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

QUARTERLY REPORT

FOR THE PERIOD

OCTOBER 1, 1978 TO DECEMBER 31, 1978

WORK PERFORMED UNDER

DOE CONTRACT ET-78-C-02-5022

Yong Kee Ahn
Richard J. Brumberg
Eric T. Nelson
Richard P. Stringer

of

Gilbert Associates, Inc.
Reading, Pennsylvania 19603

and

Richard C. Bailie

of

Environmental Energy Engineering, Inc.
Morgantown, West Virginia 27505

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ABSTRACT

Gilbert Associates, Inc. of Reading, Pennsylvania has teamed up with Dr. Richard Bailie of West Virginia University and Environmental Energy Engineering, Inc. to perform a significant biomass contract for the U.S. Department of Energy. The two year contract is designed to develop a linear programming model which will be useful to the energy planner who must determine the most profitable combination of biomass feedstocks and conversion processes to produce a given fuel mix in order to satisfy demands of the energy market.

This is the first biomass study which includes all elements of a commercial biomass scenario, i.e., the biomass resources, biomass to fuels conversion technology, and fuels utilization. It includes a market analysis of the need for biomass derived fuels, and national and regional availability of biomass resources on seasonal bases.

Secondly, it will include development of biomass conversion profiles for 100 biomass materials including wood, bagasse, sugar cane, wheat and rice straw, corn stover, and others. Conversion profiles will be developed from Thermal Gravimetric Analyzer (TGA) runs under various conditions of temperature, pressure, and particle size and in the presence of catalysts. Gasification, pyrolysis, and direct combustion shall be the modes of conversion.

An attempt will be made to develop biomass-to-fuels process models and to verify them using process development unit runs. Then a data bank shall be developed for commercial scale process design and the associated economics.

Finally, a linear programming model shall be developed for evaluating specific biomass feedstocks and the conversion processes required to supply a given volume of fuel under given market conditions. The data banks of market conditions, biomass conversion profiles, and commercial scale process design and economics will be used as input to the model.

Dr. Bailie will supervise the TGA work at West Virginia University and the Process Development Unit work at Environmental Energy Engineering, Inc. Gilbert Associates will perform the project management, market analysis, process modeling, and linear programming portions of the project.

The project began on September 1, 1978. Since then, candidate biomass materials for use in the experimental analysis portions of the project have been identified. Standard procedures are being developed for analyzing biomass and biomass conversion products from the TGA runs. Equipment has been ordered for making modifications on the TGA's and Process Development Units.

In addition, a linear programming problem involving three biomass feedstocks for production of methanol used in three market sectors has been formulated. The example problem was hand-solved and is being used as a model to develop a computer package for system optimization.

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A. INTRODUCTION TO PROJECT

A.1 INTRODUCTION

Of the various energy supply alternatives now available, energy from biomass appears to be the most economically competitive, technically sound and environmentally acceptable solar option in the near-term. This technology offers the potential for converting the large scale renewable resource of biomass into energy forms suitable for a variety of uses in the transportation, electric utility, industrial, and commercial sectors.

Studies have been performed that place primary emphasis on identification of biomass feedstock resources with some initial investigation of conversion technologies and markets for the derived energy forms.

The strategy to be used by Gilbert Associates is to concentrate on a procedure that places the first order of importance on the market demands for energy forms that can be derived from biomass. This approach involves quantification of market penetration potentials. In parallel, the conversion technologies that are available to produce the energy forms most in demand by the market will be identified and characterized. An analysis of the cost associated with conversion and utilization of biomass feedstock will be conducted.

The proposed work includes development of a data base that will inventory the behavior of biomass materials in a wide variety of thermal systems. This experimental data will be developed in conjunction with West Virginia University (WVU) and Environmental Energy Engineering, Inc. (EEE). Areas of responsibility for these organizations are listed here and shown in Figure A.1.

