developed for adding new information.

Appendix A of the SRI Study[1] contains end-use demand estimates for the regions selected by SRI. However, the GAI regions were selected on the basis of feedstock characteristics rather than on the basis of the census regions. Therefore, the following reallocation method was employed to apply this product fuel demand data to the regions used in this study.

a. Allocate the SRI demand for each SRI region to each state within that region.

b. Re-combine the resulting demand information by adding the demand for each state in each GAI region.

Product demand data in quadrillion Btu's is designated by region in Table 2-13.

TABLE 2-13

TOTAL DEMAND FOR PRODUCTS IN QUADRILLION BTU'S

Region	Low Btu Gas	Medium Btu Gas	Fuel Oil	Electricity	SNG	Ammonia	Methanol	Gasoline
1	1.9	1.9	.80	0.98	1.80	.01	.14	1.40
2	0.29	0.29	.25	0.80	1.45	.04	.12	1.25
3	0.63	0.64	.27	1.45	3.96	.06	.19	2.00
4	0.50	0.50	.50	0.84	2.50	.02	.15	1.45

Selling Prices (Product Fuels)

Free on board (FOB) selling prices of product fuels were obtained from reliable sources (see footnotes for Table 2-14). Prices for 1985 were extrapolated and were half the difference between existing 1980 and projected 1990 prices. The biomass allocation model uses FOB selling prices rather than retail selling prices because the profit of a given allocation is based on the difference between the manufacturing cost and the selling price. The profit is that obtained by the manufacturer, not by the middleman and wholesaler who sell the product at a higher price because of transportation changes and their additional profit.

Table 2-14 shows the product selling prices for the GAI regions. These are also shown as a computer printout in Appendix B.

When prices were not available (such as in the cases of low and medium Btu gas), the price of the nearest equivalent fuel was used as a "bid price" in order to complete the development of the computer program.

Provisions have been made in the program to update product fuel selling prices. (See Section 4.0 and Appendix C.)

TABLE 2-14

PROJECTED 1985 FOB SELLING PRICES OF BIOMASS DERIVED FUELS

	1985 F.O.B. Selling Prices[f] in $/MMBTU			
	Region			
Product Fuel	1	2	3	4
Gasoline[a]	8.03	7.90	8.05	8.24
Methanol[b]	15.21	14.82	14.45	15.53
SNG[c]	5.04	3.83	4.45	4.69
Electricity[d]	26.38	24.18	25.80	25.79
Fuel Oil[e]	6.37	6.49	6.61	6.40
Ammonia[f]	12.62	9.86	11.39	11.08
Low Btu Gas	5.04	3.83	4.45	4.69
Medium Btu Gas	5.04	3.83	4.45	4.69

(a) Gasoline refinery gate selling prices from "Wholesale Price Index" data for February 1980.

(b) Methanol terminal or factory prices from June 1980 "Chemical Marketing Reporter" 6/16/80. Price in 4,000 gallon tanks, FOB producing point or terminals.

(c) SNG wholesale prices from 1979 AGA "Quarterly Report of Gas Industry Operation."

(d) Electricity cost for comparison purposes would be marginal cost to the electric utility. Source of data is a paper by W. M. McMahon, "The Economics of Large and Small Coal and Nuclear Plants," presented to the Conference on Utilization of Small and Medium Size Power Reactors in Latin American, Montevideo, Uruguay, May 12-15, 1980. Figures shown are leveled costs for a new 400 MW coal-fired plant with FGD. Fuel price was $1.60/MMBtu.

(e) From January 1980 PPI, for No. 2 fuel oil sales to resellers.

(f) Terminal or factory anhydrous ammonia prices were obtained from a 1980 issue of "Green Markets," a McGraw Hill Publication.

2.3 RESULTS

Data generated during the market analysis are presented in Appendix B. A table of contents for Appendix B is shown below.

APPENDIX B

TABLE OF CONTENTS

3.0
THERMOCHEMICAL CONVERSION
PROCESS ECONOMICS

3.0 THERMOCHEMICAL CONVERSION PROCESS ECONOMICS

3.1 OBJECTIVES

Economic analyses of several biomass conversion processes have been performed with the purpose of generating inputs for the biomass allocation system data bank. Information from the data bank is used to execute the biomass allocation model. In fulfilling this purpose, the following objectives were satisfied:

- Creation of a data bank for storage of raw process economics data pertinent to thermochemical biomass conversion processes.
- Development of a computer program which can use available information on a specific biomass conversion process to estimate the economics of similar process configurations with variations in either process or financial parameters.
- Execution of the program to generate cost data for selected biomass derived products such as low Btu gas, medium Btu gas, substitute natural gas (SNG), methanol, and ammonia.

The computer program developed provides flexibility since it is capable of utilizing more recent cost data as they are developed. If desired, a user may use alternate methods to develop process efficiency and manufacturing cost data for use in the biomass allocation model.

3.2 METHODS

3.2.1 Approach

The desire to develop a flexible system for process economics analysis, capable of utilizing the best available information on biomass conversion, was a key consideration in development of the approach. Flexibility is also desirable due to inconsistencies of available economic data on biomass conversion systems. Furthermore, as subsequent process economics data are developed, they should be substituted through a simple operation for the obsolete information.

The biomass process economics data bank is the information source utilized by the process economics model. It contains available information on selected biomass conversion systems. The data stored include identification codes and references, capital costs, operating costs, process parameters (including capacity, capacity factor, biomass type, biomass density, biomass moisture fraction, etc.) and base year of the analysis. As new information, developed either in-house or by other researchers, becomes available, it may easily be substituted for existing information. In addition, the data bank may be easily expanded to include other process configurations, if desired.

The process economics model allows the user to determine the economics of biomass conversion for process configurations characterized in the data bank. The model estimates capital costs, operating costs, and product selling costs, by both the Discounted Cash Flow (DCF) and Utility Financing Method (UFM). The user selects the desired process configuration and may designate the following parameters:

- Process parameters: plant capacity, capacity factor, and thermal efficiency

- Feedstock parameters: biomass type, heating value, moisture content, and cost

- Economic analysis parameters: base year desired (with appropriate inflation factors), DCF and UFM financial paramters.

Additional detail on the estimating procedures employed in the process economics model are given in Section 3.2.2, Methodology for Economic Analysis.

Having selected an overall approach, it was then implemented by sequential performance of the following activities:

- Designation of desired process configurations, identification of best available process economics data for each configuration, and incorporation into the data bank

- Preliminary parametric evaluation of the process configurations to determine those factors having greatest impact on product costs. The preliminary investigation also permitted identification of erroneous entries to the data bank and allows the users to become more familiar with the process economics computer programs.

- Final economic evaluation of capital, operating and product costs for each configuration, examining in detail those parameters having greatest influence on product costs.

- Evaluation of 61 biomass species in each of the process configurations to determine manufacturing costs for the biomass allocation model.

3.2.2 Methodology for Economic Analysis

a. Data Collection and Storage

The first step in the task of analyzing process economics was to identify best available data characterizing the selected process configurations. Once identified, the information was then entered into a data bank which could be accessed by the computer program which was used to analyze process economics.

As an illustrative example, the data entry for an 850 ton/day (oven dry basis) Purox/medium Btu gas plant (4) is shown in Table 3-1. Included in the table is an explanation of the nomenclature employed. Some cost items are represented differently in the data bank than in the source reference. An example from Table 3-1 is C(3), 0.930 in which the capital cost for gas cooling includes the costs for an electrostatic precipitator, compressor, condenser and air separator, each of which have separate capital costs reported for them in the source reference (4).

Best available information on each of the selected process configurations was identified, modified as required and entered into the data bank. For some but not all configurations, only one set of process economics data were identified.

b. Computer Program for Estimating Process Economics of User-Designated Biomass Conversion Systems

Execution of the program is initiated by the user selecting a process configuration from the data bank. The computer prints information from the data bank and permits the user to verify or modify his selection. The user then inputs desired process parameters and an appropriate inflation factor. Parameters

TABLE 3-1

EXAMPLE DATA BANK ENTRY

```
I = 2     MEDIUM BTU GAS PLANT   -   PUROX PROCESS
J = 1       Q=10.85        X=850.0        SILVA CULTURE BIOMASS FARMS VOL V
          HHV=8500.        D=42.40        WHITE OAK
           MF=0.50         Y=1.00          N=0.80         0=0.20      ETA=0.75
           U1=4.22        U2=0.70         U3=0.60        MID 1976
            C=1.500   0.740=8.000      0.930 0.       0.     0.       0.    0.       0.
              0.         0.    0.      0.    0.       0.     1.120    0.300 0.170  0.
          BHP=0.          P13=0.         P14=0.        B15=0.         S16=0.
J=2         Q=21.70        X=1700.        SILVA CULTURE BIOMASS FARMS VOL V
          HHV=8500.        D=42.40        WHITE OAK
           ME=0.50         Y=1.00          N=0.80         0=0.20      ETA=0.75
           U1=8.44        U2=1.12         U3=0.75        MID 1978
            C=1.710   1.660 12.80     1.530  0.       0.     0.       0.    0.       0.
              0.         0.    0.     0.     0.       0.     1.800    0.300 0.340  0.
          BHP=0.          P13=0.         P14=0.        B15=0.         S16=0.
```

<u>Nomenclature</u>: I = Process Configuration Number

J = Data entry for a specified value of I

Q = Plant energy output, 10^9 Btu/day

X = Biomass feed rate, oven dry ton/day

HHV = Biomass higher heating value, Btu/lb

D = Biomass density, lb/ft^3

MF = Biomass moisture fraction

Y = Biomass cost, $\$/10^6$ Btu

N = Plant capacity factor

O = Oxygen/biomass weight ratio

ETA = Thermal efficiency

U1 = Annual feedstock cost, 10^6 \$/YR

U2 = Annual utility cost, 10^6 \$/YR

U3 = Annual operating labor cost, 10^6 \$/Yr

C = Unit Operation Capital Costs, MM\$

C(1) = Biomass preparation	C(6) = Gas purification
C(2) = Gasification	C(7) = Methanation
C(3) = Oxygen plant	C(8) = Gas compression
C(4) = Gas cooling	C(9) = Dehydration
C(5) = Gas shift	C(10) = Methanol synthesis

TABLE 3-1 (Cont'd)

Nomenclature:

C(11) = Ammonia synthesis

C(12) = Fuel oil pyrolysis

C(13) = Combined cycle power plant

C(14) = Conventional power plant

C(15) = Storage

C(16) = Steam generation

C(17) = Utilities

C(18) = Offsites

C(19) = Site improvements

C(20) = M-gasoline process

BHP = Gas Compression Brake Horespower, HD

P13 = Combined Cycle Power Plant Capacity, MW

P14 = Conventional Power Plant Capacity, MW

B15 = Storage Capacity, B61

S16 = Steam generated, lb/hr

which may be specified include biomass feed type, biomass feed heating value, biomass feed cost, process capacity, capacity factor and thermal efficiency. The computer uses an estimating procedure to approximate the capital cost for the user-specified process configuration based on cost information from the data file. For example, the capital cost of a biomass gasification unit would be adjusted by the following equation:

$$\text{Cost (Adjusted)} = \text{Cost (Data Bank)} \times \left[\frac{\text{Feed Rate (Adjusted)}}{\text{Feed Rate (Data Bank)}}\right]^{\eta}$$

η = scaling exponent

The capital costs of the other process units are calculated by equations of similar form. The ratio of other factors such as plant output, storage capacities, and feed densities may be used for capital cost estimates. Exponents used in the equations vary between 0.6 and 0.85, depending on the complexity of the process unit. Selected exponent values are stored as constants in the computer program. The capital costs are then escalated by the user-specified inflation factor.

After tabulating capital costs the user may input specific data on costs for catalysts and chemicals, ash removal, and potential by-product credits. Plant operating costs are then calculated either by estimate from the data bank information, or as a percentage of capital costs as is frequently done in process economics evaluations. The computer prints a capital cost summary.

The user may then specify financial parameters for calculation of product costs by both Discounted Cash Flow (DCF) and Utility Financing Methods (UFM). The baseline financial parameters given below were used for all computations in this report without modification:

- DCF parameters:
  - Project life = 20 years
  - Years of depreciation = 16 years
  - DCF return rate = 10%
  - Federal income tax = 4.8%
  - Construction period = 1.875 years
  - Interest during construction = 10%

- UFM parameters:
  - Percent debt = 35%
  - Interest on debt = 8.5%

DCF and UFM product cost equations for the above financial parameters are as follows:

DCF Formula:

$/MMBtu = (1.0000*NO + 0.2328*TPI + 0.1175*SC + 0.1923*WC))/G

UFM Formula:

$/MMBtu = ((10.000/PLIF)*NO + (C-WC)/PLIF + (C+WC) * 0.0774)/G

Where:

SC = Startup Costs ($MM)

WC = Working Capital ($MM)

NO = First Year Operating Cost ($MM)

TPI = Total Plant Investment ($MM)

G = Production (Trillion Btu/yr)

C = Total Capital Cost ($MM)

PLIF = Project Life (Years)

A sample computer run is shown in the Appendices.

3.2.3 Process Configurations Selected for Study

Process configurations for biomass conversion were limited to combustion and thermochemical processing methods. Aqueous and bioconversion processing techniques such as carboxolysis, bacterial digestion, hydrolysis and fermentation were not considered. Products considered are as follows:

(1) medium Btu gas
(2) low Btu gas
(3) substitute natural gas (SNG)
(4) ammonia
(5) methanol
(6) gasoline
(7) fuel oil
(8) electricity

Brief discussions of the process configurations selected follow for each of the designated end products.

a. Medium Btu Gas (MBG)

A schematic materials flow diagram for the process is shown in Figure 3-1. In this process, wood biomass would be delivered by truck to a feed hopper and then fed to a hammermill where it is chipped to -3 in. The chipped wood is then injected into the oxygen-fed shaft furnace. The oxygen is supplied by an on-site cryogenic air separation unit that produces gaseous oxygen.

Oxygen enters the furnace through tuyeres near the bottom and provides a sufficient thermal driving force to maintain a temperature range of 2,900° to 3,100°F in the partial combustion zone. This temperature fuses biomass fuel ash to a molten slag that gravitates to the bottom of the furnace and is tapped continuously. The refractory lining is contained within a water-cooled steel shell and is coated with congealed slag.

Hot combustion gases rise through the descending column, decomposing the organic materials to gases, liquids, and char. The char and tarry liquids pass down into a partial combustion zone where the reducing atmosphere, resulting from a deficiency of oxygen, converts all carbonaceous material primarily into carbon monoxide and hydrogen. In the top half of the furnace, the rising gas dries and preheats the charge. High boiling liquids are condensed on the surface of the cooler solids.

The gas produced in the furnace from the combustible portion of the wood leaves at 400°F near the top of the furnace. The volume of this gas is only 5 to 10 percent of the gas volume produced in a conventional combustion process because of the absence of nitrogen and complete combustion. Production of nitrogen oxides is also precluded for the same reason.

The exit gas from the furnace passes through an electrostatic precipitator to remove condensed droplets of oil and the bulk of the remaining fly-ash, both of which are recycled to the furnace to crack the oil to gaseous products and to remove the fly-ash with the molten residues. The gases then pass into an acid absorber where a neutralizing solution removes any H_2S and organic acid that may be present. The solution of salts is continuously bled from the recycled absorbed liquid and fed to the furnace, where the salts are eliminated with the slag. Moisture is removed from the saturated gas in a condenser.

The heating value of the medium Btu gas is on the order of 250 to 300 Btu/SCF, varying with the biomass feedstock and process operating conditions[4]. With regard to emissions, the process produces a clean fuel gas and slag ash which is usually disposed in landfill. Contaminants contained in the gaseous stream are scrubbed in a series of water sprays and entrained tar oils are removed and recycled. From the precipitator, the gases pass through a condenser to remove water from the saturated vapor. Waste water from the spray scrubber and the condenser is reported to be biodegradable and should, therefore, not present a disposal problem. Stack emissions from the combustion of the medium-Btu gas are cleaner than from burning fuel oil because potential contaminants have been scrubbed out.

b. Low Btu Gas (LBG)

Low Btu gas is produced from biomass by air fired gasification of biomass. As can be seen from Figure 3-2, the only difference in the process flow scheme is elimination of the oxygen plant and utilization of air to the gasifier[8]. The product gas heating value is about half that of medium Btu gas, with a representative value of 140 Btu/SCF assumed.

The average thermal conversion efficiency of producing MBG (75 percent), however, can be 10 to 15 percent higher than that of LBG. Therefore, less feedstock is required to produce MBG with a heating value equivalent to that of LBG. This greater thermal efficiency of an MBG system is offset, however, by the lower capital cost associated with a LBG plant.

Advantages of low-Btu gasification of biomass include:

1. Existing gas and oil-fired boilers could be easily converted to low-Btu gas;

2. Capital cost of low-Btu gasification equipment is low; and

3. Low-Btu gas is a clean, easy-to-use fuel and would minimize the expense and problems associated with hogged-fuel and coal combustion, stack emissions, and effluent treatment.

Some of the disadvantages include:

1. LBG must be used on-site; and

2. Existing gas/oil fired boilers would be derated by conversion to LBG.

c. Synthetic Natural Gas (SNG)

SNG is produced by methanation of medium Btu gas[4]. Figure 3-3 illustrates methanation technology by showing a schematic flow diagram in which two-thirds of the clean fuel gas from the MBG process is preheated to 550°F by heat exchange with the shift-converter product gas prior to entering the converter. The other one-third is cooled to 200°F in a waste-heat recovery system before combining with the shift-converter product gas that is also cooled to 200°F in a heat recovery unit. The two-heat recovery units produce the steam needed in a shift reaction. Following the shift reactors, a two-stage hot potassium carbonate system is employed to reduce the CO_2 content to 1.0 percent and remove trace amounts of the H_2S and COS. One-third of the regenerated carbonate solution enters midway in the absorber and flows countercurrent to the gas stream removing the greater part of the CO_2 in the lower half of the absorber.

The clean gas is then passed through sulfur guard vessels containing spent methanation catalyst to remove trace amounts of sulfur compounds. The heating value of the gas is increased to 950 Btu/SCF by reacting H_2 with CO in the presence of a nickel catalyst in a fixed-bed adiabatic reaction to form CH_4 and H_2O by methanation. The product gas stream leaving the methanator at 900°F is cooled to 100°F in a series of product gas coolers. Following cooling, product gas flows to a triethylene glycol dryer to reduce the mixture to the trace amounts specified by pipeline transmission companies.

d. Ammonia

Converting MBG to ammonia requires conversion of the syngas to essentially a 100 percent hydrogen stream. The technology to achieve this is well established and widely practiced. The challenge in ammonia synthesis is to obtain hydrogen at least cost.

In a process for ammonia production, shown in Figure 3-4, the synthesis gas is compressed to 200 psi and then fed to the gas purification system, where any H_2S present and carbon dioxide are removed. The cleaned gases together with an excess of steam are then fed to a shift converter where an iron oxide catalyst is used to reduce carbon monoxide to less than one percent by means of the water-gas reaction:

$$CO + H_2O \longrightarrow CO_2 + H_2$$

The carbon dioxide is again removed and a final cleanup of residual carbon monoxide (to less than 10 ppm) is accomplished by washing the gases with a solution of ammoniacal cuprous formate. After purification, nitrogen is added to a H/N ratio of 3/1. The mixture is compressed to reaction pressure (300 atm) and fed to the ammonia synthesis unit where the following reaction occurs.

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

The air separation facility provides an ample supply of nitrogen for ammonia production.

At the inlet to the ammonia synthesis reactor, the fresh feed is joined by a recycle stream of unconverted nitrogen and hydrogen. Within the reactor system, heat exchangers raise the temperature of the feed gases to approximately 475°C. The ammonia reactor catalyst is basically iron oxide enhanced by small additions of aluminum, potassium, calcium, and magnesium oxides. The gases leaving the reactor are cooled and some ammonia liquefaction occurs. Part of the gas is purged and used as fuel to control the level of diluents such as nitrogen, argon, and methane. The conversion of ammonia per synthesis pass is approximately 20 percent and the overall yield with recirculation could approach 90 percent of theoretical yield[(6)].

The product leaving the synthesis reactor system is in the form of anhydrous ammonia suitable for storage. Anhydrous ammonia is readily liquefiable at moderate pressures and temperatures, about 175 psi at room temperature, and is commonly marketed as liquid ammonia.

As compared with other chemical processes, ammonia synthesis is a relatively clean operation. No solid materials are produced as waste so there is no particulate emission problem in gas streams. The main waste product, carbon dioxide, is generally not regarded as an undesirable emission and can therefore be released to the atmosphere. The wastes that can be of main concern are minor impurities such as the sulfur that may be present in the synthesis gas and leaks or spills of the product ammonia itself. However, biomass-derived synthesis gas should contain minimal amounts of sulfur.

e. Methanol

A variety of technology is available to convert MBG to methanol[4]. In this analysis, the ICI low-pressure methanol process is considered. A flow diagram is shown in Figure 3-5. Synthesis gas is cleaned, compressed, and then passed through the shift reactor to adjust the H_2/CO ratio. In this case, the gas need not be desulfurized prior to entering the shift reactor since a sulfided catalyst is used. The shifted gas goes to the purification system after waste-heat recovery, where a hot-carbonate scrubbing system is used to remove sulfides in the gases down to 10 ppm, and to remove CO_2 down to 7 percent, so that a ratio of $H_2/(CO + 1.5\ CO_2)$ - 2.05 in product gas can be achieved. Regenerator off-gas would normally go to a sulfur recovery system where about 97 percent of the sulfur can be recovered in elemental form. This step would be omitted in the case of biomass feedstock.

The purified gas is then passed through an iron sponge drum and a sulfur guard drum to remove traces of sulfur. Following the guard drums, the gas, which is essentially sulfurless, is compressed from about 385 psia to 1500 psia and combined with recycled gas to pass through a fixed-bed catalytic (highly-active copper catalyst) converter to produce crude methanol. The methanol is condensed and separated from the untreated gas, which is recycled to the converter. The pressure is then reduced, and dissolved gases are flushed off from the crude methanol. Some of the flash gas is purged for use as a fuel in order to control the concentration of inert components in the converter system. The crude methanol is purified by distillation to produce fuel-grade methanol.