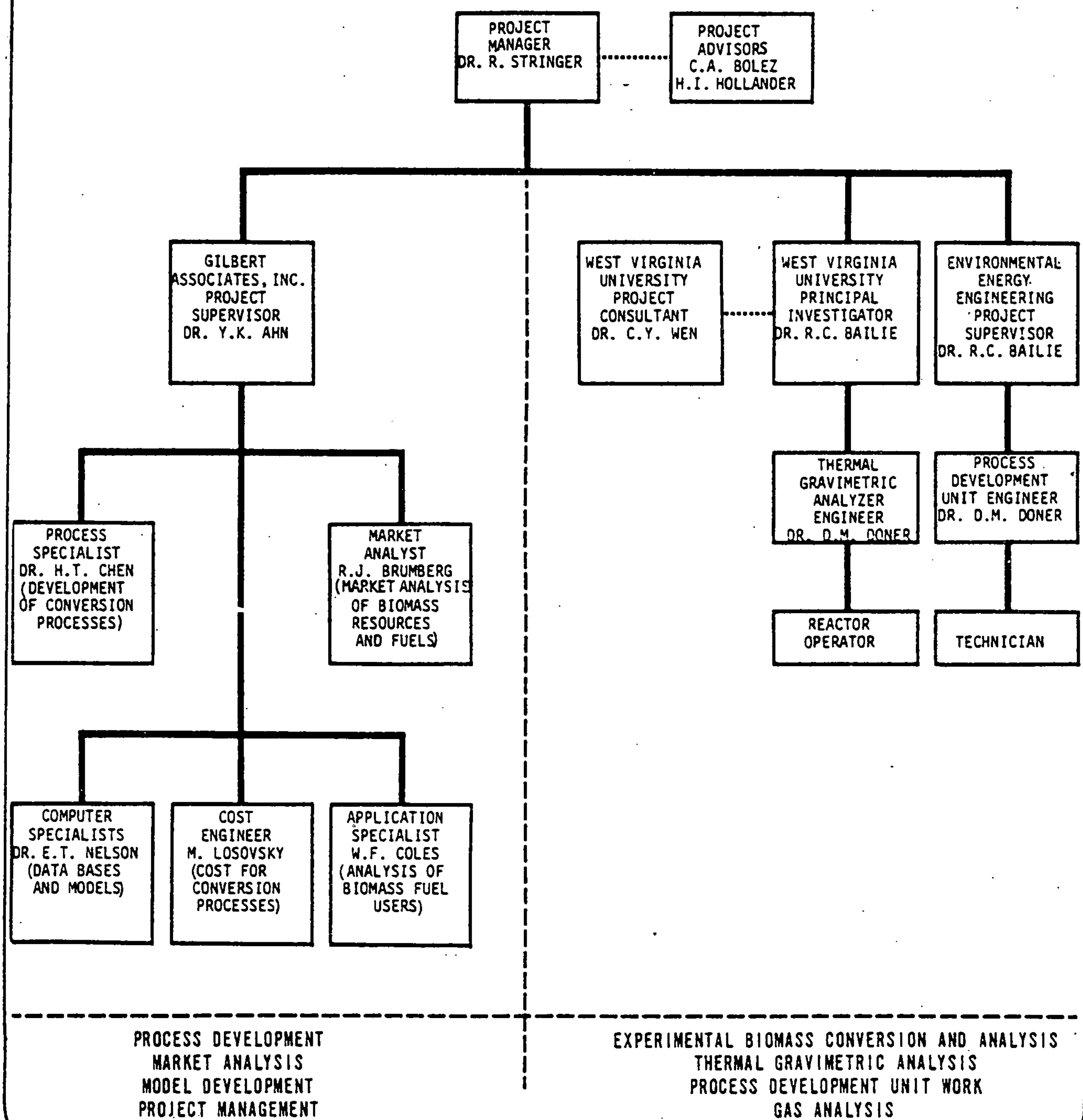
WVU - All thermal gravimetric analyzer (TGA) experiments
EEE - All process development unit testing

The work conducted will maximize the use of existing equipment, with minor modifications being made where necessary in order to conduct the proposed experiments and tests. These laboratory and process development unit activities will form the basis of process models for use in predicting and verifying the outcomes of various biomass conversion processes.

The process models will be verified in the process development unit tests prior to their use in developing commercial scale process design and economics. The verified process models will be the basis for performing biomass conversion system analysis studies by integrating them with the results of market analysis.

The results of the proposed study effort will be technical and economic data concerning conversion characteristics of alternate biomass materials and an evaluation of feedstock resource-conversion-utilization systems. This evaluation will be combined with a market analysis to identify high priority feedstock resource options. The selection of these resources will be determined by considering the regional and seasonal demands of the energy forms that can be derived from biomass materials. Also, the relationship between the variation in these demands and the growing cycles of identified biomass materials will be characterized.

FIGURE A.1
PROJECT ORGANIZATION CHART



The following market sectors will be considered in this study:

- o Transportation Sector - Alcohols and F.T. liquids
- o Residential Sector - SNG
- o Chemical and Allied Products Sector - synthesis gas as feedstock for production of chemicals, petrochemicals such as ammonia
- o Electric Utility Sector - combustion products, gasification products, alcohols

A vehicle will be needed that can logically synthesize the input data developed and make the analysis results readily available to the user. In order to accomplish this, a deterministic model using a linear programming technique will be developed. The user's manual will enable the user with the prepared input cards to execute the computer programs and analyze the results. This will allow the user to evaluate a given mix of resources and conversion systems subject to a number of user identified constraints such as market demand and cost of resource availability at a given time and place. (See Figure A.2)

The contribution that this project will make to DOE's fuels from biomass program will be to reveal the most profitable routes to follow for converting specific biomasses to specific fuel mixes based on supplies and demands for biomass resources and fuels, and data generated about conversion technologies.

An example of how the model could be used is shown below:

- o An energy use analysis identified the gap between energy supply and demand for transportation and electric utility sectors for New England region in winter months. The fuel types which can be supplied from biomass conversion are identified to be low Btu gas, medium Btu gas, methanol and combustion products for the utility sector and methanol and pyrolysis liquid for the transportation sector. The results of the market analysis are contained in the data bank.

- o We are faced with selection of the best combination of biomass feedstock-conversion-utilization (electric utility and transportation (fuels) system to contribute to the identified energy gap.

- o The criteria for selecting the best system will be to maximize the profits for producing the desired amount and type of fuels from various biomass feedstocks available.

- o The profit maximization program will utilize the process design and economics data obtained and stored in the data bank.

- o The biomass resource availablility will be constrained by the region (New England) and the season (winter). For example, New Hampshire has one of the best wood resources. The feasibilities for processing the wood species to the identified fuel type via various conversion processes will be assessed. The plants will be constrained by plant capacity and the fuel by product specifications.

- o The program output will be the results of a search performed for all possible combinations of processing various wood species in New England to produce the desired amount and fuel types dictated by the market analysis at maximum possible profits.

FIGURE A.2

PROJECT OUTPUT

DATA BASES

COMMERCIAL SCALE PROCESS MODELS

- BIOMASS
- FUELS

BIOMASS TGA PROFILES

- ± 100 BIOMASS FEEDSTOCK

MARKET ANALYSES

- BIOMASS FEEDSTOCKS
- BIOMASS DERIVED FUELS

LINEAR PROGRAMMING MODEL

OUTPUT: MOST PROFITABLE COMBINATION OF BIOMASS. FEEDSTOCK AND PROCESSES TO PRODUCE A GIVEN FUEL MIX

A.2 OBJECTIVES

The preferred program objectives are to:

- o Characterize the markets for SNG, methanol, low/medium-Btu gas, ammonia, oil and Fischer-Tropsch liquids derived from biomass resources by considering the demands for the energy forms on a regional and seasonal basis.

- o Characterize, using experimental data, the biomass conversion facilities and processes that can provide the energy forms demanded by the market.

- o Identify those biomass resource materials best able to meet the conditions required by the conversion-utilization systems available.

This approach considers the market prospects, the conversion technologies, and the biomass resources as a combined system. By using this approach it is possible to evaluate the system based on regional and seasonal variations in supply of the biomass feedstock and the demand for the energy forms derived from biomass resources.

In order to attain the stated objectives, efforts will be directed towards accomplishing the following:

- Conducting systematic bench scale low char, high gas yield gasification experiments and correlating resultant experimental data. Gasification reactions will include biomass-steam, biomass-oxygen, biomass-carbon dioxide as well as reactions by thermal means only.

- Developing process models based on the bench scale experimental data.

- Verifying the process models in selected process development unit runs.

- Performing commercial scale biomass process design and economic studies using the verified models.

- Formulating a regional and seasonal linear programming model that would allow evaluation of alternate biomass feedstock-conversion-utilization systems to meet the market demands for various consuming sectors.