Like ammonia, methanol sysnthesis is a relatively clean operation. No solid materials are produced as waste so there is no particulate emission problem in gas streams. A waste product, carbon dioxide, is generally not regarded as an undesirable emission and can, therefore, be release to the atmosphere, if it is not otherwise recovered as a salable product. The wastes that can be of main concern are minor impurities such as the sulfur that may be present in the synthesis gas and leaks and spills of the product methanol itself. However, wood-derived synthesis gas should contain inconsequential amounts of sulfur.

f. Gasoline

Application of technology developed by Mobil[9] can convert biomass derived methanol to a high octane unleaded gasoline. The additional processing steps required are illustrated in Figure 3-6.

Crude methanol is vaporized and flows dimethylether (DME) reactors where it is catalytically converted to an equilibrium mixture of dimethylether, methanol, and water. The operating conditons are 300 psig and 600°F. The mixture then flows to five parallel reactors where catalytic conversion to M-Gasoline occurs. A recycle stream from phase separation is exchanged against the reactor effluent, and is introduced along with DME reactor effluent into the conversion reactors. The recycle stream controls the temperature of the highly exothermic reaction in the conversion reactors. The effluent stream is cooled further by preheating boiler feed water and air cooling and flows to phase separation where the hydrocarbons and water are separated. The water is sent to waste water treatment for treatment and discharge. The hydrocarbons flow through an absorber, stripper, and depentanizer for fractionation into a fuel gas stream, an olefinic stream, and a gasoline blending stream. The olefinic stream is depropanized due to the small quantity of propylene available for alkylation, and the butenes and pentenes are alkylated into additional liquid product in the alkylation plant. The alkylate is blended with the gasoline stream and results in a 92 research octane (clear) product suitable for use directly or for blending with petroleum derived gasoline.

g. Fuel Oil

Figure 3-7 is the schematic flow diagram of the process which has been used as the basis for compiling cost data(4). Biomass feedstock is delivered to a live-storage hopper and then to a rotary kiln type drier to reduce the moisture content to about three percent. The dried feedstock then passes to a shredder which reduces the chip size to about minus 10 mesh, the equivalent of a fine sawdust. This material is mixed with recycled solids from a char burner at a weight ratio of about five to one, char to wood, and the mixture carried into a vertical transport reactor by recycled product gas. Rapid mixing occurs within the reactor as the suspension passes upward under turbulent flow. This achieves high heat-transfer rates within the mixture during a very short residence time, which minimizes excessive thermal degradation of the materials and maximizes liquid yield.

Material leaves the pyrolysis reactor and passes through a cyclone separator to remove the char. Excess char that is not recycled to the reactor can be sold as a product, or failing this disposed of as landfill.

Outlet gases form the quench system are cooled to 180°F. A portion of the cooled and cleaned gas is heated by a process heater and used to carry feed material into the flash pyrolysis reactor. The remainder of the gases are burned in the process heater to heat the carrier gases. These pyrolysis gases have a heat content of approximately 200 to 300 Btu per scf, and should supply sufficient heat to eliminate the need for additional fuel. The combustion air may be drawn from the wood dryer as a heat recovery measure, if warranted. Heat exchange with other process streams lowers the temperature of the combustion products down to 350°F. These gases are then passed through a suitable clean-up device, such as a bag filter, before being discharged to the atmosphere.

h. Electricity

Seven alternatives were evaluated for generation of electricity from biomass feedstocks. These alternatives are summarized in Table 3-2. The four power systems employed (conventional gas fired power plants, combined-cycle power plants, gas turbine, and direct combustion steam-electric plant) are described below.

(h-1) Conventional Power Plant

The conventional power plant produces electricity from biomass. A flow schematic is shown in Figure 3-8. The power system consists of a steam generator (boiler), steam turbine, and power transmission equipment[5]. Fuel gas, either MBG or LBG produced from biomass is fired in the boiler to produce steam. The low sulfur, low nitrogen fuel gases eliminate the need for stack gas treatment. High pressure steam produced in the boiler is used to drive the steam turbine which produces electrical power. The power transmission system distributes electricity to consumers.

(h-2) Combined Cycle Power Plant

Biomass derived MBG, LBG and methanol were analyzed for producing electricity in combined cycle power systems[5]. A process flow schematic of the combined cycle power system is shown in Figure 3-9.

Biomass derived MBG, LBG, or methanol are sent to the combined cycle facility where compressed air and fuel are fired in the combustion chamber of the gas turbine. The hot combustion gases are then expanded through the turbine to generate electrical power. The exhaust from the gas turbine is used further to generate high pressure steam in an unfired boiler before being sent to the stack. The high pressure steam drives a steam turbine to generate additional electrical power. The intermediate pressure exhaust steam from one of the stages of the steam turbine is used as gasification process steam. The CO_2 and H_2O in the MBG and LBG gases fed to the gas turbine combustor assist in reducing NO_x in the combustion gases, by reducing combustion temperature.

(h-3) Gas Turbine

Utilization of biomass derived methanol in a gas turbine to produce electricity assumes application of a simple cycle gas turbine and power generation/transmission facilities. A process flow diagram is shown in Figure 3-10. Biomass derived methanol is combusted and the combustion product gases expanded through the gas turbine. The turbine drive is used to generate electricity.

(h-4) Direct Biomass Combustion

This configuration burns biomass as a fuel, uses the heat of combustion to produce steam, and converts the steam to electricity in steam turbines and generators[4]. A process flow diagram is shown in Figure 3-11. The wood-fired electric power generating plant consists of five equipment groups: the standard front-end wood-handling equipment, the boiler plan, the steam turbine plant, the electric generation plant, and power transmission. Appropriate support facilities are also included.

The biomass feedstock is subjected to vibratory screening before combustion to separate out fines and sand. The fines are fed separately to the combustion zone above the traveling grate where they are burned in suspension. Separate feeding of fines ensures a uniformly-sized fuel feed, and, consequently, uniform combustion on the traveling grate. The heat release for this type of furnace, equipped with a traveling grate, can range from 750,000 Btu per sq ft per hour to over 1,000,000 Btu per sq ft per hour.

No drying occurs for the feedstock prior to combustion, since satisfactory combustion can be achieved with 50-percent moisture-content feedstock. Variations in moisture content of the fuel can affect the steam output of a specific boiler, but this may be considered to be less of a problem than operating hogged-wood driers.

The steam turbine/electrical generation equipment is conventional and can be selected to meet the particular requirements, although in the current state-of-the-art of wood-fired power plants the turbine operates at lower steam pressures and temperatures (e.g., 1,000 psig at 1000°F with possible reheat) than do modern high-capacity coal-fired utility power plants (e.g., 3,500 psi and 1,000°F with 1,000°F reheat).

3.2.4 Preliminary Analysis

The economic analysis procedure was developed to provide inputs on process conversion efficiencies and product manufacturing costs to the biomass allocation model for 61 selected biomass species. While baseline economic data for the selected process configurations were being assembled, preliminary testing of the process economics model was performed. The preliminary testing provided a crude parametric analysis of the variables which influence product costs for each of the process configuratons. Four variables have pronounced effects on product costs: process capacity, process thermal efficiency, biomass feedstock cost, and biomass heating value. The assignment of values to these four key variables for the purpose of developing inputs was based on the following rationale.

As process capacity increases, production costs decrease. Selection of a reasonable process capacity is difficult. A base process capacity of 750 oven dry ton per day was selected for all process configurations which do not produce electricity as a product. This is larger than biomass pilot plants, which are typically not larger than 300 oven dry tons/day, but, is considered small enough to minimize transportation costs for the biomass feedstock materials. The seven process configurations which produce electricity were evaluated at the electrical capacities shown in Table 3-2. Costs of product electricity at these process capacities were used as inputs to the biomass allocation model. Because of the importance of capacity in determining product costs production costs were also evaluated at larger capacities (25 and 50 billion Btu/day output).

Process thermal efficiency determines the amount of energy produced for a specified process configuration. Minimal data are available correlating thermal efficiency and biomass feedstock type. Thermal efficiencies given in the literature sources are based on higher heating values of biomass feedstocks of 50 percent moisture content. In order to estimate thermal efficiency variations, the 61 biomass feedstock types were considered in five categories:

a. Woody biomass with moisture content between 45 and 55 percent,

TABLE 3-2

ALTERNATIVES CONSIDERED FOR PRODUCTION OF ELECTRICITY
FROM BIOMASS FEEDSTOCK MATERIALS

Process	Power System	Type of Service	Base Capacity, MW	Capacity Factor
Direct Biomass Combustion	Conventional Boiler	Baseload	200	0.8
Low Btu Gas	Conventional Boiler	Baseload	200	0.7
Medium Btu Gas	Conventional Boiler	Baseload	200	0.7
Low Btu Gas	Combined Cycle	Baseload	200	0.7
Medium Btu Gas	Combined Cycle	Baseload	200	0.7
Methanol	Combined Cycle	Intermediate	100	0.4
Methanol	Gas Turbine	Peaking	50	0.1

b. Woody biomass with moisture content greater than 55 percent,

c. Woody biomass with moisture content less than 45 percent,

d. Non-woody biomass (agricultural crop residues) with moisture content greater than 50 percent, and

e. Non-woody biomass (agricultural crop residues) with moisture content less than 50 percent.

Moisture content was determined from a review of the available literature[10]. Table 3-3 summarizes the classifications of the 61 biomass species. Group 1, woody biomass with moisture content between 45 and 50 percent, was designated the base case and assigned thermal efficiencies reported in the literature sources. Efficiencies for the other groups were adjusted based on estimated biomass lower heating values. In approximating the lower heating values, the following simplifying assumptions were made:

a. Group 1 - woody biomass, assumed moisture content of 50 percent (actual > 45 to < 55%), higher heating value of 8,600 Btu/lb;

b. Group 2 - woody biomass, assumed moisture content of 55 percent (actual ≥ 55%), higher heating value of 8,600 Btu/lb;

c. Group 3 - woody biomass, assumed moisture content of 45 percent (actual ≤ 45%), higher heating value of 8,600 Btu/lb;

d. Group 4 - non-wood biomass, assumed moisture content of 55 percent (actual > 50%), higher heating value of 7,500 Btu/lb; and

e. Group 5 - non-wood biomass, assumed moisture content of 45 percent (actual < 50%), higher heating value of 7,500 Btu/lb.

TABLE 3-3

CLASSIFICATION OF BIOMASS SPECIES

	SPECIES/CLASSIFICATION NUMBER *			SPECIES/CLASSIFICATION NUMBER *	
1.	Oaks, White (S,E)	(3)	31.	Ponderosa/J. Pine	(2)
2.	Oaks, White (O,E)	(3)	32.	Fir, Douglas (W)	(1)
3.	Oaks, Red (S,E)	(3)	33.	Firs, True (W)	(2)
4.	Oaks, Red (O,E)	(3)	34.	Cyprus (E)	(2)
5.	Hickory (E)	(3)	35.	Pine, Sugar (W)	(2)
6.	Birch, Yellow (E)	(3)	36.	Pine, White (W)	(2)
7.	Maple, Hard (E)	(3)	37.	Redwood (W)	(2)
8.	Maple, Soft (E)	(3)	38.	Spruce, Sitka (W)	(2)
9.	Beech (E)	(3)	39.	Engelmann (+O,W)	(2)
10.	Sweetgum (E)	(2)	40.	Larch (W)	(1)
11.	Tupelo/B.Gum (E)	(1)	41.	Cedar, Red (W)	(2)
12.	Ash (E)	(3)	42.	Cedar, Incense (W)	(2)
13.	Basswood (E)	(2)	43.	Pine, Lodgepole (W)	(1)
14.	Poplar, Yellow (E)	(1)	44.	Softwood (O,W)	(1)
15.	Cottonwood/ASP	(2)	45.	Wheat	(5)
16.	Walnut, Black (E)	(3)	46.	Corn, Grain	(4)
17.	Cherry, Black (E)	(2)	47.	Soybeans	(5)
18.	Hardwoods (O,E)	(1)	48.	Oats	(5)
19.	Alder, Red (W)	(1)	49.	Potatoes	(4)
20.	Oak (W)	(2)	50.	Barley	(5)
21.	Hardwoods (O,W)	(1)	51.	Sugarbeets, Field	(4)
22.	Longleaf/SP (E)	(1)	52.	Sorghum, grain	(4)
23.	Shortleaf/LOB,E	(1)	53.	Rice, Straw	(5)
24.	Pine, Yellow (O,E)	(2)	54.	Sugarcane, Field	(4)
25.	Pine, R/W (E)	(2)	55.	Cotton	(4)
26.	Pine, Jack (E)	(2)	56.	Peanuts	(5)
27.	Spruce/B. Fir (E)	(2)	57.	Bagasse	(5)
28.	Hemlock (E)	(1)	58.	Rye	(5)
29.	Hemlock (W)	(2)	59.	Grasses, seed	(5)
30.	Softwood (O,E)	(1)	60.	Hulls, rice	(5)
			61.	Sugarbeet, pulp	(5)

*(1) = woody biomass, >45 to <55 percent moisture

(2) = woody biomass, ≥55 percent moisture

(3) = woody biomass, ≤45 percent moisture

(4) = non-woody biomass, >50 percent moisture

(5) = non-woody biomass, <50 percent moisture

All higher heating values were defined on a dry basis. Lower heating value estimates were made based on the method of Kollman and Cote[11].

3.3 RESULTS (Thermochemical Conversion Process Economics)

3.3.1 Process Efficiencies

Group 1 serves as a base case for woody biomass species. The thermal efficiencies reported in the literature sources were assigned for biomass feedstocks in this group. Efficiencies for Groups 2 and 3 were modified as follows:

$$\eta' = \eta \frac{LHU'}{LHV}$$

where η' = adjusted thermal efficiency
η = base thermal efficiency
LHU' = lower heating value of Group 2 or 3 biomass
LHV = lower heating value of Group 1 biomass

Non-wood biomass species were evaluated by analagous comparison with a hypothetical base case non-wood of 50 percent moisture content and higher heating value of 7,500 Btu/lb. (Actually, all the non-wood species considered are high or low moisture and fall in Group 4 or 5.) Table 3-4 summarizes the estimated thermal efficiencies.

Feedstock cost and heating value are interrelated as developed in the market analysis work. Costs in dollars per dry ton were developed for hardwoods, softwoods, low moisture non-woods and high moisture non-woods. The heating value of a selected biomass species determines the cost of that material in dollars per million Btu. In cases where biomass higher heating values were unknown, 8,600 Btu/lb was assumed for woody biomass and 7,500 Btu/lb for non-wood biomass. The relationship between feedstock costs and product costs is linear (assuming other variables are held constant). To simplify analysis, each process configuration was evaluated for three biomass costs at heating values and efficiencies for each of the five biomass groups.

TABLE 3-4

THERMAL EFFICIENCY ESTIMATES

Process Configuration	Thermal Efficiency, by Biomass Group 1	2	3	4	5
Low Btu Gas	0.650	0.596	0.686	0.585	0.693
Medium Btu Gas	0.750	0.687	0.791	0.675	0.799
Substitute Natural Gas	0.660	0.605	0.696	0.594	0.703
Ammonia	0.658	0.602	0.694	0.592	0.701
Methanol	0.450	0.412	0.475	0.405	0.479
Gasoline	0.405	0.371	0.427	0.365	0.431
Fuel Oil	0.610	0.559	0.643	0.549	0.650
Electricity					
Direct Biomass Combustion	0.310	0.284	0.327	0.279	0.330
LBG/Combined Cycle	0.254	0.233	0.268	0.229	0.271
MBG/Combined Cycle	0.306	0.280	0.323	0.275	0.326
LBG/Conventional Power Plant	0.212	0.194	0.224	0.191	0.226
MBG/Conventional Power Plant	0.270	0.247	0.285	0.243	0.288
Methanol/Combined Cycle	0.203	0.186	0.214	0.183	0.216
Methanol/Gas Turbine	0.149	0.136	0.157	0.134	0.159

The relationship between biomass feedstock cost and product cost is linear for each process configuration, providing other parameters are held constant. For each process configuration five linear equations, corresponding to the five biomass feedstock groups were determined. Specific costs for each of the 61 biomass species were substituted into the appropriate equations to determine estimated product manufacturing costs. These product cost values were used in the biomass allocation model.

3.3.2 Manufacturing Costs

Overall product primary and secondary manufacturing costs are shown in Tables 3-5 through 3-9 and in Appendix B, Section 3.2. These values are used as inputs to the biomass allocation model. Primary Manufacturing Cost (MFG_p Cost) is defined as:

$$MFG_p\ \text{Cost} = \frac{(\text{Annual Operating Cost}) + (0.05 \times \text{Total Capital Cost})}{(\text{Total Product Output, } 10^{12}\ \text{Btu/yr})}$$

Substitute natural gas, ammonia, methanol, and gasoline are produced by further processing of medium Btu gas. Secondary manufacturing costs for the four secondary products (SNG, methanol, gasoline, and ammonia), are held constant in spite of variation in biomass feedstock costs. These secondary manufacturing costs are defined as:

$$MFG_s\ \text{Cost} = \frac{(AOC_{FINAL} - AOC_{MBG}) + (0.05)(TCC_{FINAL} - TCC_{MBG})}{TPO_{FINAL}}$$

where:

AOC = Annual Operating Cost
TCC = Total Capital Cost
TPO = Total Product Output

TABLE 3-5

RESULTS OF PROCESS ECONOMICS ANALYSIS FOR PRODUCTION OF MEDIUM BTU GAS

Biomass Species Number	MFG Cost, $\$/10^6$ Btu	Biomass Species Number	MFG Cost, $\$/10^6$ Btu
1	3.44	31	3.65
2	3.44	32	3.20
3	3.44	33	3.57
4	3.44	34	3.57
5	3.44	35	3.57
6	3.44	36	3.57
7	3.56	37	3.51
8	3.44	38	3.60
9	3.44	39	3.53
10	3.94	40	3.28
11	3.62	41	3.57
12	3.44	42	3.63
13	3.94	43	3.28
14	3.73	44	3.28
15	4.08	45	4.46
16	3.44	46	6.14
17	3.94	47	4.46
18	3.74	48	4.46
19	3.62	49	6.14
20	4.07	50	4.46
21	3.62	51	6.14
22	3.29	52	6.14
23	3.29	53	4.81
24	3.57	54	6.14
25	3.57	55	6.14
26	3.53	56	4.46
27	3.57	57	4.46
28	3.29	58	4.23
29	3.57	59	4.46
30	3.57	60	4.37
		61	4.46

TABLE 3-6

RESULTS OF PROCESS ECONOMICS ANALYSIS FOR PRODUCTION OF LOW BTU GAS

Biomass Species Number	MFG Cost, $\$/10^6$ Btu	Biomass Species Number	MFG Cost, $\$/10^6$ Btu
1	2.93	31	3.02
2	2.93	32	2.70
3	2.93	33	2.93
4	2.93	34	2.93
5	2.93	35	2.93
6	2.93	36	2.93
7	3.08	37	2.86
8	2.93	38	2.97
9	2.93	39	2.88
10	3.36	40	2.70
11	3.09	41	2.94
12	2.93	42	3.00
13	3.36	43	2.70
14	3.22	44	2.70
15	3.51	45	3.98
16	2.93	46	5.98
17	3.36	47	3.98
18	3.23	48	3.98
19	3.09	49	5.98
20	3.48	50	3.98
21	3.09	51	5.98
22	2.70	52	5.98
23	2.70	53	4.38
24	2.93	54	5.98
25	2.93	55	5.98
26	2.88	56	3.98
27	2.93	57	3.98
28	2.70	58	3.71
29	2.93	59	3.98
30	2.70	60	3.87
		61	3.98

TABLE 3-7

RESULTS OF PROCESS ECONOMICS ANALYSIS FOR PRODUCTION OF FUEL OIL

Biomass Species Number	MFG Cost, $\$/10^6$ Btu	Biomass Species Number	MFG Cost, $\$/10^6$ Btu
1	4.01	31	4.16
2	4.01	32	3.78
3	4.01	33	4.07
4	4.01	34	4.07
5	4.01	35	4.07
6	4.01	36	4.07
7	4.17	37	4.00
8	4.01	38	4.11
9	4.01	39	4.02
10	4.53	40	3.70
11	4.20	41	4.07
12	4.01	42	4.14
13	4.53	43	3.78
14	4.33	44	3.78
15	4.69	45	5.19
16	4.01	46	7.42
17	4.53	47	5.19
18	4.35	48	5.19
19	4.20	49	7.42
20	4.66	50	5.19
21	4.20	51	7.42
22	3.78	52	7.42
23	3.78	53	5.61
24	4.07	54	7.42
25	4.07	55	7.42
26	4.02	56	5.19
27	4.07	57	5.19
28	3.78	58	4.90
29	4.07	59	5.19
30	3.78	60	5.08
		61	5.19

TABLE 3-8

RESULTS OF PROCESS ECONOMICS ANALYSIS FOR PRODUCTION OF ELECTRICITY VIA DIRECT COMBUSTION

Biomass Species Number	MFG Cost, $\$/10^6$ Btu	Biomass Species Number	MFG Cost, $\$/10^6$ Btu
1	10.26	31	10.54
2	10.26	32	9.80
3	10.26	33	10.36
4	10.26	34	10.36
5	10.26	35	10.36
6	10.26	36	10.36
7	10.58	37	10.22
8	10.26	38	10.43
9	10.26	39	10.25
10	11.26	40	9.80
11	10.62	41	10.36
12	10.26	42	10.50
13	11.26	43	9.80
14	10.89	44	9.80
15	11.59	45	12.56
16	10.26	46	16.86
17	11.26	47	12.56
18	10.98	48	12.56
19	10.62	49	16.86
20	11.51	50	12.56
21	10.62	51	16.86
22	9.80	52	16.86
23	9.80	53	13.39
24	10.36	54	16.86
25	10.36	55	16.86
26	10.25	56	12.56
27	10.36	57	12.56
28	9.80	58	12.00
29	10.36	59	12.56
30	9.80	60	12.34
		61	12.56

TABLE 3-9

SECONDARY MANUFACTURING COSTS

Product*	MFG Cost, $\$/10^6$ Btu
Substitute Natural Gas	1.84
Ammonia	2.56
Methanol	2.57
Gasoline	4.45

* These products are produced from a medium Btu gas intermediate product.