Date requirements are shown in Figure A.3.
The output of this activity will be a computer based model of an integrated biomass resource-conversion-utilization system.

This study will develop tools that will allow the energy planner and design engineer to analyze the response of the energy from biomass system to a number of variables. These variables will be large in number and will be related to a wide range of energy system related issues such as market demand, resource costs, technology, and legislative impediments or incentives.

FIGURE A.3

DATA REQUIREMENTS

I. BIOMASS RESOURCES

- REGIONAL SUPPLIES
- COSTS

II. PROCESSES FOR CONVERTING BIOMASS TO FUELS

- PYROLYSIS, COMBUSTION, GASIFICATION
  - — EFFECTS OF PRESSURE, TEMPERATURE, CATALYSTS, PARTICLE SIZE
- COSTS AND PROCESS MODELS FOR COMMERCIAL SCALE PLANTS

FIGURE A.3 (CONT'D)

III. BIOMASS DERIVED FUELS

- POTENTIAL SUPPLY
- DEMANDS IN COMMERCIAL SECTORS
  - — TRANSPORTATION — (ALCOHOLS AND FT LIQUIDS)
  - — RESIDENTIAL — (SNG)
  - — CHEMICAL AND ALLIED PRODUCTS — (SYNTHESIS GAS)
  - — ELECTRIC UTILITY — (COMBUSTION AND GASIFICATION PRODUCTS, ALCOHOLS)
- COSTS OF FUELS

For example, the system model can assist in determining:

- Manufacturing costs for biomass fuels
- Locations and sizing information for biomass conversion facilities
- Cost effective uses of specific biomass fuels under given market conditions
- Optimal process configurations for producing a given fuel from a given biomass resource

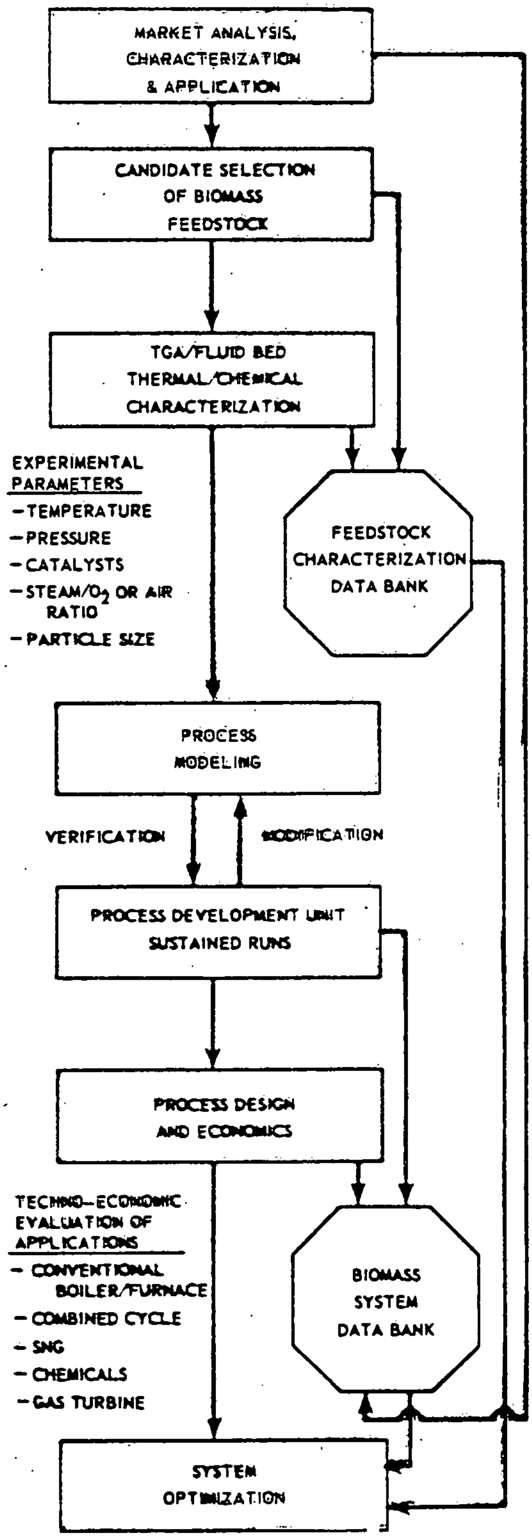
Deliverables from this project are the following:

- Market analysis of national and regional needs for biomass derived fuels on seasonal basis
- Market analysis of national and regional availability of biomass resources on seasonal basis
- Biomass conversion profiles for approximately 100 biomass materials derived from Thermal Gravimetric Analyzer gasification runs under various conditions of temperature and pressure and in the presence of catalysts. The fluidized bed operational mode will be used to examine the effects of particle size on the biomass conversion processes
- Data bank for regional availability and conversion profiles of biomass resources
- Process models for converting biomass resources to fuels
- Verification of selected process models from process development unit runs
- Data bank for commercial scale process designs and economics
- Computer model for evaluating biomass feedstocks for conversion processes required to supply biomass derived fuels under various market conditions
- User's manual for the Biomass Resource-Conversion-Utilization Model

A.3 APPROACH

Figure A.4 is a summary of the approach which will be used to execute the project tasks.

FIGURE A.4
SCHEMATIC SUMMARY OF PROJECT ACTIVITY



Project Tasks

Task 1 - Market Analysis

- o Determine the national and regional applications for fuels and other energy forms that can be derived from biomass resources via thermochemical conversion methods. Use existing DOE studies and data base materials initially and fill gaps in data coverage using other materials or development of assumptions where necessary.

  Analyze the incremental growth in demand for the fuel and energy forms which could be met via biomass conversion. Scenarios previously developed by DOE will be examined for those which best match the study data needs.

  Recommend specific locations for selecting the biomass samples to be used in laboratory TGA experiments. These locations will be chosen to represent biomass resource regions which exhibit strong and growing demands for the fuels and energy forms derived from the biomass conversion.

  Assess the regional and seasonal requirements for the fuels and energy forms analyzed above in order to determine the relationships between supply and demand at locations chosen for the study.

  Analyze the above supply/demand relationships as they are related to the growing cycles of those biomass resources characterized during the laboratory analyses.

  Determine availability and application of the biomass fuels and energy forms to the following market sectors.

  - o Transportation
  - o Electric Utility
  - o SNG (Residential)
  - o Chemical and Allied Products

Task 2 - Fuel Characterization by Atmospheric TGA Runs

- o Develop biomass conversion profiles for approximately 100 biomass materials using a Thermal Gravimetric Analyzer (TGA) available at West Virginia University. Among the biomass resources which will be considered are corn stover, bagasse, and wood materials including mill and logging residues. These biomass profiles will consist of: (1) Total weight of the sample as a function of time; (2) Rate of weight loss as a function of time; (3) Gas composition as a function of time. Typical chart recordings of Items 1 and 3 above are shown in Appendix A Figures 2 and 3 respectively. Reactions will take place in atmospheres of hydrogen, air, steam and in inert atmospheres. In addition to the profiles, variables to be investigated in TGA runs with the various biomass materials will include: (1) Various rates of temperature rise (in the range of 700 to 2000^{o}F) during the reaction; (2) Various biomass material preparations; and (3) Final char fraction. Profiles of the biomass materials will be supplied to a data bank (Task 6) which will later be used to evaluate biomass conversion alternatives (Task 14).

Task 3 - Pressurized TGA Runs: Evaluation of Effects of Temperature and Pressure

- o Determine the combined effects of temperature and pressure on biomass conversion profiles using the high pressure Thermal Gravimetric Analyzer (TGA) available at West Virginia University. Reaction will take place in atmospheres of hydrogen, air, steam and in inert atmospheres. Obtain profiles of six different biomass materials selected in Task 2 using three pressures (150, 300, and 500 spig) and three temperatures in the range of 500 to 2000^{o}C. Selection of the six biomass materials will be based on those which give the highest gas and lowest char yields. The purpose of Task 3 is to determine what significant changes in product gas composition will occur when the gasification takes place under pressure and high temperatures that cannot be achieved in the atmospheric TGA used in Task 2. Profiles of the biomass materials will be supplied to a data bank (Task 6) which will later be used to evaluate biomass conversion alternatives (Task 14).