The four secondary manufacturing costs were developed for an average biomass feedstock cost. A plant life of 20 years is assumed in all calculations.

Production of electricity by direct combustion of biomass was more economically attractive than by the other process configurations. Therefore, electricity manufacturing costs used in the biomass allocation model are based on direct biomass combustion.

Manufacturing costs for non-wood biomass species (numbers 45-61) are higher because of higher costs for these materials as determined in the market study. It should be pointed out that aqueous processing of non-wood biomass species may be preferable to thermochemical processing. The process configurations, as defined have simple handling and sizing equipment for biomass preparation. To utilize non-woods, in particular high moisture varieties, additional processing in the form of drying and classification may be required. These production costs further extend the advantages of thermochemical processing of wood biomass species.

Additional results of process economics analysis of each of the major product types is given in Section 3.2 of Appendix B.

Appendix D for the process economics analysis consists of three parts. The first part (D.1) is a sample computer run illustrating the procedure and describing the options available to the user. The second part (D.2) is a set of figures which show the sensitivity of product costs to variations in plant capacity and biomass feedstock costs. The remainder of the appendix (D.3) is a set of tables summarizing the results of the process economics analysis for each process configuration.

The costs developed during the process economics analysis are based on modifications of published literature data. Costs for all products considered in the biomass allocation model are based on economic analysis data developed by MITRE Corporation. The fact that all data were developed by one organization and were modified by the same rationale provides a consistent set of relative costs for biomass conversion products. These costs provide a reasonable input for execution of the biomass allocation model. In absolute terms however, these costs may vary from those developed in more recent detailed economic evaluations. It is recommended that the process economics data base be updated to include more recent information. Ideally, a broad based effort such as the MITRE study, would provide better product costs, both in relative and absolute terms.