Task 4 - Catalyst Testing by Atmospheric TGA Runs

- o Determine quantitatively the influence that catalyst may have on product yields and compositions of the biomass conversion processes. The larger atmospheric TGA at West Virginia University will be used with the following catalysts: (1) nickel-based catalyst, (2) limestone, (3) dolomite, and (4) metal oxide. The runs with catalysts will be similar to those of Task 3. Other catalysts, such as ash produced from biomass conversion experiments, and elevated pressures will be used if catalysts provide significant alteration of the gas composition and rate of reactions. These tests are being performed because it may be possible to catalytically alter the gas composition to meet the needs of the consumers.

Task 5 - Evaluation of the Effect of Biomass Particle Size on Fluidized Bed Runs

- o Determine effect of particle size on pyrolytic thermal treatment of biomass using the fluidized bed existing at Environmental Energy Engineering Plant facilities. The runs in this task will be made under the following conditions:

  (1) The fluidized bed material will be composed of an inert solid that does not take part in any of the reactions.
  (2) The temperature range studied will be from 500 to 1000^{o}C.
  (3) Four biomass feedstocks will be used with four particle sizes and three temperatures for each combination of size and biomass feed.
  (4) The gases will be analyzed for CO, CO_2, hydrogen, methane, ethane and ethylene.
  (5) Amount and composition of the pyrolysis liquid and solid products will be determined.

Task 6 - Creation of Feedstock Characterization Data Bank

- o Prepare a biomass feedstock data bank for storage on magnetic tape and a computer program to generate and update the biomass feedstock data bank. The data bank will be used for the system analysis study proposed in Task 14 and will be largely based on the experimental data obtained from Tasks 2 through 5. Gilbert's in-house computer programs will be modified for use in this task. A format for this data bank is presented in Apppendix D Table 1.

Task 7 - Develop Process Models

- Develop kinetics of both catalytic and noncatalytic biomass conversion based on experimental data obtained in Tasks 2 through 5 stored in the data bank tape created in Task 6. Kinetic studies will be performed gasification in atmospheres of hydrogen, air, steam and in inert atmospheres. P.D.E. Solven and/or nonlinear regression least square computer program will be used during this task.

Task 8 - Select Process Configurations to Test the Process Models and Modify Process Development Unit Equipment for Tests

- Select process configurations to be tested in the process development unit runs both with and without catalysts (Task 9 and 10, respectively) and modify process development unit for runs to test scaleability and validity of process models developed in Task 7.

Task 9 - Verify Process Models for Selected Noncatalytic Runs

- Evaluate validity of noncatalytic process models developed in Task 7 using process development unit equipment at Environmental Energy Engineering, Inc. The reactor systems to be used for testing are a fluidized bed, a packed bed (pyrolysis only), an entrained bed, and a free fall bed. The modes of operation will include combustion, pyrolysis, and gasification. Each of the ten combinations of reactor configurations and modes of operations will be run at two temperature levels using two biomass particle sizes. A total of forty runs ($2^2 \times 10$) will be made for each biomass material for two hours of steady-state operation using approximately 200 to 400 lbs of biomass material. It is anticipated that three biomass feedstocks -- (1) forest biomass, (2) bagasse, and (3) corn stover -- will be used for the process development unit testing.

Task 10 - Verify Process Models for Selected Catalytic Runs

- Evaluate validity of process models developed for catalytic combustion, pyrolysis, and gasification of biomass in Task 7 using results of Tasks 4 and 5. The testing will be limited to a fluidized bed mode using the same procedure described in Task 9 except that the bed will be composed of a solid catalyst rather than an inert solid. The one or two catalysts which show the most potential in the TGA runs will be used. A total of eighteen runs will be made for each catalyst (three operating modes for each of the three major biomass materials and two temperature levels).

Task 11 - Demonstrate Sustained Process Development Unit Runs

- Demonstrate several sustained runs of 24 to 40 hours duration using one to three tons of one or more biomass feedstocks, both with and without catalysts. The sustained runs will allow the system to approach an equilibrium condition that will not be obtained in the shorter runs. Biomass materials selected will be based on the results of Task 9 and 10. Sustained runs will be made in the preferred process development unit configuration (fluidized bed), unless early results indicate other configurations are far superior. The number of runs will be limited to seven, which will include:

- One run at a high temperature pyrolysis range (1000°C) and one at a low temperature pyrolysis range (500°C) using corn stover and without catalyst
- One run in a combustion mode using wood and one run in the gasification mode using bagasse, both without catalyst
- Three runs of catalytic pyrolysis using a solid catalyst in the bed in place of the inert bed used in the other run.

Task 12 - Process Design and Economics

o Perform process design and economics of converting biomass to marketable products such as low or medium Btu gas, methane (SNG), NH_3, and methanol. Process design of full scale process will be based on the process models developed in Task 7 and verified in Tasks 9 and 10. Conversion plant capacity and product(s) will be dictated by the market analysis in Task 1. The design and economic data will be supplied to a product data bank (Task 13) which will later be used to evaluate biomass conversion alternatives (Task 14).

Task 13 - Create Biomass System Data Bank

o Prepare biomass system data bank on magnetic tape with the collection of performance data, capacities, and costs of final utilization products obtained from various biomass feedstocks via both catalytic and noncatalytic combustion, pyrolysis, and gasification processes. The core of the data bank will be based on the data generated in Task 12. Gilbert's in-house computer models will be modified for use in this task.

Task 14 - Develop Biomass Analyses Program

o Formulate a linear program which will utilize the data contained in the feedstock (Task 6) and the biomass system (Task 13) data banks. Determine from the market analysis (Task 1) the seasonal and regional gaps between energy supply and demand in a market sector. Determine the delivery system for a biomass conversion commodity to contribute to the given energy supply and demand gap. The simplex, General Linear Programming (LRLTRAN) computer program will probably be used for this task.

Task 15 - Reports

A.4 PROJECT SCHEDULE

Figure A.5 shows the three phases of the project.

FIGURE A.5

PROJECT PHASE (DURATION 24 MONTHS)

STARTED SEPTEMBER 1, 1978

ENDS AUGUST 31, 1980

PHASE I

- ANALYZE MAREKTS FOR BIOMASS RESURCES AND FUELS
- OBTAIN CANDIDATE BIOMASS MATERIALS
- DEVELOP STANDARDIZED TGA AND PDU PROCEDURES
- DEVELOP PRELIMINARY FORMAT FOR DATA BANKS AND SYSTEM ANALYSES PROGRAM

FIGURE A.5 (CONT'D)

PHASE II

- DEVELOP TGA DERIVED FINGERPRINTS OF BIOMASS MATERIALS
- DEVELOP AND VERIFY PROCESS MODELS ON PDU
- DEVELOP SYSTEM AND ECONOMICS OF COMMERCIAL SCALE PLANTS

PHASE III

- FINALIZE SYSTEM ANALYSES PROGRAM
- SUBMIT FINAL REPORT

B. SIGNIFICANT PROGRESS

B.1 BIOMASS FUELS ANALYSIS

Scope

Prediction of Behavior of Commercial Plants Based on Laboratory Studies

It is proposed that the "Biomass Thermal Profile" can be useful in design of a commercial unit to produce a desired fuel product. Figure B.1 shows the plan to achieve this objective.

1. The laboratory data developed by W.V.U. will be fed to Gilbert to develop a process model.
2. The process model developed by Gilbert will predict the behavior of the P.D.U. at E.E.E.
3. If the predictions are substantiated then the prediction of the commercial unit will take place.
4. If prediction is not substantiated the P.D.U. results will be fed back to alter the process model and re-interpret the laboratory results.

The final step--the actual commercial facility is beyond the scope of this study.

Summary of Activities For West Virginia University

The subcontract work at W.V.U. is devoted to an experimental investigation of the behavior of a wide variety of feed biomass materials when exposed to thermal stress (elevated temperature) in various environments (gas phase compositions). The behavior will be characterized by "Biomass Thermal Profiles" which is a term coined to represent -

1. Weight loss as a function of time
2. Rate of weight loss as a function of time
3. Gas composition of gas generated as a function of time.