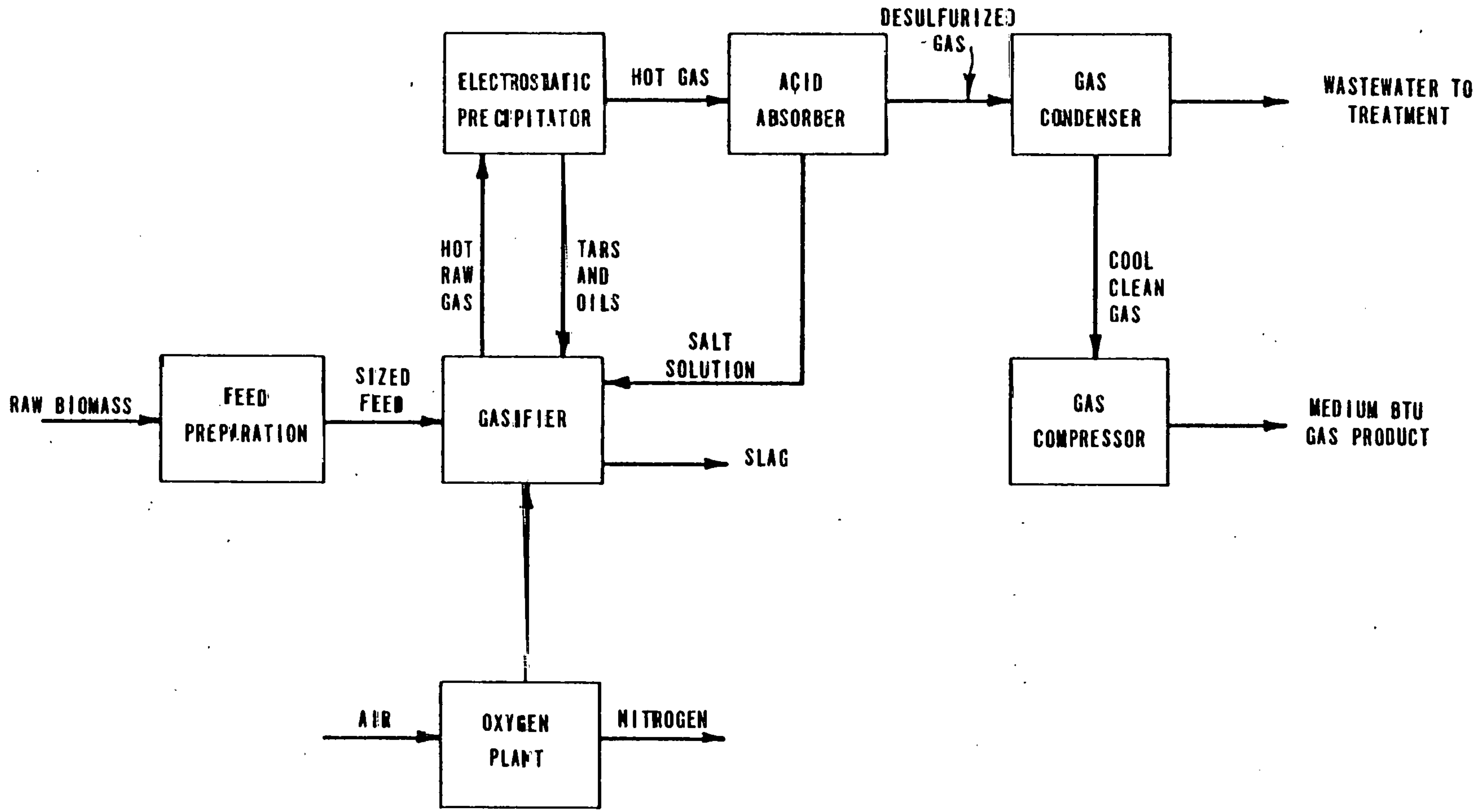


FIGURE 3-1
PROCESS FLOW SCHEMATIC FOR MEDIUM BTU GAS

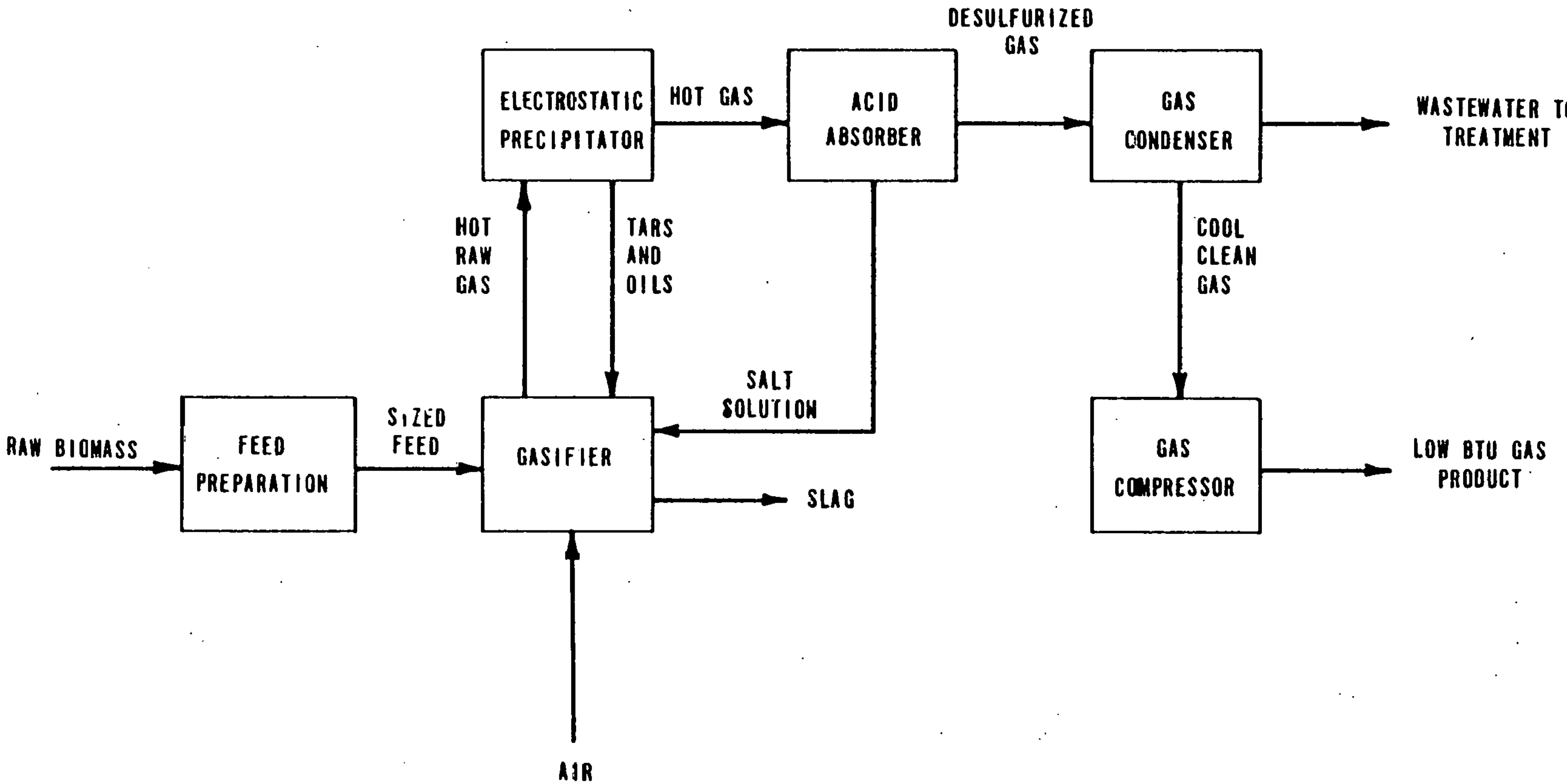


FIGURE 3-2
PROCESS FLOW SCHEMATIC FOR LOW BTU GAS

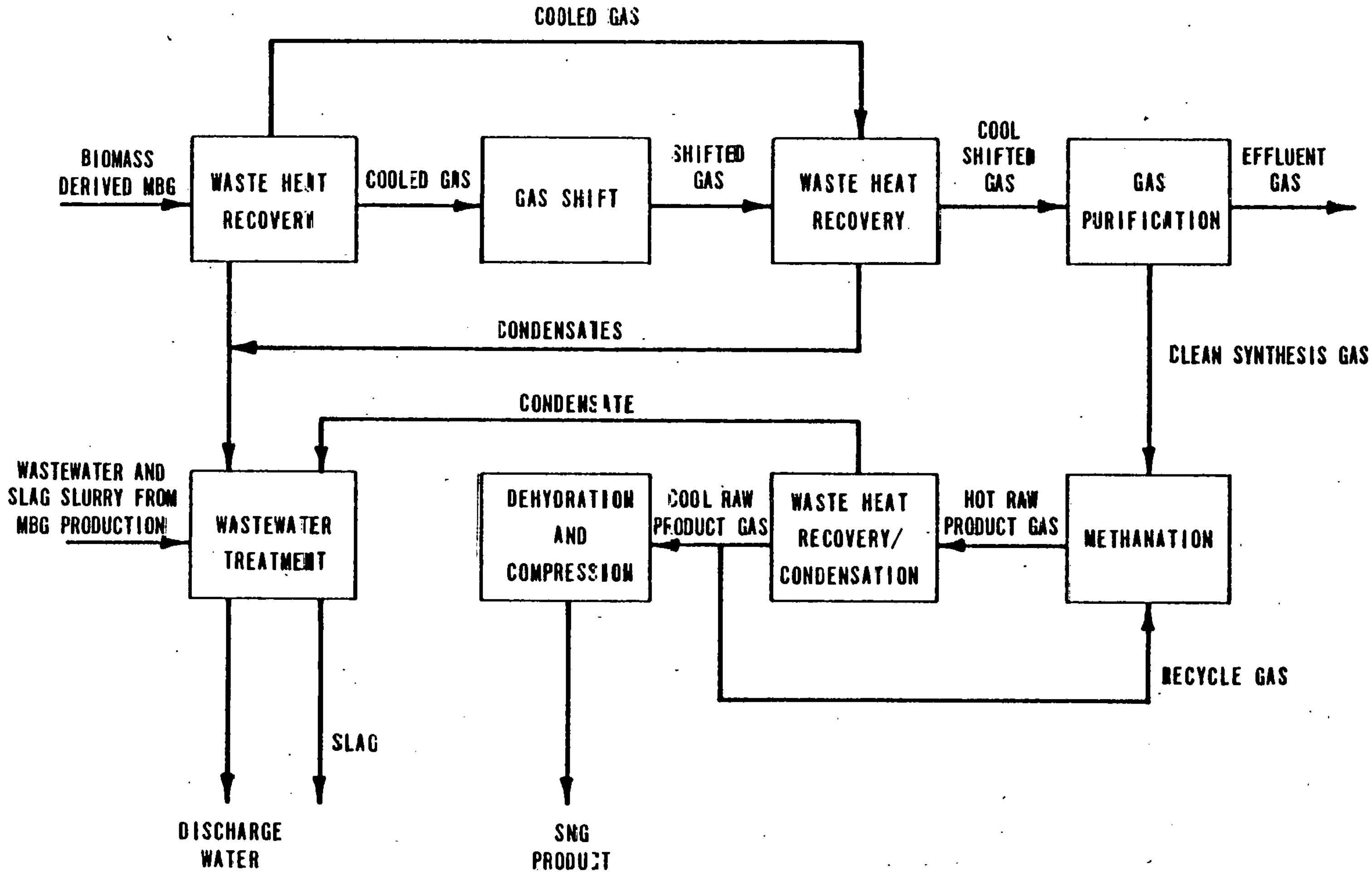


FIGURE 3-3
PROCESS FLOW SCHEMATIC FOR PRODUCTION OF
SNG FROM BIOMASS-DERIVED MBG

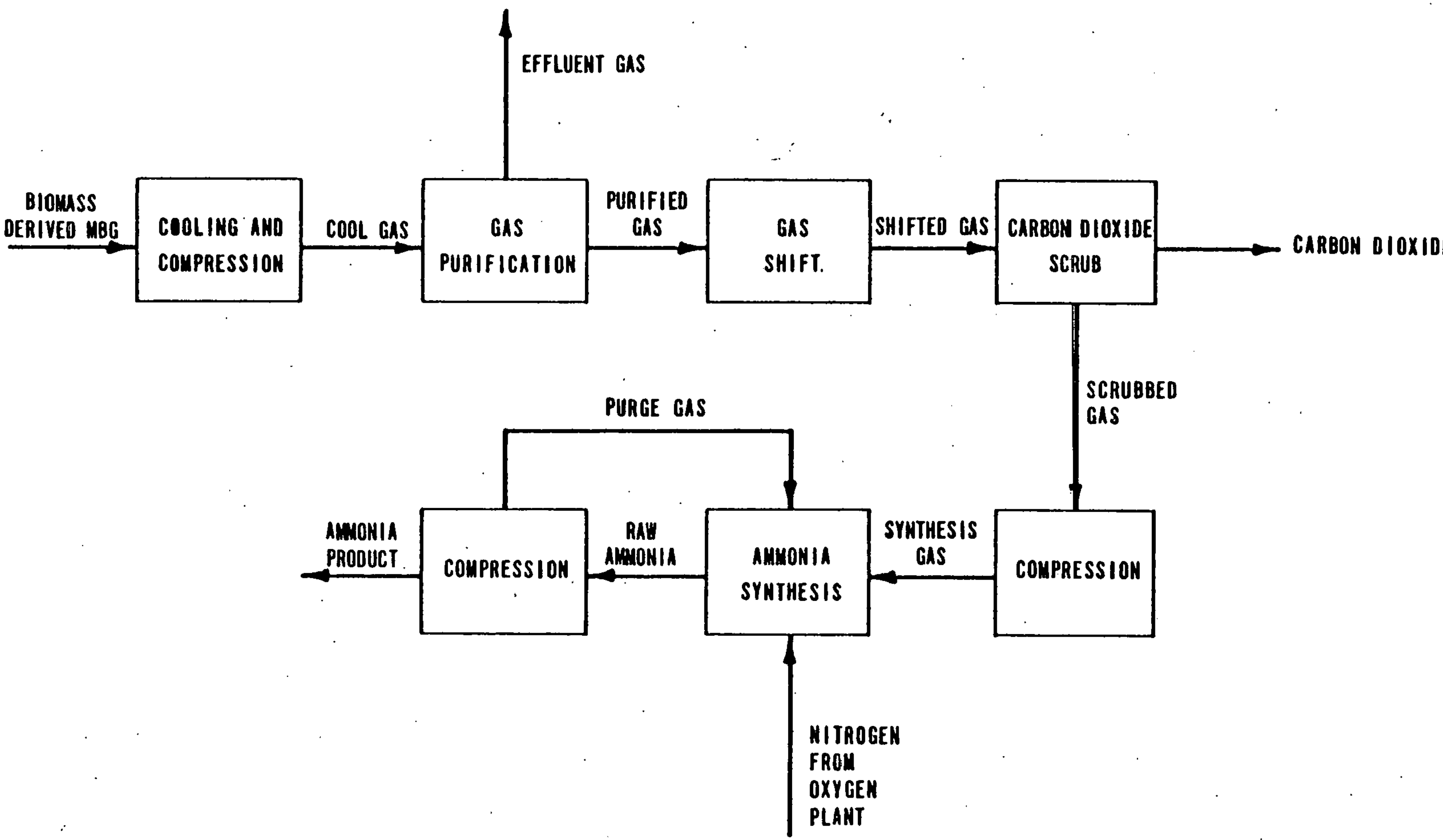


FIGURE 3-4
PROCESS FLOW SCHEMATIC FOR PRODUCTION OF
AMMONIA FROM BIOMASS-DERIVED MBG

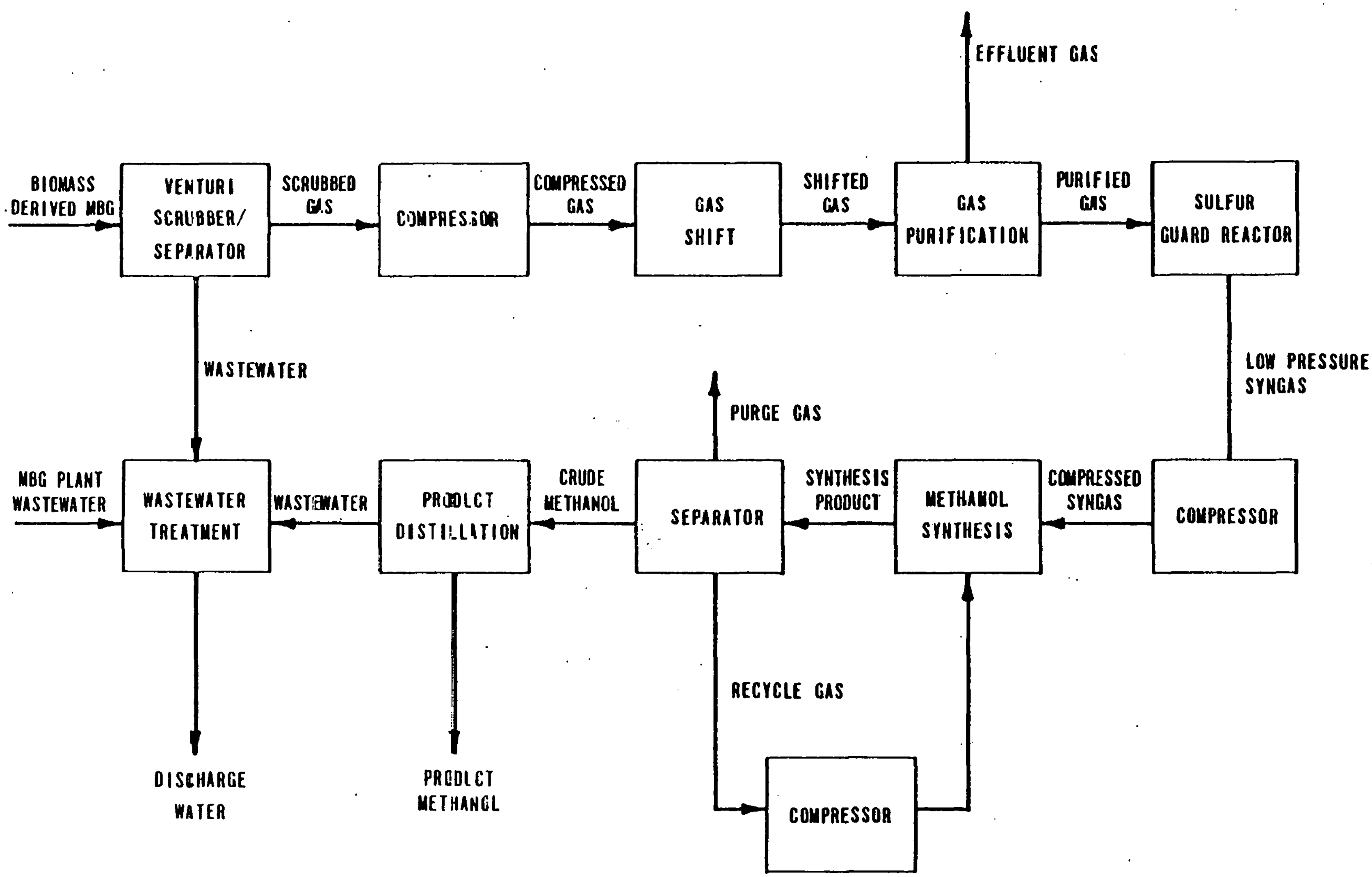


FIGURE 3-5
PROCESS FLOW SCHEMATIC FOR PRODUCTION OF METHANOL FROM BIOMASS-DERIVED MBG

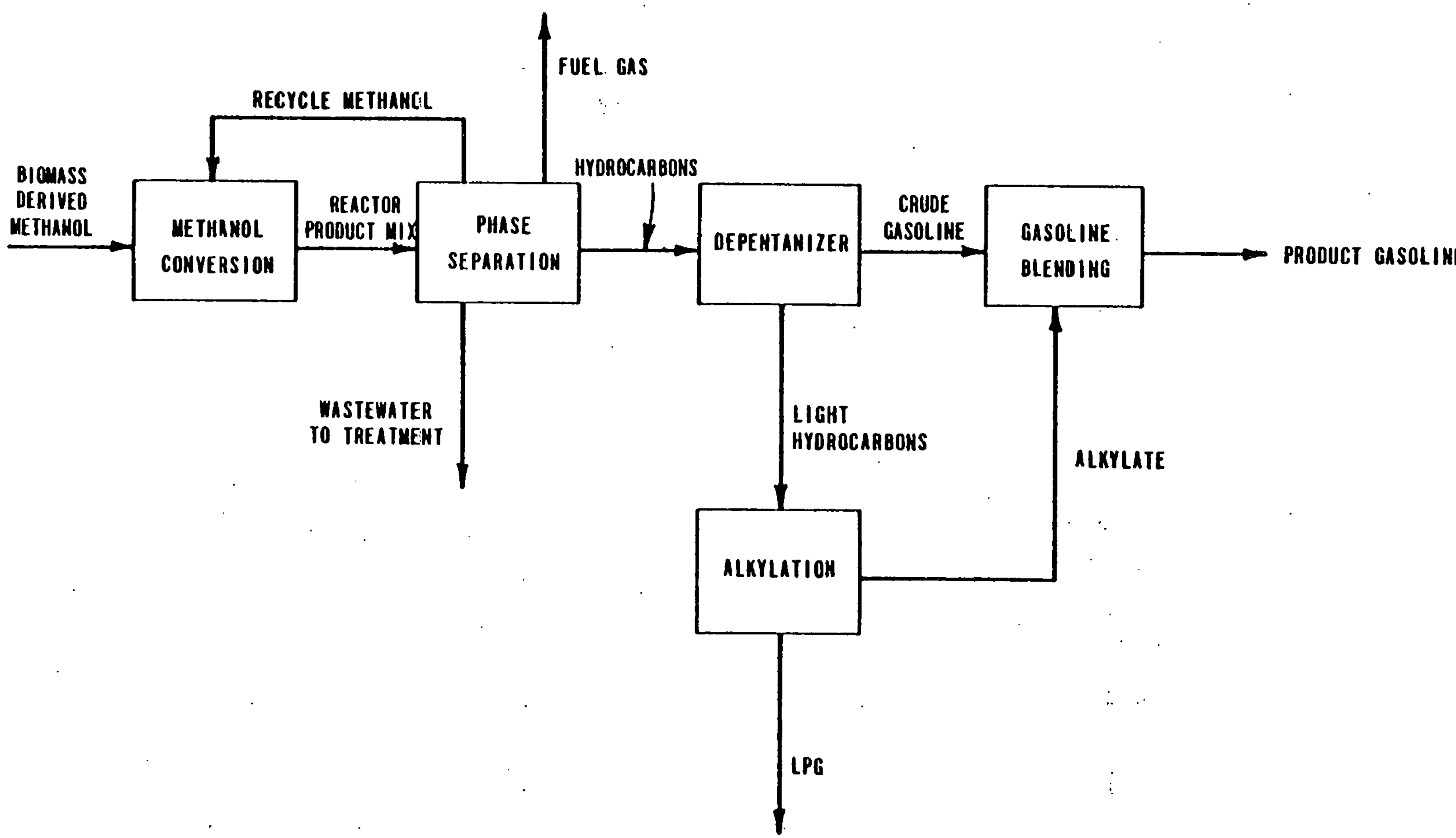


FIGURE 3-6
PRODUCTION OF GASOLINE FROM
BIOMASS-DERIVED METHANOL

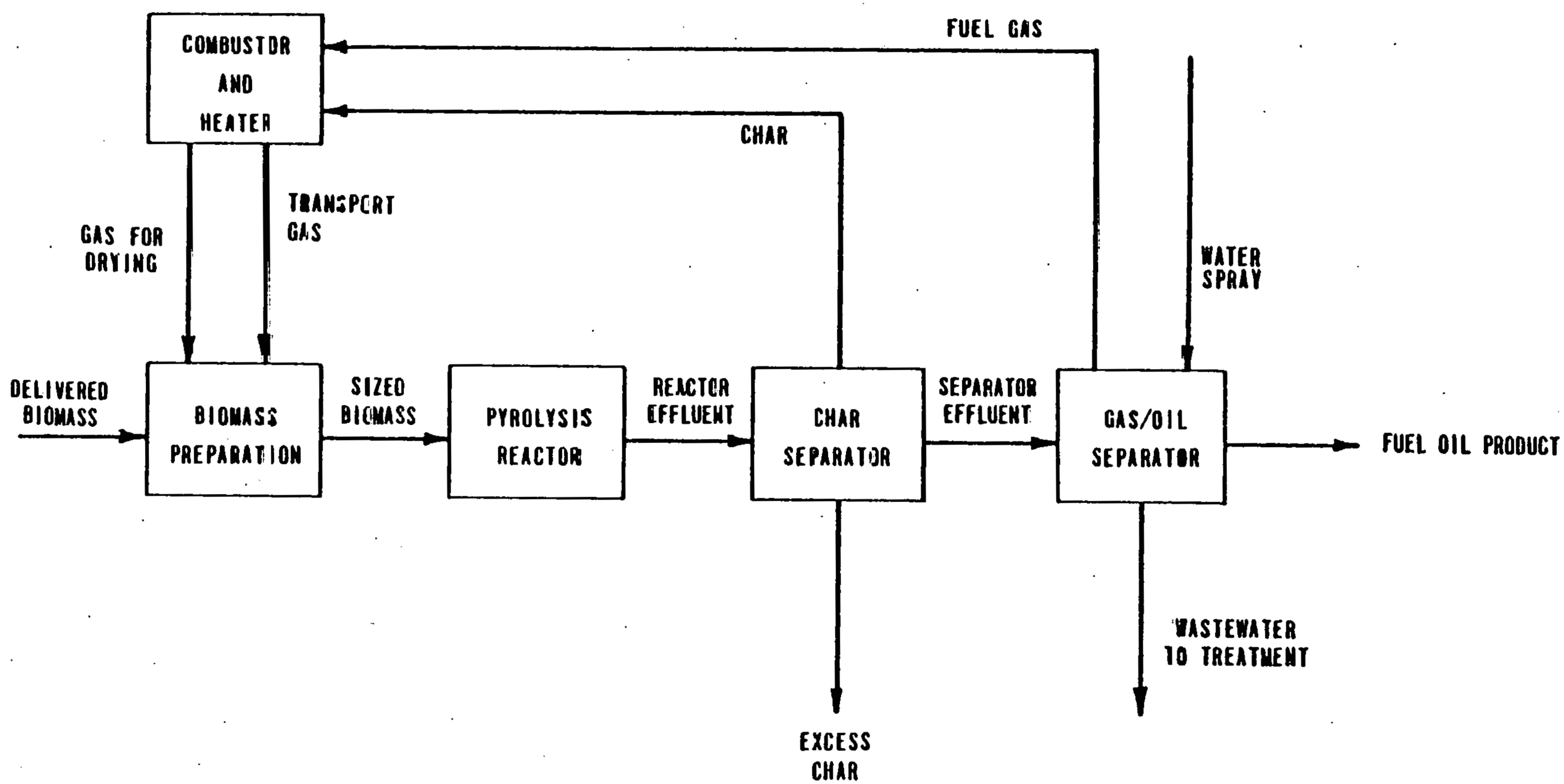


FIGURE 3-7
PROCESS FLOW DIAGRAM FOR PRODUCTION OF
FUEL OIL FROM BIOMASS

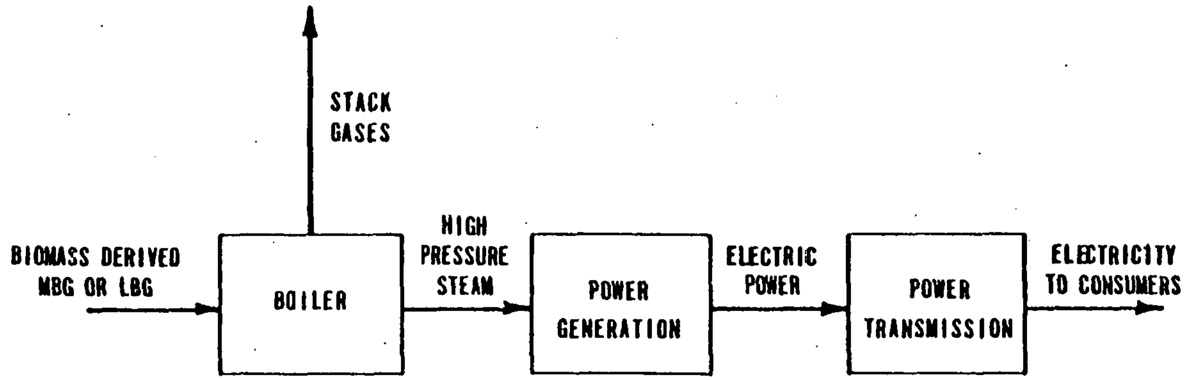


FIGURE 3-8
PROCESS FLOW DIAGRAM FOR ELECTRICITY
PRODUCTION BY CONVENTIONAL POWER SYSTEMS

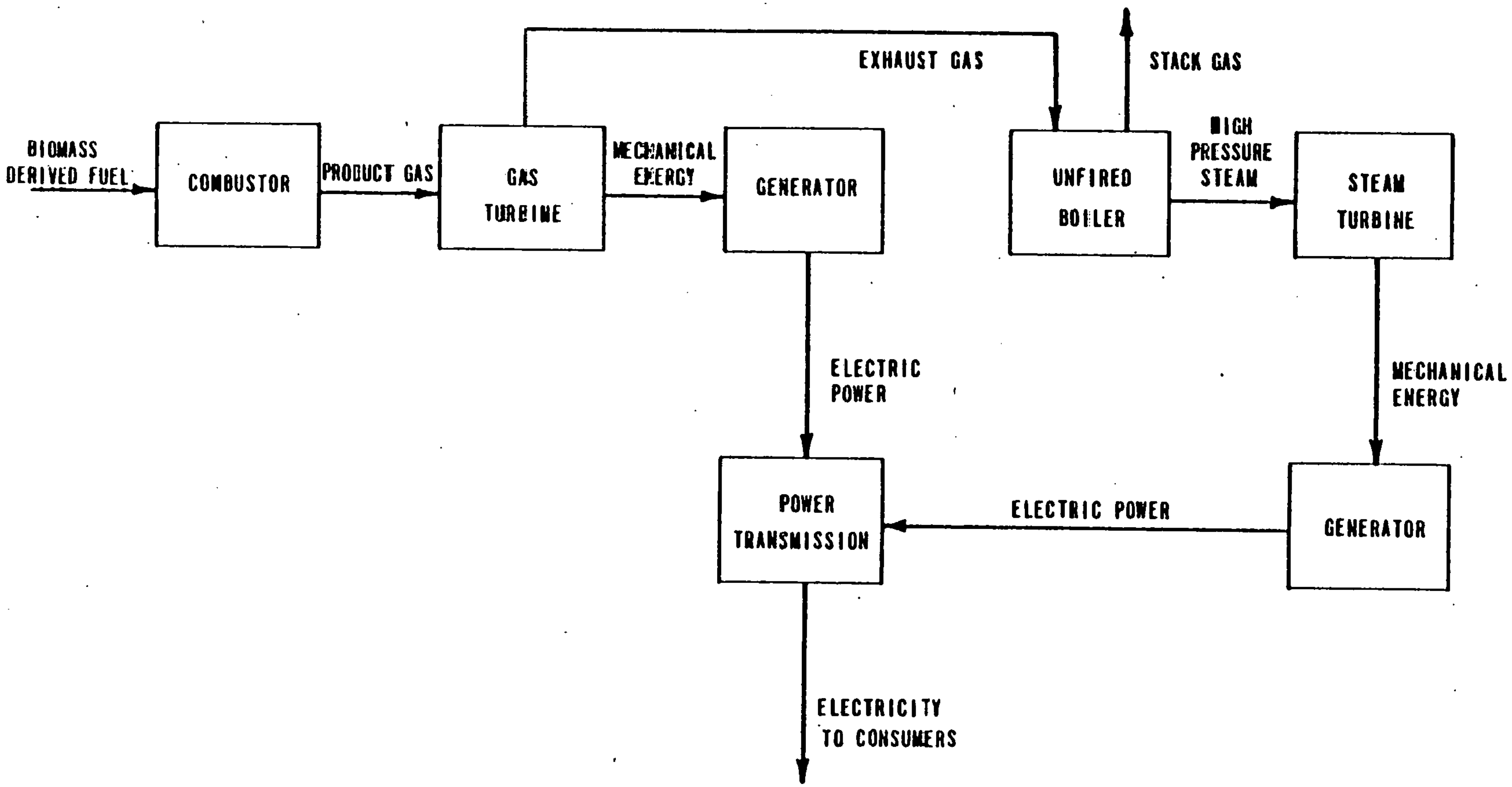


FIGURE 3-9
PROCESS FLOW DIAGRAM FOR PRODUCTION
OF ELECTRICITY IN A COMBINED CYCLE
POWER SYSTEM

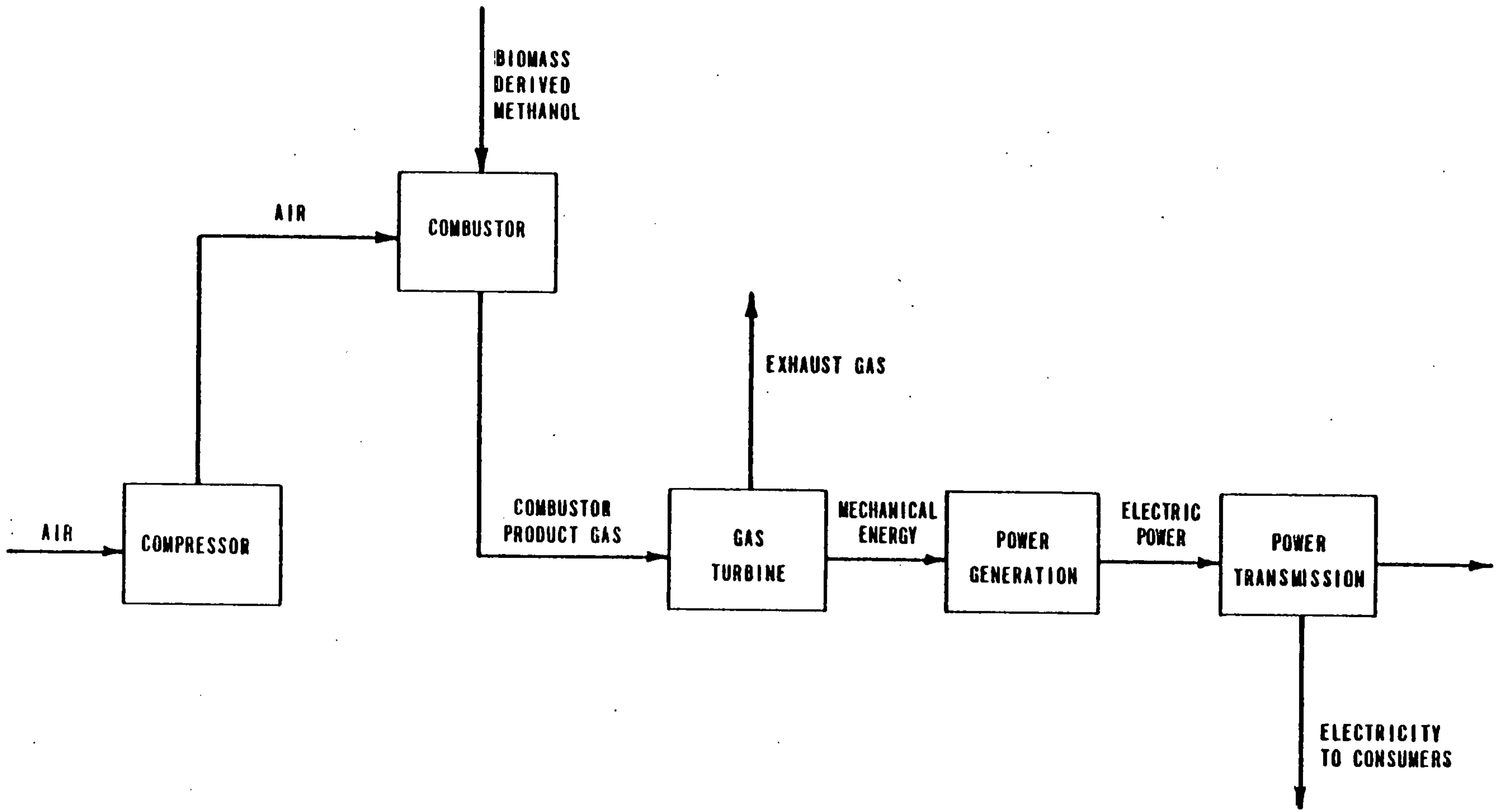


FIGURE 3-10
PROCESS FLOW DIAGRAM FOR PRODUCTION
OF ELECTRICITY IN A SIMPLE CYCLE
GAS TURBINE

4.0
DATA STORAGE AND RETRIEVAL SYSTEM

4.0 DATA STORAGE AND RETRIEVAL SYSTEM

4.1 OBJECTIVES

In order for the biomass allocation model to be operable, it must have access to a data base containing the feedstock and product price and availability data from the market analysis task of the study and the thermochemical conversion process efficiencies and manufacturing cost data from the processing tasks of the study. It was therefore necessary to design and construct a computer based storage and retrieval system to serve this purpose.

The purpose of the various data files is shown in Figure 4-1. The amounts and costs of the feedstocks are the primary inputs to the allocation problem.

Whereas the feedstock amounts enter into the allocation problem directly, the feedstock costs enter indirectly, in that they are used to estimate manufacturing costs.

The manufacturing costs and the product costs play a major role in determining each allocation as they are used to calculate the total profit which is then maximized during the allocation process. The various efficiencies and manufacturing costs were derived from engineering studies which are described in Section 3.0.

In the data base design phase of the project the objectives were to provide the information flow paths shown in Figure 4-1 in such a manner that the data base would contain all of the features required by the original work statement. Of necessity, these objectives had to be met early, and then the resulting file structures maintained throughout the remainder of the project.

4.2 METHODS

The key data base files are shown in Table 4-1.

The approach for using them is as follows. First, the information from the market analysis task was summarized in card input form. This initial information is listed in Appendix B.2.1. The program DATGEN was designed to read each initial parameter and generate a smoothed data base of regional feedstock amounts and costs. This initial step was introduced in order to avoid the large amount of scatter which was found to exist in the original data.

The next step was to provide for the addition of new data. This was accomplished by writing a second computer program called BMCARDS.

In order to develop the overall system the same code was inserted in the program DATGEN to provide simulated process efficiencies and manufacturing costs. That code has been retained but the simulated results have been overwritten with calculated efficiencies and manufacturing costs by means of the BMCARDS program.

Some of the information in File Nos. 13, 14, 15, and 18 are not required as input information to the allocation equations. For example, the feedstock cost information must be available for use by persons responsible for generating the primary manufacturing costs, but it is not needed by the optimization software.

In order to facilitate making cross-reference between Section 8.0 of Appendix C, and other sections of this report, the mnemonic symbols which have been used in Section 8.0 are also shown in Figures 4-2 through 4-5.

TABLE 4-1

KEY DATA FILES

Feedstock Amounts (F_i) Feedstock Costs* Product Amounts (D_j) Product Costs (S_j)	File No. 5 (Figure III B-2)
Feedstock Names* Feedstock Heating Values*	File No. 14 (Figure III B-3)
Primary Efficiencies (EPRIM) Primary Manufacturing Costs (MPRIM)	File No. 13 (Figure III B-4)
Secondary Efficiencies (ESEC) Secondary Manufacturing Costs (MSEC) Final Efficiencies (EFIN) Final Manufacturing Costs (MFIN)	File No. 18, Record 1 (Figure III B-5)

*NOTE: These inputs are not required for the optimization procedure, but it was convenient to store this information in the files indicated.

The initial feedstock amounts (Figure 4-2) are calculated at the time that the corresponding input data are processed by the DATGEN and FPSTOR by the programs. At this time the feedstock names, heating values, and amounts in tons per year are also read into File No. 14. In addition, the product amount and cost information is read into File No. 15.

The file system provides for a maximum of twelve products, and each product may be modified in order to satisfy the specifications required by each market sector. Since there are up to five market sectors, it follows that there can be 12 x 5 = 60 product/sector combinations.

As not all combinations are feasible (for example, ammonia for the residential section is not feasible), the maximum possible number of product/sector combinations was limited to 32. In the discussions which follow, when mention is made of energy flow along a feedstock-to-product path (using the notation $f_{i,j}$), it is one of these 32 product numbers which is being referenced.

The 18 product/sector combinations (out of the possible 32) that have been implemented are shown below. The numbers in the tabulation below are "product pointers." See notes "i" and "p" in Appendix A.

	1.Transportation	2.Residential	3.Chemicals	Utility 4.Electric
1. Low Btu	-	-	4	5
2. Medium Btu	-	-	6	7
3. Fuel Oil	13	14	15	16
4. Electricity	-	18	19	20
5. SNG	-	2	-	3
6. Ammonia	-	-	1	-
7. Methanol	10	-	11	12
8. Gasoline	8	-	-	-

Note: Combination 9 and 17 do not exist.

The secondary and final efficiencies and manufacturing costs are input to the system by means of a separate program, BMCARDS. This information is read into File No. 18. File No. 18 is a general purpose file. Since a smaller amount of secondary and final efficiency and cost information is required, a separate file is not needed. Instead, one record of File No. 18 has been used.

It should be noted that the system has been designed for up to 128 feedstocks. This was done in order to provide some expansion capability.

4.2.1 Initial Data Base

The initial data base of feedstock availabilities was based upon previous supply and demand studies, and upon the most recent statistical information published by the U.S. Department of Agriculture. As a result, it is unlikely that the user will wish to change availabilities on an individual species basis. Rather, it is probable that the entire availability data base will be updated.

In the event that availabilities for specific species must be changed, it can be done by having data input cards keypunched and the new data entered into the system by executing the program DATGEN.

In order to revise the availability data base as a whole, it is necessary to make changes to the input card data file ADDL (shown in Appendix B) in the three areas as shown in Figures 4-6 through 4-8.

Figure 4-6 shows the total availabilities in millions of tons for each region. The system expects these eight cards to follow the first 128 feedstock name cards. Following these cards there should be 128 cards, as shown in Figure 4-7, and as many availability cards as necessary for each region.

The resulting card deck is maintained in the file ADDL which is read by the program DATGEN. For further information, see the documentation describing the software system in Appendix C (Program Description).

4.2.2 Data Base Additions

At the time that the initial data base was generated the only feedstock prices available were average prices for the following categories:

- o Softwoods,
- o Hardwoods,
- o Cellulosic (low moisture) materials, and
- o High moisture materials.

Some dependencies upon heating value, availability, and regional labor costs were superimposed upon these highly aggregated prices; no dependency upon feedstock handleability and prepareability was included.

In recognition of the fact that feedstock prices will change and the fact that more reliable price information will be published in the future, a capability was provided to revise the initial data base or to make additions. If, for example, it is necessary to change the autumn prices for feedstocks 16 and 34 in region 2, then it will be necessary to have the cards shown in Table 4-2 keypunched. It should be noted that for the season and region being updated, the record number must be calculated from the relationship:

Record Number = Season + 4 (Region - 1)

and entered in columns 5 through 7 of the first card.

SEASON + 4 (REGION - 1)

DATA CARD LAYOUT

JOB ______ DEPT. ______ DATE ______

```
FEED007
 16 WALNUT,BLACK(E)        3.5E4     1.76    8600
 34 CYPRUS(E)             1.72E6     1.92    8700
999


                                         HEATING VALUE (BTU/LB)
                              FEEDSTOCK COST ($/MMBTU)
                    FEEDSTOCK AMOUNT (MMBTU/YR)
     FEEDSTOCK NAME (16 CHARACTERS MAXIMUM)
    BLANK
FEEDSTOCK NUMBER (999 TERMINATES FEEDSTOCK DATA)
```

Table 4-2 Input Format for Updating Feedstock Data

Also, it should be noted that all of the information on the second and third cards must be included (even though some of the items may not change); otherwise, those fields will be deleted from the data file.

In addition to this method of adding or changing feedstock information, the user may generate a new initial data base by making appropriate changes to the input card deck. For a detailed description of this approach, see Appendix C (Program Description).

In entering published information into the data base, care must be taken to make certain that the data are not scattered to such an extent that the resulting allocations will be meaningless. Prior to changing any prices it is suggested that the published data be plotted and the resulting smoothed data entered into the system.

As there are only eight products and four regions, no program was provided for reading input cards. To revise the product data base it is necessary to alter data statements in the subroutine PRSTOR. The appropriate statements are shown in Figure 4-9 together with numbers corresponding to the tables described in Section 5.0.

4.3 RESULTS

A data storage and retrieval system has been developed for manipulating the data bases needed for operating the biomass allocation model. Appendix B contains the raw data.

The data base for the system is formed by means of the following two-step process:

a. The data file FEDAT, which is listed in card image form in Appendix B, Section 2.1, is entered into the system by executing the program DATGEN.

b. The data file ADDL, which is listed in card image form in Appendix B, Section 2.2, is entered into the system by executing the program BMCARDS.

These input decks are not particularly user-oriented; furthermore, the data files themselves are not particularly user-oriented. For this reason, two additional programs were written, as follows:

a. The program FDPRINT searches the appropriate data files (BMF 14 and BMF 15) for the feedstock availabilities, feedstock prices, product demands, and product prices, and prints out the results in a form suitable for the user. This information is shown in Appendix B, Section 3.1.

b. The program SDPRINT searches the appropriate data files (BMF 13 and BMF 18) for the manufacturing costs and conversion efficiencies and prints out the results in a form suitable for the user. This information is shown in Appendix B, Section 3.2.

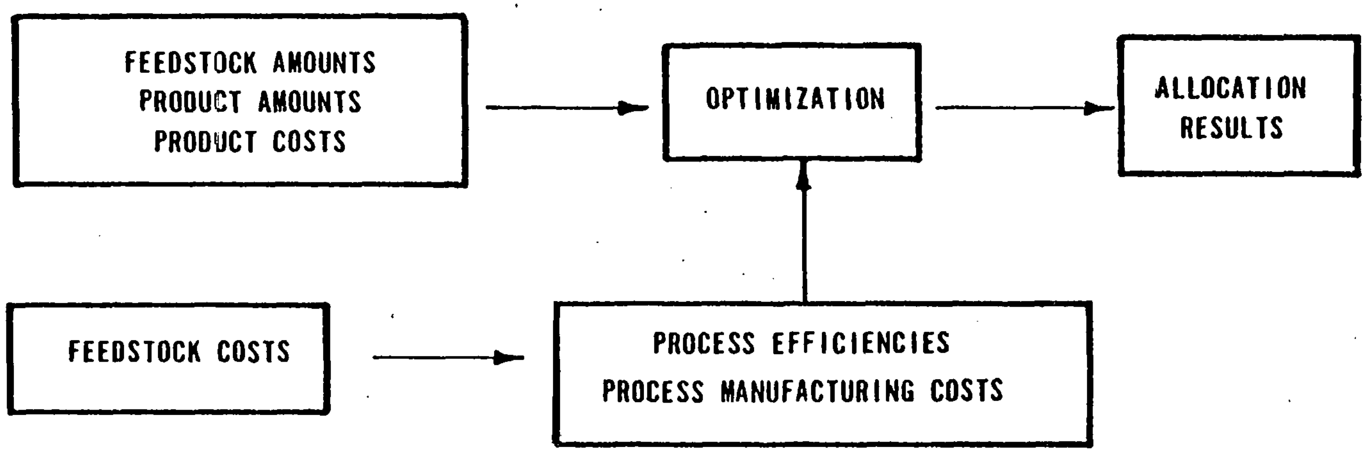


FIGURE 4-1
PRIMARY ROLE OF ALLOCATION SYSTEM DATA FILE

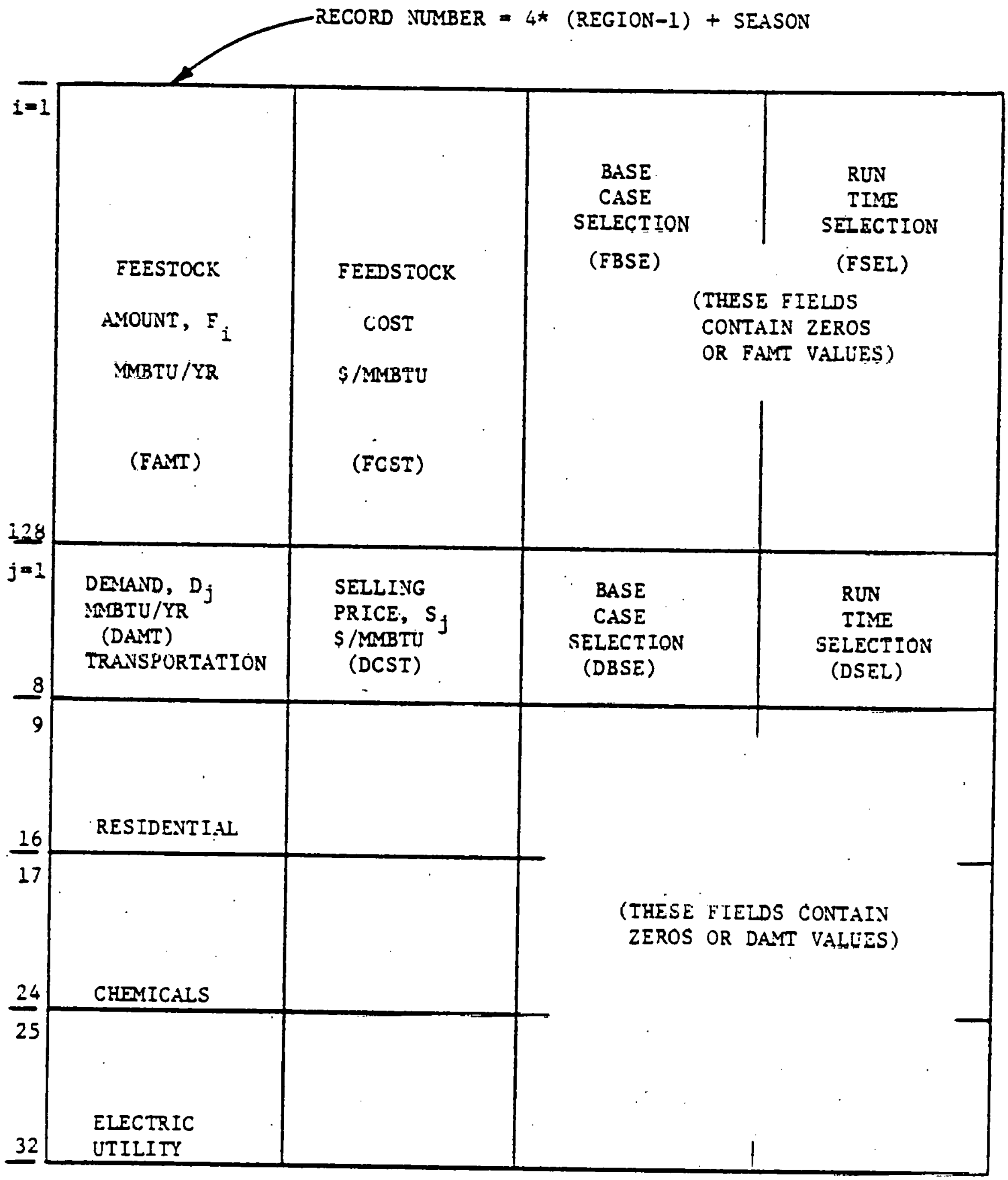


Figure 4-2 Feedstock File #5

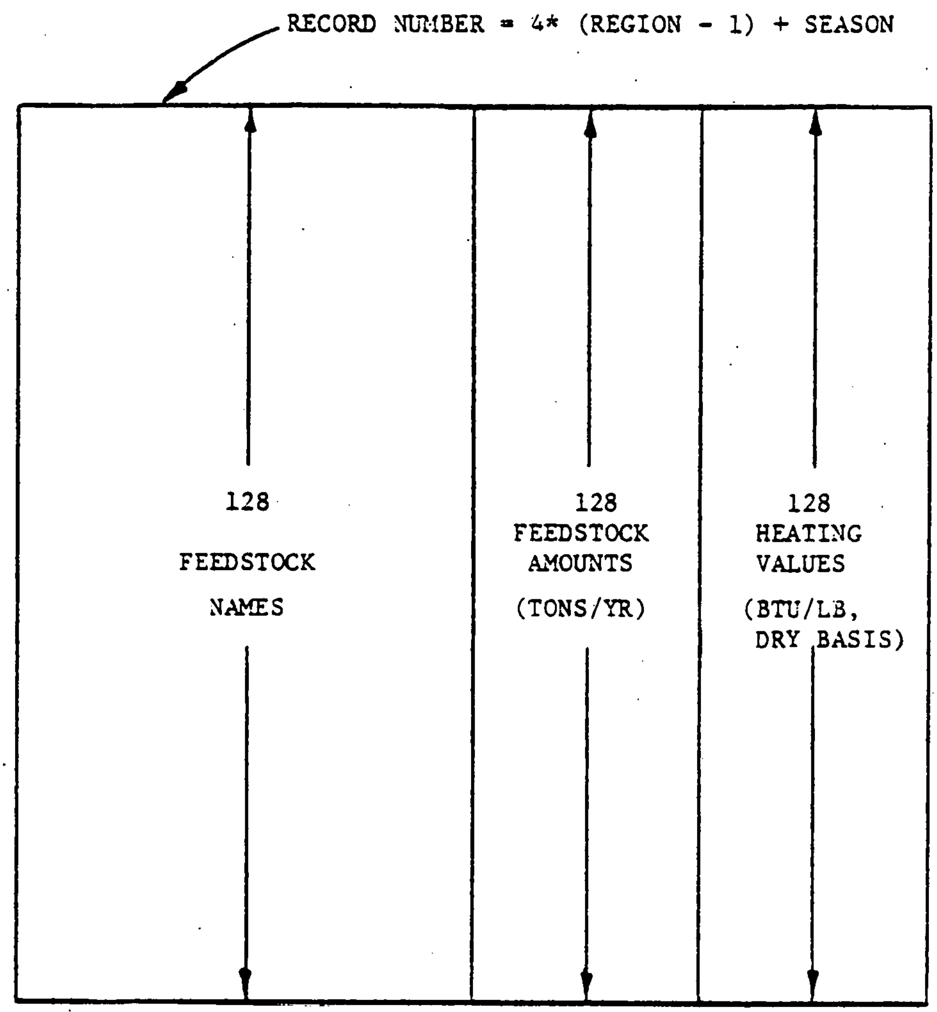


Figure 4-3 Feedstock File #14

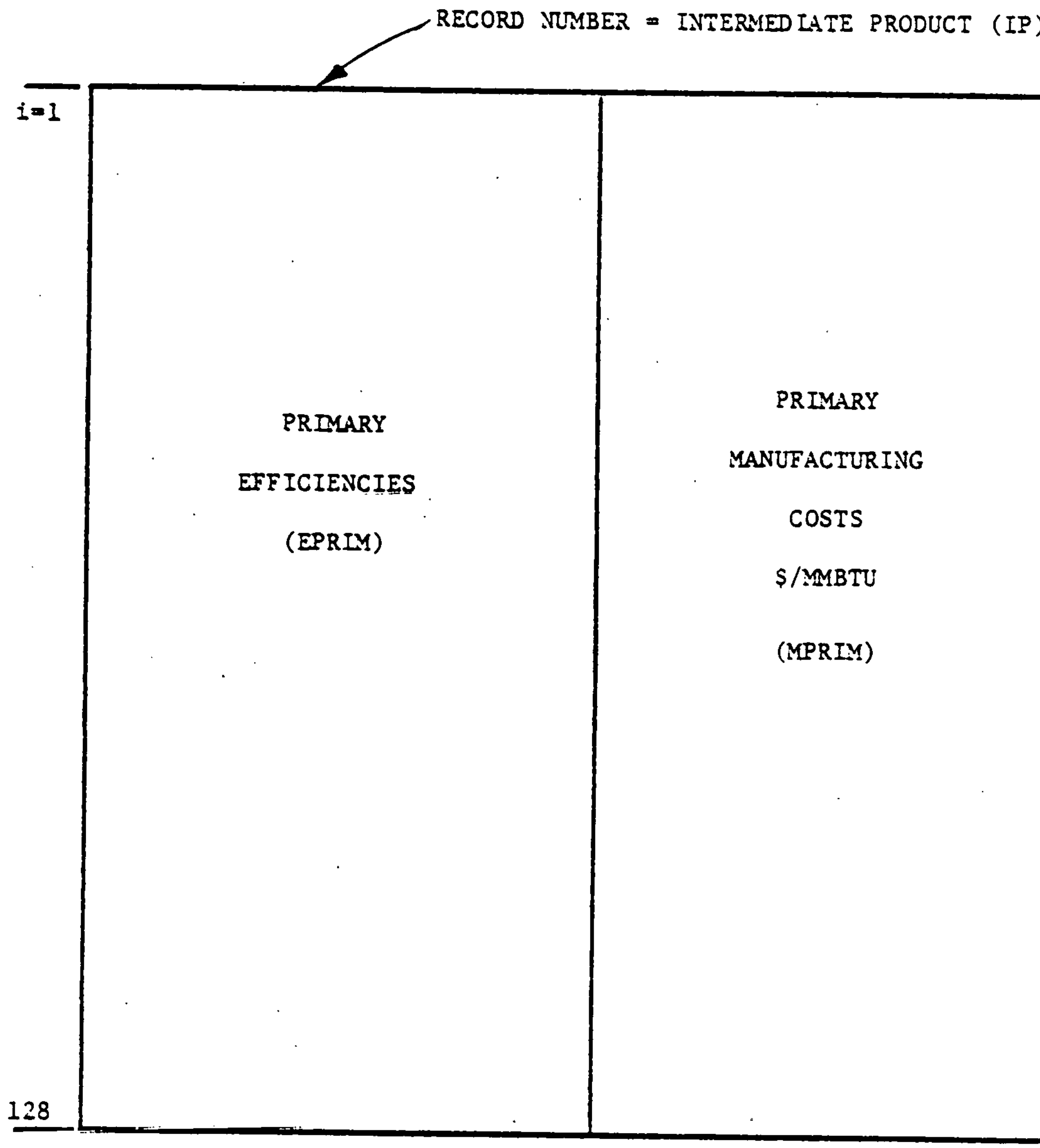


Figure 4-4 System File #13

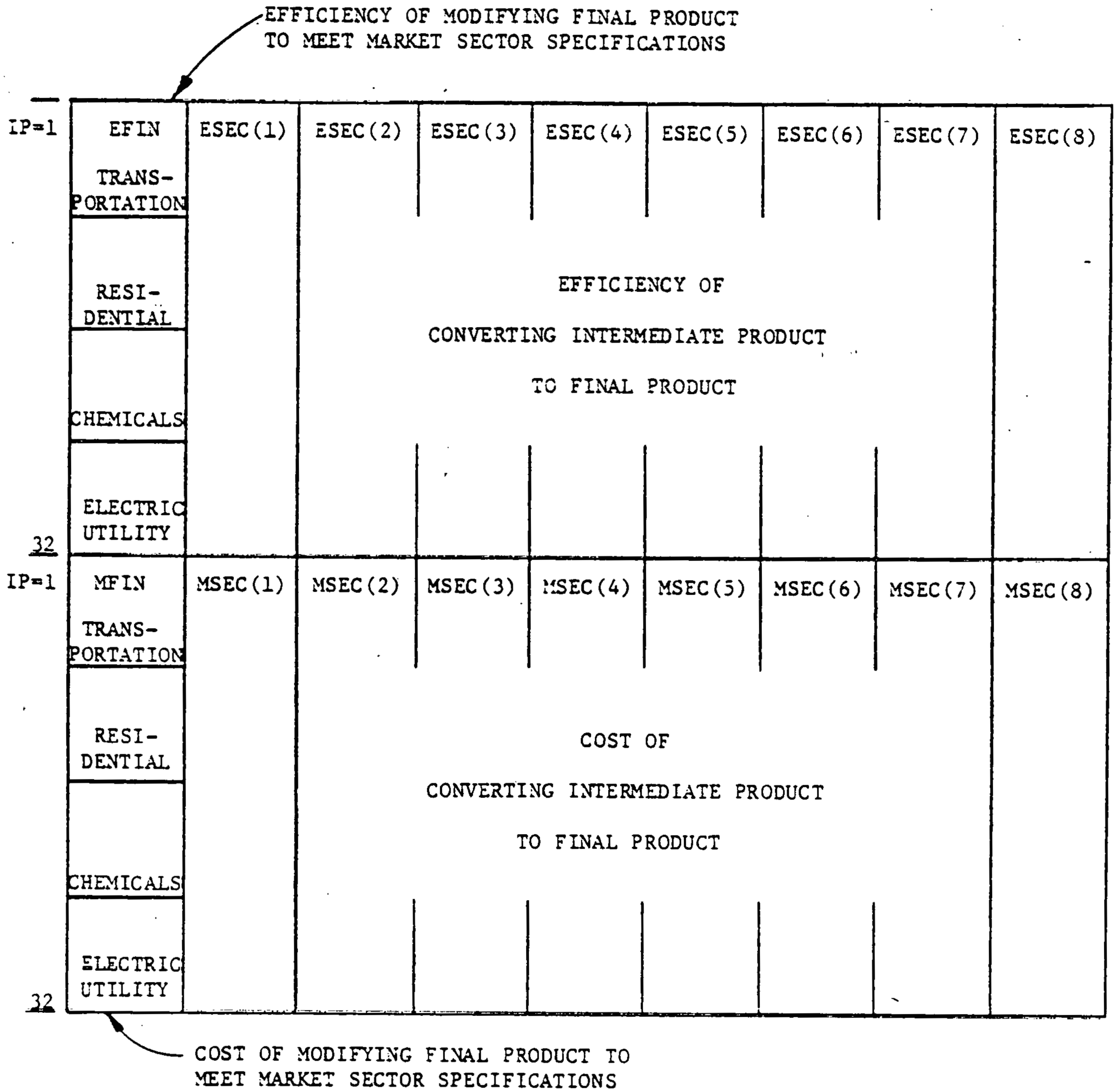


Figure 4-5 File #18 Record 1

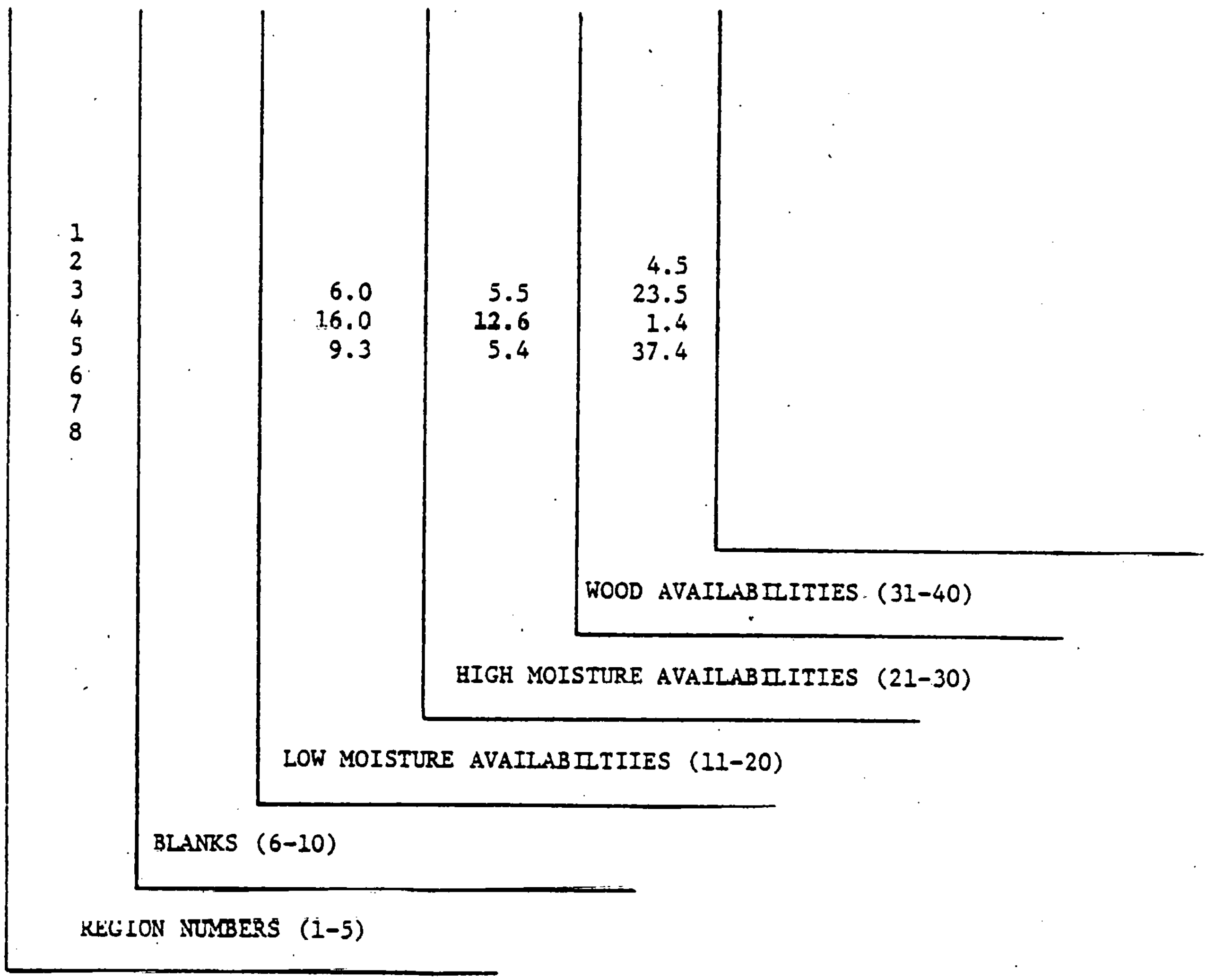


Figure 4-6 Input Format For Total Availabilities In Millions of Tons/Year

FEEDSTOCK NO. (1-5)	HEATING VALUE (6-10)	TYPE OF MATERIAL (11-15)	HANDLEABILITY (16-20)	PREPARABILITY (21-25)	SEASONAL AVAILABILITIES (%)			
					SPRING	SUMMER	AUTUMN	WINTER
REGION = 4								
1	8600	2	3	3	25	25	25	25
2	8600	2	3	3	25	25	25	25
3	8600	2	3	3	25	25	25	25
4	8600	2	3	3	25	25	25	25
5	8600	2	3	3	25	25	25	25
6	8600	2	3	3	25	25	25	25
7	7990	2	3	3	25	25	25	25
8	8600	2	3	3	25	25	25	25
9	8600	2	3	3	25	25	25	25
10	8600	2	3	3	25	25	25	25
11	8600	2	3	3	25	25	25	25
12	8600	2	3	3	25	25	25	25
13	8600	2	3	3	25	25	25	25
14	8150	2	3	3	25	25	25	25
15	8050	2	3	3	25	25	25	25
16	8600	2	3	3	25	25	25	25
17	8600	2	3	3	25	25	25	25
18	8050	2	3	3	25	25	25	25
19	8600	2	3	3	25	25	25	25
20	8170	2	3	3	25	25	25	25
21	8600	2	3	3	25	25	25	25
22	8600	1	3	3	25	25	25	25
23	8600	1	3	3	25	25	25	25
24	8600	1	3	3	25	25	25	25
25	8600	1	3	3	25	25	25	25
26	8800	1	3	3	25	25	25	25
27	8600	1	3	3	25	25	25	25
28	8600	1	3	3	25	25	25	25
29	8600	1	3	3	25	25	25	25
30	8600	1	3	3	25	25	25	25
31	8150	1	3	3	25	25	25	25
32	8600	1	3	3	25	25	25	25
33	8600	1	3	3	25	25	25	25
34	8600	1	3	3	25	25	25	25
35	8600	1	3	3	25	25	25	25
36	8600	1	3	3	25	25	25	25
37	8890	1	3	3	25	25	25	25
38	8410	1	3	3	25	25	25	25
39	8790	1	3	3	25	25	25	25
40	8600	1	3	3	25	25	25	25
41	8600	1	3	3	25	25	25	25
42	8210	1	3	3	25	25	25	25
43	8600	1	3	3	25	25	25	25
44	8600	1	3	3	25	25	25	25
45	7500	3	3	3		78	22	
46	7500	4	3	3		78	22	
47	7500	3	3	3		78	22	
48	7500	3	3	3		78	22	
49	7500	4	3	3		78	22	
50	7500	3	3	3		78	22	
51	7500	4	3	3		78	22	
52	7500	4	3	3		78	22	
53	6550	3	3	3		78	22	
54	7500	4	3	3		78	22	
55	7500	4	3	3		78	22	
56	7500	3	3	3		78	22	
57	8300	3	3	3		78	22	
58	7500	3	3	3		78	22	
59	8000	3	3	3		78	22	
60	7800	3	3	3		78	22	
61	7500	3	3	3		78	22	

62
63
64
65 } BLANK CARDS
.
.
.
128

Figure 4-7 Input Format For Seasonal Availabilities

Feedstock numbers (columns 4-5) and end codes (columns 1-5)	Blanks	Availabilities (in arbitrary units)	
1		2301.	WOOD RELATIVE AVAILABILITIES
2		2104.	
3		937.	
4		6311.	
5		2485.	
7		29.	
8		872.	
9		193.	
10		4630.	
11		3591.	
12		725.	
13		58.	
14		1893.	
15		150.	
16		21.	
17		92.	
18		2601.	
22		9425.	
23		25129.	
24		1743.	
25		188.	
28		19.	
30		169.	
34		1046.	
99999			
45		.99	LOW MOISTURE RELATIVE AVAILABILITIES
47		5.67	
48		.21	
50		.10	
53		.22	
56		.80	
57		.26	
58		.08	
59			
60			
61			
99998			
46		2.34	HIGH MOISTURE RELATIVE AVAILABILITIES
49		.31	
51			
52		.08	
54		.92	
55		.30	
99997			

AVAILABILITIES (IN ARBITRARY UNITS)

BLANKS

FEEDSTOCK NUMBERS (COLUMNS 4-5)
AND END CODES (COLUMNS 1-5)

Figure 4-8 Input Format For Relative Availabilities

```
      SUBROUTINE PRSTR(/IREC/)
      DIMENSION FEED(128,4),DMD(32,4),PRM(128,2),SF(32,26)
      DIMENSION GAIR(12),REGC(12,4),KFWD(60,FEFF(12)
      DIMENSION NREG(24),NSEC(8),NPROD(30),REGA(12,4),SECR(4)
      DATA REGA/
      11.9,1.9,.8,.98,1.8,.01,.14,1.4,0.,0.,0.,0.,
      2.29,.29,.25,.8,1.45,.04,.12,1.25,0.,0.,0.,0.,
      3.63,.64,.27,1.45,3.96,.06,.19,2.0,0.,0.,0.,0.,
      4.5,.5,.5,.84,2.5,.02,.15,1.45,0.,0.,0.,0./
      DATA NREG/
      1'NY/P','A/WV','    ',
      2'GA/A','L/MS','    ',
      3'IN/I','L/IA',    ',
      4'OR/W','A   ',    '/
      DATA NSEC/
      1'  TR', 'ANS/',
      2'    ', 'RES/',
      3'   C', 'HEM/',
      4'   E', 'LEC/'/
      DATA SECR/.25,.2,.05,.25/
      DATA NPROD/
      1'LOW ','BTU ','GAS ',
      2'MED ','BTU ','GAS ',
      3'FUEL', ' OIL',
      4'ELEC','TRIC','ITY',
      5'SNG ','    ','    ',
      6'AMMO','NIA', '    ',
      7'METH','ANOL','    ',
      8'GASO','LINE','    ',
      9'    ','    ','    ',
      A'    ','    ',    '/
      DATA FEFF/.7,1.0,1.0,1.0,.70,
      1.70,.70,.70,.90,.38,0.,0./
      DATA KFWD/
      10,0,13,0,0.0,10,8,0,0,0,0,
      20,0,14,18,2,0,0,0,0,0,0,0,
      34,6,15,19,0,1,11,0,0,0,0,0,
      45,7,16,20,3,0,12,0,0,0,0,0,
      50,0,0,0,0,0,0,0,0,0,0,0/
      DATA GAIR/
      12.31,2.57,3.25,13.46,2.57,6.44,7.76,4.09,0.,0.,0.,0./
      DATA REGC/
      11.,1.,1.,1.,1.,1.,1.,1.,1.,1.,0.,0.,
      2.76,.76,1.02,.92,.76,.78,.97,.98,0.,0.,0.,0.,
      3.88,.88,1.04,.98,.88,.90,.95,1.,0.,0.,0.,0.,
      4.93,.93,1.,.98,.93,.88,1.02,1.03,0.,0.,0.,0./
C***
C***   8.4.1
C***
       JREC=1
       DEFINE FILE 13(32,2560,L,JREC)
       DEFINE FILE 18(32,2560,L,JREC)
C***
C***   ASSUME COAL REFERENCE PRICE OF $1.96/MMBTU FOR 1985
C***
       COAL=1.96
C***
```

Figure 4-9 Product Data Statements

5.0
BIOMASS ALLOCATION
MODEL

5.0 BIOMASS ALLOCATION MODEL

5.1 OBJECTIVES

Any biomass production plan can not require that all available conversion processes be used continuously and simultaneously at maximum capacity. Many allocations of conversion processes will work, but some will be technically infeasible or prohibitively high in cost.

The production of a quantity of any product to meet a market demand is usually planned according to the performance characteristics (efficiencies) and manufacturing costs for the individual processes involved. Therefore, to a large extent, the objective of the project from an engineering point of view is to generate a data base of thermal conversion efficiencies and costs for use in developing feedstock allocations.

In addition to this engineering information, the data base must contain all of the feedstock supply and product demand information needed to formulate energy allocation problems for which the user needs recommended solutions.

The primary role of the computer is to generate the best energy allocation (on a maximum profit basis) for a given set of demands.

In general, the amount of energy to be supplied from biomass feedstocks will depend upon the extent to which the biomass conversion processes can compete with other energy conversion processes which are capable of producing the same products. This means that some provision should be made for factoring interfuel competition effects into the allocation system. Since it is beyond the scope of the current project to include the effects of interfuel competition, a demand from biomass feedstocks was assumed which corresponds to an estimated fraction of the total demand; this is shown by the ratio $\frac{rt}{t}$ in Figure 5-1. When the market analysis data is input to the current version of the system, it is assumed that the biomass share can be obtained by multiplying each input by "r", which will be estimated from the energy supply and demand data base and presented to the user as a suggestion to be accepted or altered for the purpose of conducting sensitivity analyses.

As an estimated demand must be regarded as the starting point for any feedstock allocation problem, it follows that the steps in a typical planning session are as follows:

a. Select a set of biomass feedstocks from the current data base.

b. Select a set of fuel demands to be satisfied by the converted feedstocks.

c. Allocate feedstocks to fuel demands on a maximum profit basis and print out the resulting allocation.

By adjustment back and forth between the current information base and the current allocation of economically and technically feasible processes, better long range plans can be generated.

The purpose of this project is to establish the first base of information for the various biomass conversion processes, and also to develop a means by which optimum allocations can be generated.

Linear programming is one of the most common techniques available for generating optimum allocation of resources to meet a given set of market demands. Since most linear programming problems require extensive numerical computation, the use of a digital computer is a necessity. As a result, the planning tool described in this report is primarily an optimization program which has access to a supply and demand data file and a file of conversion process efficiencies and manufacturing costs as shown in Figure 5-2. Upon execution of this optimization software, the result is an allocation of the type shown in Figure 5-3. In this figure the symbols are defined as follows:

F_i = amount of feedstock $_i$ available
$\eta_{i,j}$ = efficiency of converting feestock $_i$ to product $_j$
$f_{i,j}$ = feedstock $_i$ which is converted to product $_j$
D_j = energy demand for product $_j$ from biomass

A detailed description of the optimization programming procedure and the overall structure of the model is provided in Appendix C. A "User's Manual" is included in Appendix A.

5.2 METHODS

5.2.1 Economic Basis

For a given region and season a record exists within the data base which can contain up to 128 feedstocks and up to 12 products, each of which can be used to satisfy the demand in any of five market sectors.

In general, each set of demands for energy from biomass for a region can be satisfied in an infinite number of ways. An example of an allocation is shown in Figure 5-3.

In order to determine whether one allocation is better than another it is necessary to employ a measure of the relative merit of each feasible energy allocation. Since the profit earned is a generally accepted measure it was selected for use in this project.

For simplicity each process may be viewed as a single process with a single efficiency and a single manufacturing cost. Assuming that the process which converts feedstock 3 to product 4 has an efficiency of $\eta_{3,4}$ and an overall manufacturing cost of $M_{3,4}$ \$/MMBtu and that the fourth product sells for S_4 \$/MMBtu, it follows that the profit associated with energy stream $f_{3,4}$ can be expressed as:

$$P_{3,4} = (S_4 - M_{3,4})\ \eta_{3,4}\ f_{3,4}\ \$/Yr$$

The profit (or loss) associated with all other energy streams in the system can be expressed in a similar manner. As a result, the total net profit for the selected system of feedstocks and energy demands can be expressed as:

$$P = \sum_{j=1}^{j_{max}} \sum_{i=1}^{i_{max}} (S_j - M_{i,j})\ \eta_{i,j}\ f_{i,j} \qquad (1)$$

In order to proceed with a quantitative analysis of alternative distributions it is necessary to write an energy balance for each feedstock and each demand. For a given feedstock (for example, feedstock 2) it follows that energy can flow to more than one process (or sequence of processes) as follows:

$$F_2 = f_{2,1} + f_{2,2} + f_{2,3} + f_{2,4} \qquad (2)$$

Also, for a given demand (for example, for Product 3) it follows that:

$$D_3 = \eta_{1,3}\ f_{1,3} + \eta_{2,3}\ f_{2,3} + \ldots + \eta_{10,3}\ f_{10,3} \qquad (3)$$

Because equation 2 is an inequality, a slack variable (W_2), which corresponds to the amount of feedstock unused, must be added to the right hand side. When this is done for all of the feedstock equations, the result is a system of m equations in n variables.

Given such a system of m equations in n variables with n-m of those variables set to zero, it follows that a basic feasible solution can be found if the m variables occurring in the various energy balances are linearly independent and non-negative.

An algebraic procedure for finding an optimum solution to this economic problem would be as follows:

a. Compute all basic feasible solutions by setting all combinations of the n-m variables to zero and solving the resulting system of equations.

b. Compute the total net profit for each basic feasible solution found in Step 1.

For any linear programming problem, a set of values for the variables which satisfies all of the constraints is called a feasible solution, of which there are an infinite number. There are a finite number of basic feasible solutions. However, the possible number can be extremely large even for relatively small values of m and n. For example, for n = 30 and m = 10 there are more than 30 million basic feasible solutions. Clearly the above two-step procedure is impractical except for very small linear programming problems.

Fortunately, a method for finding the optimal solution of a linear programming problem which does not enumerate all basic solutions is available. This method, called the simplex method, has been used in this project.

Although an optimum profit is sought each time the biomass allocation program is executed, the actual numerical value of the profit is less important than the resulting allocation of energy flows. The profit is merely used as a means of evaluating one distribution against another. From a users point of view the computer satisfies the following requests:

a. For a given region and season, find the quantities of energy available in the form of the following feedstocks:
   (user inputs feedstock numbers)

b. For the same region and for the following products and market sectors, retrieve the appropriate energy demand and selling price information:
   (user inputs market sector and product numbers)

c. For the above feedstocks and demand, retrieve all efficiency and manufacturing cost data from the system data base:
   (user makes no entry)

d. System outputs a demand based on the supply available.
   (user adjusts demand estimate if necessary)

e. Solve the resulting allocation problem.
   (user makes no entry)

f. Print out the resulting allocation. At this point the program prints out the results as shown in Figure 5-4.

5.2.2 Linear Programming

Several commercial program packages are available for solving linear programming problems. Also some published programs are available. The use of one such program (developed by the Lawrence Livermore Laboratory) was investigated. This program was originally written in LRLTRAN (a FORTRAN-like language) and was translated into FORTRAN IV for use on the Gilbert Associates Computer System. At the same time a biomass problem-oriented matrix generator program was designed, implemented and checked out using an LP program written from scratch. At this point it was determined that, in order to change the size of the LP problem at run time, the LRLTRAN package would require more conversion work than was first thought. Also, it was found that the matrix generator (which was of necessity, problem-dependent) represented such a large fraction of the total programming effort that it was easier to continue to develop the in-house simplex program. This program is outlined in the following section. Some programming information is included, but most of the programming details are explained in Appendix C.

In general, the system of i_{max} plus j_{max} equations given by

$$\sum_{j=1}^{j_{max}} f_{i,j} \leq F_i \qquad (4)$$

and:

$$\sum_{i=1}^{i_{max}} \eta_{i,j} f_{i,j} = D_j \qquad (5)$$

has an infinity of solutions. Each solution depends upon the specific set of feedstocks selected (F_i) for satisfying the demands (D_j), and the way in which those feedstocks are allocated. The objective of developing a solution is to determine the $f_{i,j}$ such that the total profit is as large as possible

The total profit (P) being given by the equation (1)

$$P = \sum_{j=1}^{j_{max}} \sum_{i=1}^{i_{max}} (S_j - M_{i,j}) \eta_{i,j} f_{i,j} \qquad (3)$$

Problems which can be formulated in this manner are called linear programming problems. They have the following three main components:

a. A linear objective function such as equation (1),

b. A linear constraint set such as equations (4) and (5), and

c. A set of nonnegativity restrictions on the variables.

Since all theory relating to linear systems deals with linear equations rather than inequalities, it is desirable to convert the inequalities represented by (2) into equations. That is, to write:

$$f_{1,1} + f_{1,2} + f_{1,3} + \cdots + W_1 = F_1$$

$$f_{2,1} + f_{2,2} + f_{2,3} + \cdots + W_2 = F_2 \text{ etc.} \qquad (4)$$

Each variable W_i may be interpreted as the amount of feedstock i not needed to satisfy the fixed total demand. These variables are called slack variables.

In order to generate an optimum solution it is convenient to start with $W_1 = F_1$, $W_2 = F_2$ etc., and with all of the $f_{i,j}$ equal to zero. Such a solution is called a basic feasible solution.

Although this basic feasible solution satisfies (2) it will not satisfy (3). In order to overcome this difficulty it is necessary to add a variable to each demand equation as follows:

$$\eta_{1,1}f_{1,1} + \eta_{2,1}F_{2,1} + \eta_{3,1}f_{3,1} + \cdots + U_1 = D_1$$

$$\eta_{1,2}f_{1,2} + \eta_{2,2}f_{2,2} + \eta_{3,2}f_{3,2} + \cdots + U_2 = D_2$$

These variables are artificial variables, not slack variables. They do not correspond to any physical quantity, and, therefore, they can not be part of the final solution.

For the purpose of solving the biomass problem they may be regarded as additional high cost energy streams which are associated with each demand made in order that the fixed demand at that mode can be met at the same time that all of the $f_{i,j}$ are assumed to be zero.

In order to generate an optimum solution, it is first necessary to increase some of the $f_{i,j}$ streams (and at the same time reduce some of the W_i) such that these high cost dummy inputs are no longer required; that is, until all of the U's are zero. The next step is to continue reducing the W_i and to continue increasing the $f_{i,j}$ until a feedstock allocation is arrived at which corresponds to maximum total net profit.

During the first step of this two step process some incentive must be used to eliminate the U's. This is done by assigning a high negative profit to each value of U. That is to maximize:

$$P = \sum_{j=1}^{j_{max}} \sum_{i=1}^{i_{max}} ([S_j - M_{i,j}]) \eta_{i,j} f_{i,j} - CU_j)$$

In this modified problem, C represents a very large positive number.

5.2.3 The Simplex Method

In the above outline it was indicated that the W_i must be reduced and the $f_{i,j}$ increased by means of a systematic approach. The systematic approach usually employed is known as the simplex method. Essentially, the simplex method is an algorithm which generates a sequence of basic feasible solutions in such a way that each new solution generated has a value of the objective function P which is at least as large as the value of P for the most recently computed solution. When a basic feasible solution and a corresponding value of P have been computed, the simplex method automatically excludes from consideration all basic feasible solutions with smaller values of P. In addition, the simplex method is able to determine when it has computed an optimal feasible solution so that it is not necessary to attempt to find better solutions when none, in fact, exists.

In order to start the simplex procedure it is first necessary to arrange the input information in tabular form. The format employed is shown in Figure 5-5 for the following 3 x 3 problem:

$$f_{1,1} + f_{1,2} + f_{1,3} + W_1 = F_1$$

$$f_{1,2} + f_{2,2} + f_{2,3} + W_2 = F_2$$

$$f_{3,1} + f_{3,2} + f_{3,3} + W_3 = F_3$$

$$\eta_{1,1}\ f_{1,1} + \eta_{2,1}\ f_{2,1} + \eta_{3,1}\ f_{3,1} + U_1 = D_1$$

$$\eta_{1,2}\ f_{1,2} + \eta_{2,2}\ f_{2,2} + \eta_{3,2}\ f_{3,2} + U_2 = D_2$$

$$\eta_{1,3}\ f_{1,3} + \eta_{2,3}\ F_{2,3} + \eta_{3,3}\ F_{3,3} + U_3 = D_3$$

Where $P = (S_1-M_{2,1})\ \eta_{1,1}f_{1,1}$

$$+ (S_1-M_{2,1})\ \eta_{2,1}f_{2,1}$$

$$+ (s_1-M_{3,1})\ \eta_{3,1}f_{3,1}$$

$$+ (S_2-M_{1,2})\ \eta_{1,2}f_{1,2}$$

$$+ (S_2-M_{2,2})\ \eta_{2,2}f_{2,2} \qquad (2)$$

$$+ (S_2-M_{3,2})\ \eta_{3,2}f_{3,2}$$

$$+ (S_3-M_{1,3})\ \eta_{1,3}f_{1,3}$$

$$+ (S_3-M_{2,3})\ \eta_{2,3}f_{2,3}$$

$$+ (S_3-M_{3,3})\ \eta_{3,3}f_{3,3}$$

Given this initial tabeau the simplex procedure as programmed is as follows:

Step 1. Form an objective column. This column consists of the negative net worth of the variables W_1 through W_3 and U through U_3. (Note: a negative net worth of unity is assumed for U_1 through U_3. This is a temporary assumption. Actually, all negative net worths associated with the U variables are summed in the EMC row. Therefore, the negative net worth, or penalty, due to each such sum can assume any desired magnitude relative to the summed negative net worths in the index row)

Step 2. Find the index number at the base of each column by multiplying the feedstock numbers in the body of that column by the corresponding numbers in the objective column. Add these products together. Then subtract the number in the objective row (for that column) from this total. This step is repeated for all columns (JJ = 1 through 15) and for rows II = 1 through 3.

Step 3. For rows II = 4 through 6 and columns corresponding to JJ = 1 through 12, multiply the demand numbers in the body of the column by the corresponding numbers in the objective column (in fact ones). Add these products together and store the result in the EMC row.

The above steps are only necessary in the initial formulation of the problem and need not be repeated once the index row has been found for the first time. When the first tableau has been properly set-up, all succeeding tableaus are obtained by repeating the following series of steps:

a. Select the smallest positive number in the index row and save it as TMIN

b. Select the smallest positive number in the EMC row and save it as EMCMIN

c. If EMCMIN is greater than zero, use the JJ value corresponding to EMCMIN as the key column. If no positive EMC elements are found, it indicates that Phase 1 has ended. At the end of Phase 1 all subsequent searches for the key column are made without regard for the contents of the EMC row. In the event that these two EMC elements are found to have the same value, then the key column is selected by summing the contents of the index and EMC rows for each value of JJ, and by selecting that value of JJ corresponding to the greatest sum.

NOTE: Steps a through c are used to determine the key column.

d. Divide positive numbers in the key column into corresponding numbers in the constant column.

e. Select the least positive ratio of these quotients. Note that this value of II is the key row, and that the element corresponding to the intersection of the key column and the key row is the key number.

f. Divide the key number into every number in the key row.

g. All other numbers for the next tableau are derived as follows:

$$\text{Derived Number} = \text{Selected Number} - \frac{\text{Corresponding Number in Key Row} \times \text{Corresponding Number in Key Column}}{\text{Key Number}}$$

h. Repeat steps "a" through "g" until no positive numbers exist in the index row (excluding the constant column). At this point an optimum solution has been obtained.

Each time a number is found, the value of JJ corresponding to that key column is stored in the vector ANS. This vector is then used in order to determine which of the variables have emerged as the solution to the problem.

5.2.4 Data Base

The primary objective of supplying the optimization program with feedstock and system information is to provide input data for the linear programming problem. Consequently, that information was organized in a way which was suitable for the problem selection, matrix set-up, and linear programming sections of the system. That organization is summarized in Table 3-1.

From Table 3-1 and the following equations:

$$P = \sum_{j=1}^{j_{max}} \sum_{i=1}^{i_{max}} (S_j - M_{i,j})\, \eta_{i,j} f_{i,j}$$

$$\sum_{j=1}^{j_{max}} f_{i,j} \leq F_i$$

$$\sum_{i=1}^{i_{max}} \eta_{i,j} f_{i,j} = D_j$$

where, $\eta_{i,j} = f_1$ (EPRIM, ESEC, EFIN)

$M_{i,j} = f_2$ (MPRIN, MSEC, MFIN)

and where f_1 and f_2 are functions described previously, it follows that all of the data needed to calculate the optimum allocation of feedstock Btu's to product Btu's (that is to calculate the $f_{i,j}$) are available.

5.2.5 Problem Selection

Each run involves the following three phases:

- A problem selection phase,
- An optimization phase, and
- A report generation phase.

A selection phase is necessary for several reasons. In the first place, if an LP problem were formulated on the basis of 100 feedstocks and 32 products, an unreasonably large initial tableau would be required. Reference to Appendix C shows that for

IMAX = 100 and JMAX = 32

NN2 = (IMAX + JMAX + 1) + IMAX + JMAX + 1 = 3334

NN4 = IMAX + JMAX + 1 = 133

This means that a tableau containing 133 x 3334 = 443,422 elements would be required. Clearly some reduction in problem size is desirable.

A selection procedure is also needed because of the fact that for purely technical reasons some manufacturing paths will be feasible and some not feasible. In addition, more than one conversion path may exist for a given feedstock and product. In order to deal with this situation programming logic has been included to select an overall conversion path of the type shown in Figure 5-6.

At the present time this selection logic is as follows:

a. Select the first intermediate product.

b. Calculate the product (EFF1) of efficiencies for the selected path.

c. Calculate the sum (MAN1) of the manufacturing costs for the selected path, but abandon any path for which any manufacturing cost is zero.

d. Calculate the ratio EFF1/MAN1

e. Repeat the above steps for each intermediate product and select the intermediate product with the highest ratio.

f. The conversion path is also abandoned in the event that no feedstock data, or product data exists or if any efficiency for the path is zero.

In order to complete the selection process, the surviving values of F_i, D_i, S_i, $\eta_{i,j}$, and $M_{i,j}$ are organized into vectors and matrices of the type required by the linear programming subroutine.

5.3 RESULTS

The objectives and methods associated with the Biomass Allocation Model have been described in previous sections and in the appendices to this report. The purpose of this section is to discuss some of the results which were obtained for a specific data base of costs and availabilities. The objective is not to draw specific conclusions from the numerical results obtained, but rather to show how the system might be used to extract useful planning information.

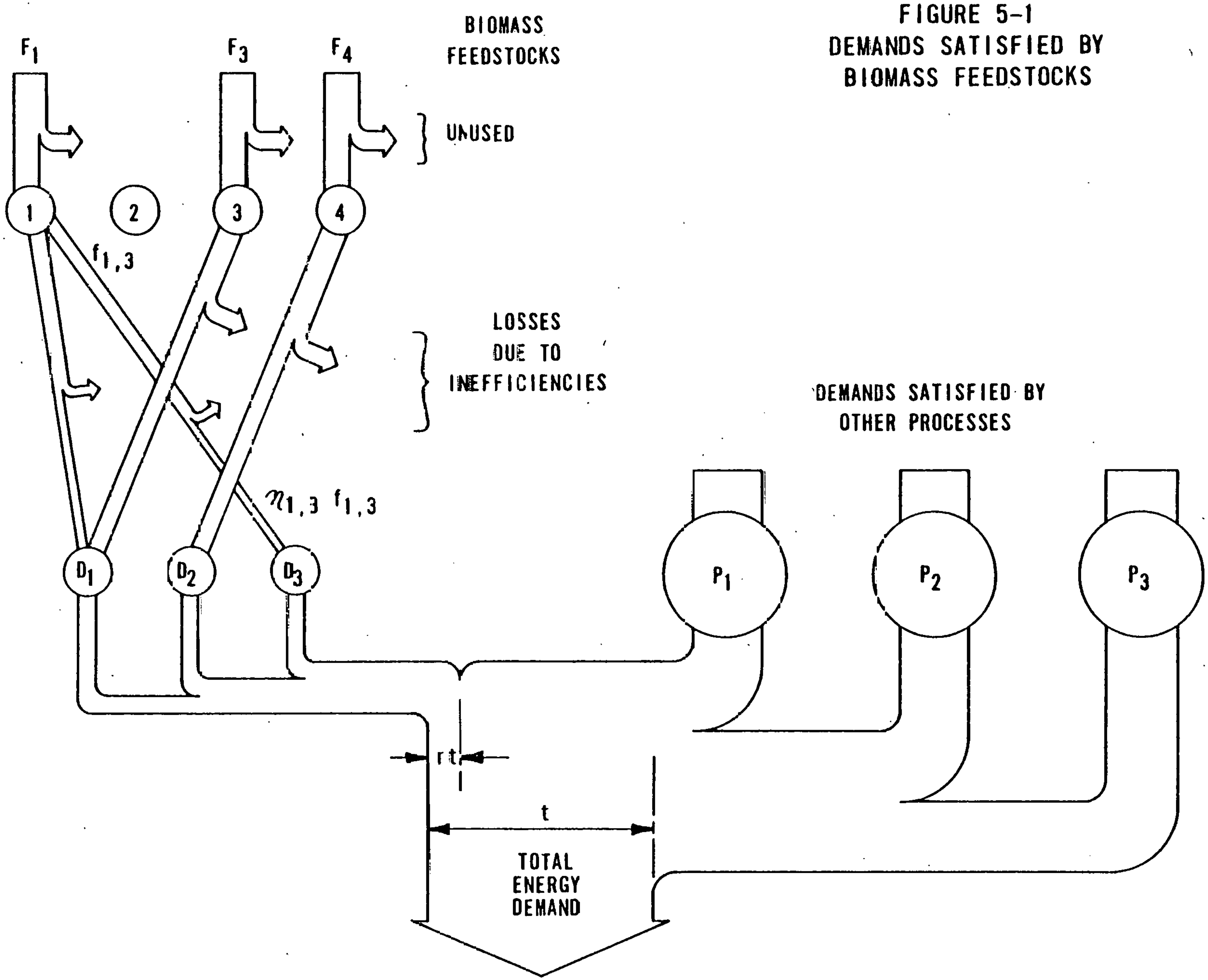
A terminal session shown in Figure 5-7 was used to generate the session shown in Figures 5-8 and 5-9. In most cases a user will wish to investigate several demands before drawing any conclusion about the desirability of the various feedstock-to-product conversion paths. For example, Figure 5-9 shows the allocation generated as a result of assuming a low demand.

Note that all of the white oak, hemlock, and softwood feedstocks have been allocated, but only a small amount of hard maple was allocated. This shows a preference for white oaks, hemlock, and softwood, given that all specified demands must be satisfied.

Useful information is also obtained by specifying a demand which is greater than the supply. This is the situation in Figure 5-10 where it should be noted that the allocation program has given preference to residential fuel oil, residential SNG, and electric power generation.

Note also that additional information can be derived from a run where a high demand is specified such as that shown in Figure 5-11. In this case, although the high demand of 49 trillion Btu per year cannot be satisfied, the system maximizes the profit by converting all feedstocks to electricity. A "User's Manual" for this allocation system is included in Appendix A.

FIGURE 5-1
DEMANDS SATISFIED BY BIOMASS FEEDSTOCKS



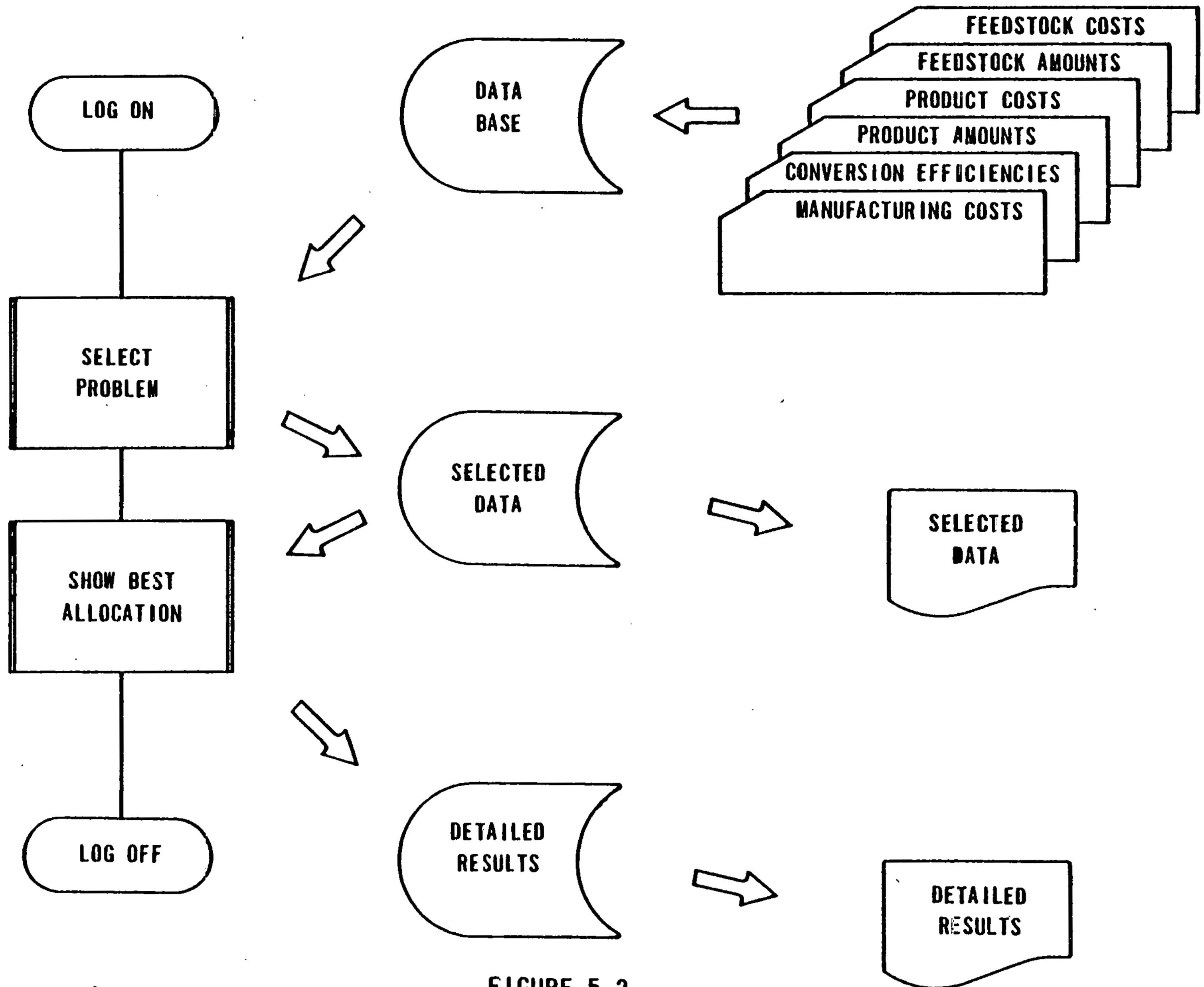


FIGURE 5-2
BIOMASS FEEDSTOCK ALLOCATION SYSTEM

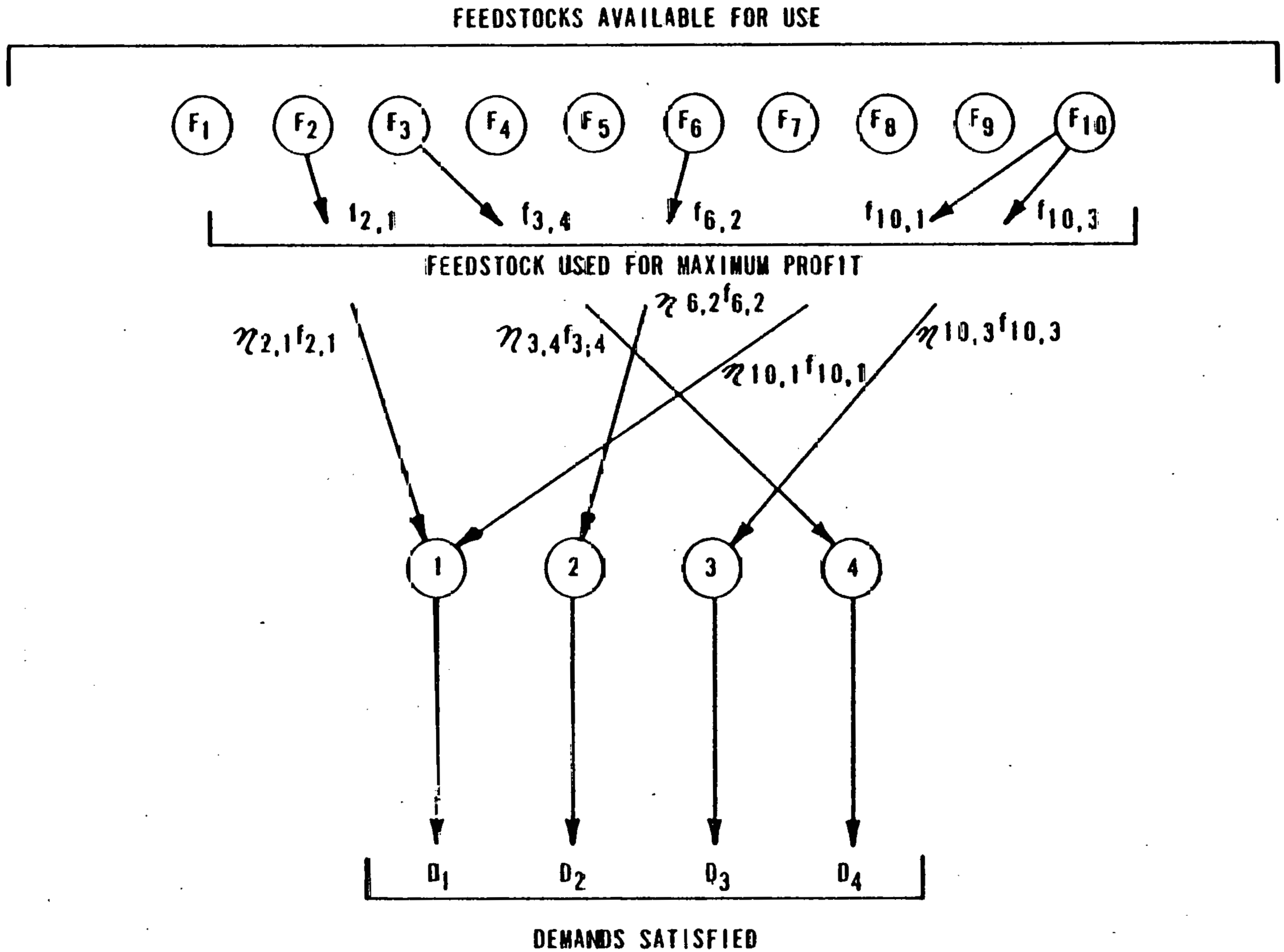


FIGURE 5-3
A TYPICAL ALLOCATION

SOLUTION FOUND

FEEDSTOCK NUMBER	FEEDSTOCK AVAILABLE (MMBtu/YR)	FEEDSTOCK USED (MMBtu/YR)	PRODUCT NUMBER	INTERMEDIATE[1] PROCESS	PRODUCT DEMAND (MMBtu/YR)	SELLING PRICE ($/MMBtu)
1	0.1361E+07	0.1361E+07	17	1	0.2425E+07	0.7056E+01
7	0.1641E+07	0.1641E+07	17	1	0.2425E+07	0.7056E+01
28	0.8820E+06	0.3735E+06	15	3	0.1078E+07	0.6664E+01
30	0.7588E+05	0.7588E+05	15	3	0.1078E+07	0.6664E+01
28	0.8820E+06	0.5084E+06	17	1	0.2425E+07	0.7056E+01

REGION=NY/PA/WV
SEASON=SUMMER
NUMBER OF ITERATIONS=10
TABLEAU SIZE=1200 BYTES
PROFIT FOR ITERATION 9 = 0.49704E+07
PROFIT FOR ITERATION 10 = 0.50155E+07

FEEDSTOCK NUMBER/NAME	PRODUCT NUMBER/SECTOR/PRODUCT		EFFICIENCY	MANUFACTURING COST	PROFIT
1.OAKS,WHITE(S,E)2	17.	RES/SNG	0.696E+00	0.528E+01	0.169E+07
7.MAPLE,HARD(E)	17.	RES/SNG	0.696E+00	0.540E+01	0.189E+07
28.HEMLOCK(E)	15.	RES/FUEL OIL	0.610E+00	0.378E+01	0.658E+06
30.SOFTWOOD(O,E)	15.	RES/FUEL OIL	0.610E+00	0.378E+01	0.134E+06
28.HEMLOCK(E)	17.	RES/SNG	0.660E+00	0.512E+01	0.650E+06

DATA BASE INCOMPLETE FOR THE FOLLOWING PAIRS OF FEEDSTOCKS AND PRODUCTS:

FEEDSTOCK NUMBER/NAME	PRODUCT NUMBER/SECTOR/PRODUCT	DATA MISSING
10.SWEETGUM(E)	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
50.BARLEY	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
58.RYE	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT

1. In some cases intermediate and secondary conversion data are used. In other cases the intermediate process is also the overall process. The following intermediate product information has been entered into the system as a function of feedstock number:
   1. Medium Btu Gas
   2. Low Btu Gas
   3. Fuel Oil
   4. Electricity

2. Feedstock names have been limited to 16 characters. The single letter in parentheses denote the following:
   - S - Select
   - O - Other
   - E - Eastern
   - W - Western

Figure 5-4 Print Out of Typical Biomass Allocation Sollution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	JJ	
		$f_{1,1}$	$f_{1,2}$	$f_{1,3}$	$f_{2,1}$	$f_{2,2}$	$f_{2,3}$	$f_{3,1}$	$f_{3,2}$	$f_{3,3}$	W_1	W_2	W_3	U_1	U_2	U_3	VARIABLE ROW	
II	CONSTANT COLUMN	$(M_{1,1} - S_1)\eta_{1,1}$	$(M_{2,1} - S_1)\eta_{2,1}$	$(M_{3,1} - S_1)\eta_{3,1}$	$(M_{1,2} - S_2)\eta_{1,2}$	$(M_{2,2} - S_2)\eta_{2,2}$	$(M_{3,2} - S_2)\eta_{3,2}$	$(M_{1,3} - S_3)\eta_{1,3}$	$(M_{2,3} - S_3)\eta_{2,3}$	$(M_{3,3} - S_3)\eta_{3,3}$	0	0	0	1	1	1	OBJECTIVE ROW	OBJECTIVE COLUMN
1	F_1	1	1	1													FEEDSTOCK EQUATIONS	0
2	F_2				1	1	1											0
3	F_3							1	1	1								0
4	D_1	$\eta_{1,1}$			$\eta_{2,1}$			$\eta_{3,1}$									DEMAND EQUATIONS	1
5	D_2		$\eta_{1,2}$			$\eta_{,2}$			$\eta_{3,2}$									1
6	D_3			η			$\eta_{2,3}$			$\eta_{3,3}$								1
7																	INDEX ROW	
																	EMC ROW	

Figure 5-5 Example of An Initial Tableau For A 3/3 Problem

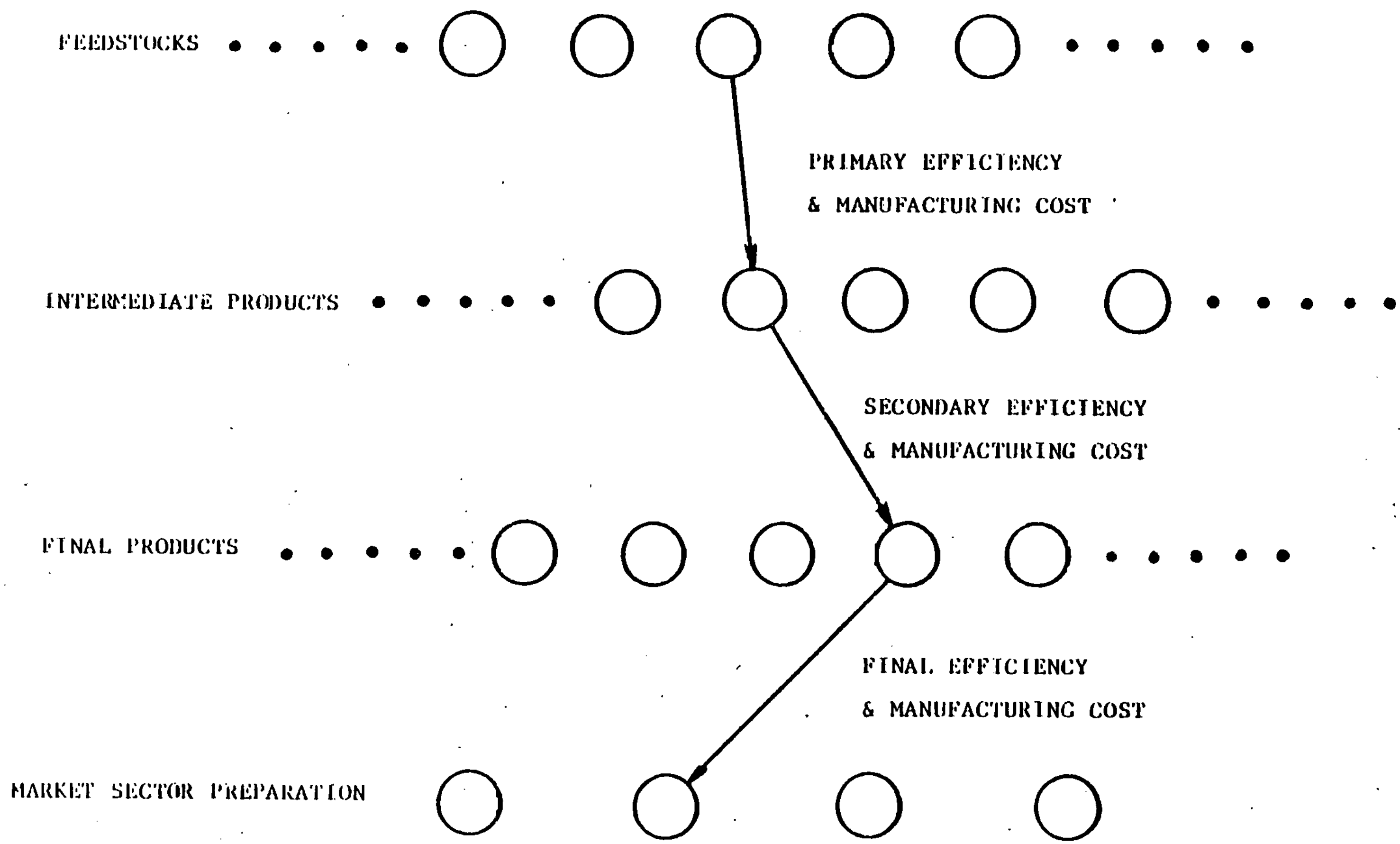


Figure 5-6 Problem Selection

```
ex biomass

SPECIFY REGION AND SEASON, THEN
SELECT FEEDSTOCKS, MARKET SECTORS AND PRODUCTS
   - TO USE BASE CASE SELECTIONS ENTER "S"
   - TO TERMINATE SELECTION PROCESS ENTER "T"
   - TO RE-START SELECTION PROCESS ENTER "A"

B. SELECT REGION ?

   1. NY/PA/WV
   2. GA/AL/MS
   3. IN/IL/IA
   4. OR/WA
=
1

C. SELECTION SEASON

   1. SPRING
   2. SUMMER
   3. AUTUMN
   4. WINTER
=
2

K. SELECT FEEDSTOCKS
=
1,7,10,28,30,49,50,58

H. SELECT MARKET SECTOR

   1. TRANSPORTATION
   2. RESIDENTIAL
   3. CHEMICALS
   4. ELECTRIC UTILITY

SELECT PRODUCT

   1. LOW BTU GAS
   2. MEDIUM BTU GAS
   3. FUEL OIL
   4. ELECTRICITY
   5. SNG
   6. AMMONIA
   7. METHANOL
   8. GASOLINE

ENTER "SECTOR", "PRODUCT"
=
2,5
=
2,3
=
1,8
=
4,4
=
t
```

Figure 5-7 A Typical Biomass Allocation Problem In The Format Which Is Used To Present It To The Computer

```
DEMAND SATISFIED BY BIOMASS = 0.53 PERCENT OF TOTAL DEMAND
IS THIS O.K.?(Y/N)
=
n
NEW PCT
=
.1
SOLUTION FOUND
```

FEEDSTOCK NUMBER	FEEDSTOCK AVAILABLE (MMBTU/YR)	FEEDSTOCK USED (MMBTU/YR)	PRODUCT NUMBER	INTERMEDIATE PROCESS	PRODUCT DEMAND (MMBTU/YR)	SELLING PRICE ($/MMBTU)
1	0.1361E+07	0.5172E+06	17	1	0.3600E+06	0.5037E+01
28	0.8820E+06	0.7144E+06	40	4	0.2450E+06	0.2638E+02
30	0.7588E+05	0.7588E+05	40	4	0.2450E+06	0.2638E+02
7	0.1641E+07	0.6598E+05	8	1	0.3500E+06	0.8016E+01
1	0.1361E+07	0.7534E+06	8	1	0.3500E+06	0.8016E+01
28	0.8820E+06	0.1675E+06	15	3	0.1600E+06	0.6370E+01
1	0.1361E+07	0.8991E+05	15	3	0.1600E+06	0.6370E+01

```
REGION=NY/PA/WV
SEASON=SUMMER
NUMBER OF ITERATIONS=23
TABLEAU SIZE=1200 BYTES
PROFIT FOR ITERATION 23=0.44219E+07
PROFIT FOR ITERATION 22=0.44219E+07
```

FEEDSTOCK NUMBER/NAME	PRODUCT NUMBER/SECTOR/PRODUCT	EFFICIENCY	MANUFACTURING COST	PROFIT
1. OAKS, WHITE(S,E)	17. RES/SNG	0.696E+00	0.528E+01	-0.856E+05
28. HEMLOCK(E)	40. ELEC/ELECTRICITY	0.310E+00	0.980E+01	0.367E+07
30. SOFTWOOD(0,E)	40. ELEC/ELECTRICITY	0.310E+00	0.980E+01	0.390E+06
7. MAPLE,HARD(E)	8. TRANS/GASOLINE	0.427E+00	0.801E+01	0.124E+03
1. OAKS, WHITE(S,E)	8. TRANS/GASOLINE	0.427E+00	0.788E+01	0.429E+05
28. HEMLOCK(E)	15. RES/FUEL OIL	0.610E+00	0.378E+01	0.265E+06
1. OAKS, WHITE(S,E)	15. RES/FUEL OIL	0.643E+00	0.401E+01	0.137E+06

DATA BASE INCOMPLETE FOR THE FOLLOWING PAIRS OF FEEDSTOCKS AND PRODUCTS: -

FEEDSTOCK NUMBER/NAME	PRODUCT NUMBER/SECTOR/PRODUCT	DATA MISSING
10. SWEETGUM(E)	ALL PRODUCTS (ABOVE)	FEEDSTOCK AMOUNT
50. BARLEY	ALL PRODUCTS (ABOVE)	FEEDSTOCK AMOUNT
58. RYE	ALL PRODUCTS (ABOVE)	FEEDSTOCK AMOUNT

Figure 5-8 Solution To The Biomass Allocation Problem Shown in Figure 5-6.

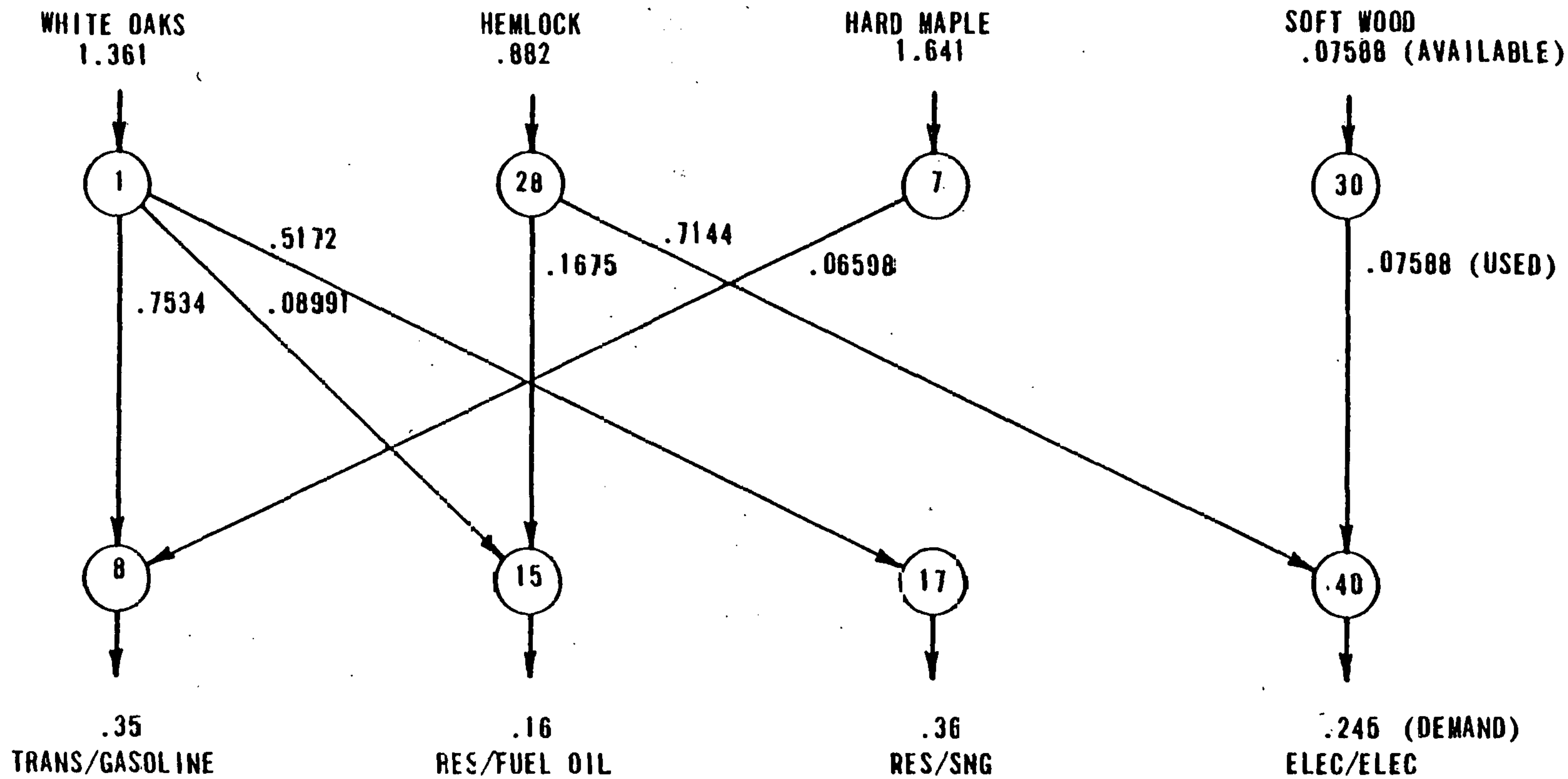


FIGURE 5-9
ALLOCATION ASSUMING A LOW DEMAND

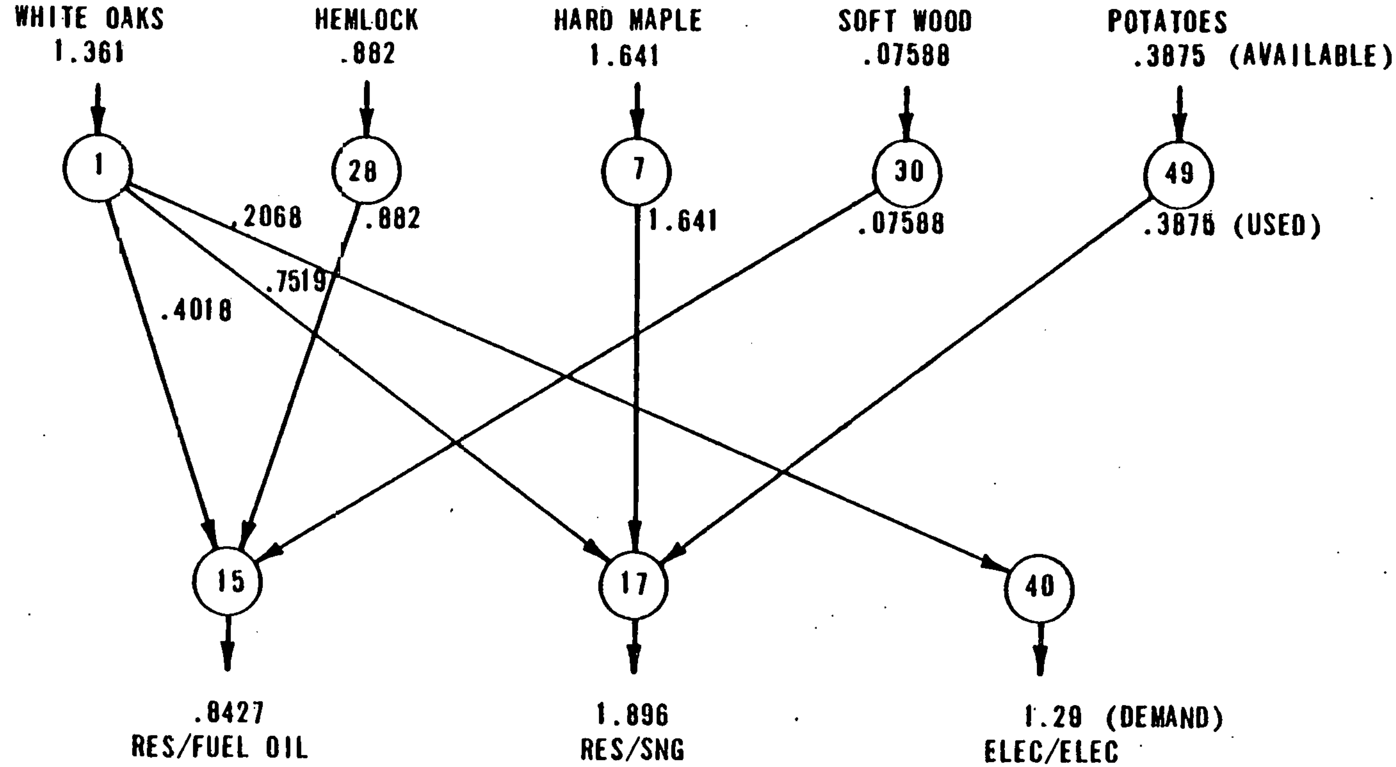


FIGURE 5-10
ALLOCATION ASSUMING A MEDIUM DEMAND

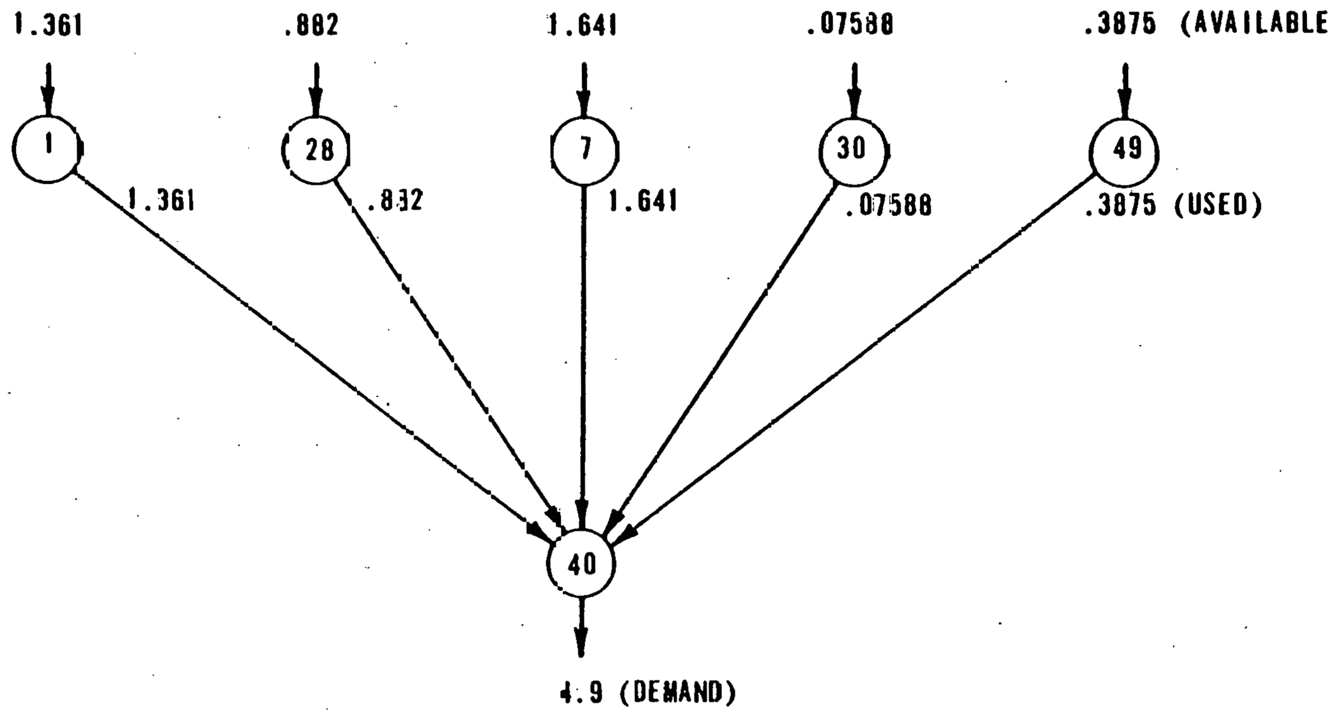


FIGURE 5-11
ALLOCATION ASSUMING A HIGH DEMAND

6.0
SUMMARY AND RECOMMENDATIONS

6.0 SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

a. A simplex computer program has been successfully developed and demonstrated for solving linear programming problems dealing with biomass allocation optimization. The program calculates the most profitable allocation of biomass materials for satisfying specific fuel needs through thermochemical conversion processes. A "User's Manual" for the system has been prepared.

Data which are considered in the calculation are regional and seasonal availabilities of biomass materials, regional costs of biomass materials, regional demands and selling prices of fuels derived from biomass, and efficiencies and manufacturing costs for the thermochemical conversion processes.

b. An initial data base has been derived from published information. Provisions have been built into the program to update the data base as new data become available. Biomass prices and fuel demand data were derived from the SRI studies. Non-woody and woody biomass availability figures were derived from EPRI and SRI studies. Fuel manufacturing costs were developed with a computer program with data from MITRE and Gilbert Associates' studies. Selling prices are based on current 1980 prices extrapolated to 1985.

c. Potential users of the system are:

   1. The energy planner who must make decisions concerning the most profitable regional allocation of biomass resources.

   2. The educator to demonstrate how market and processing conditions can affect the most profitable allocation of biomass resources.

3. The biomass program manager to provide information on research needs relating to questions such as: what are the process efficiencies and fuel manufacturing costs which must exist before a thermochemical conversion process can become commercially competitive?

4. The biomass resource planner to determine the quantity of specific biomass species which must be made available in his region in order to satisfy specific fuel needs.

6.2 RECOMMENDATIONS

a. To be of continued value, the data base for the biomass allocation model must be updated at least annually. The information entered into the existing data base has been taken from studies as old as four years. As conversion technologies are perfected, fuel manufacturing costs and process efficiencies will become more precise. Also, in many cases, biomass prices are unknown today because they have no commercial value. Studies currently in progress are developing more precise data on: fuel manufacturing costs, fuel manufacturing efficiencies, biomass costs, biomass availabilities, fuel selling prices, and fuel demands.

   As these data become available, the initial data base should be updated. Provisions have been built into the program, as described in Chapter 4, which allow for the data to be updated.

b. The data base now contains efficiencies and manufacturing costs restricted to thermochemical conversion technologies. It is recommended that the data base be expanded to include bioconversion technologies as well. Such an expansion of the data base would allow for a far more meaningful assessment of the biomass allocation options. The present computer program can accommodate the bioconversion data.

c. The existing software runs on the Gilbert/Commonwealth Corporate IBM 370 system. To use the system away from the company requires a terminal connected by a telephone line to the 370 system. This creates problems because of the reliance upon communciation systems designed for voice communication. For this reason it is recommended that the software systems be implemented on a readily available small machine or on a central system such that the program may be accessed over a time-sharing network.

d. The biomass allocation model should be tested and evaluated from a user's point of view. This would be accomplished through consultations with potential governmental and industrial users of the system and obtaining from them specifications on how the program can be applied to and possibly revised for their needs.

e. During development of the present program, specific features have been identified which would enhance the versatility of the system. It is recommended that the following capabilities be added to the system:

   1. A mechanism allowing the user to specify the year for which the biomass feedstock allocation is required. (At the present time the system provides data only for the year 1985.)

   2. A mechanism which allows for different transportation costs to be used as part of the biomass feedstock costs.

   3. A mechanism which allows the user to specify aggregates of feedstocks instead of having to specify feedstocks on an individual basis.

4. A mechanism which takes into consideration the effect that interfuel competition can have on the selling prices of biomass derived fuels.

f. The present data base is limited to four, 2 to 3 state regions in the United States. By expanding this data base to include the entire United States, the usefulness of the model would be expanded. Larger regions would expand the biomass feedstock and derived fuel options. On a larger scale, the data base could be expanded to include individual countries.

7.0
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7.0 REFERENCES

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