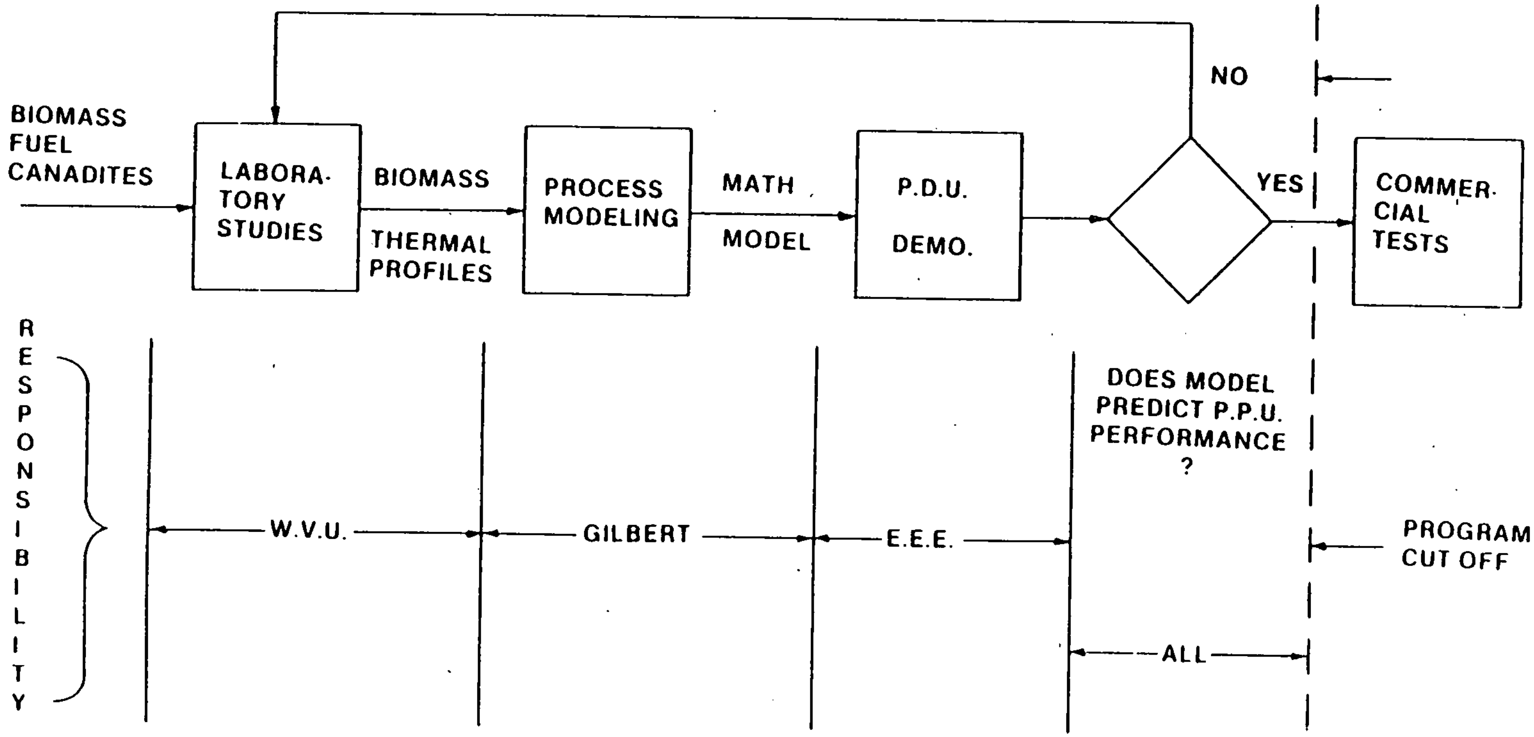
These profiles are obtained in a TGA-EGA apparatus (Thermal Gravimetric Analyzer - Effluent Gas Analyzer) at various temperatures, pressures and sample sizes. Both non-catalytic and catalytic studies are included.

The present system for analysis of fuels include ultimate analysis, proximate analysis and constituent analysis. None of these are useful in interpreting how a biomass material will behave (react) when under thermal stress and a chemically reactive environment.

It is hypothesized that the behavior will vary and the purpose of the study is to characterize the particular behavior so that it may be useful

1. In developing a process model, and
2. In diagnosing behavior of the operating system.

FIGURE B.1



PROJECT AREAS OF RESPONSIBILITY

An analogy can be made to the E.K.G. that is useful to characterize the behavior of patients exposed to physical stress.

The study will provide the "Biomass Thermal Profile" for

1. A large number of biomass stocks
2. Temperatures between 500-1500°C
3. Pressures between 1-500 psig
4. Catalytic systems
5. Reactive Environments - O_2, CO_2, H_2O, H_2

This will serve as a data resource in the development of the process models.

Summary of Activities For Environmental Energy Engineering

The subcontract work at E.E.E. is devoted to P.D.U. verification of the process models developed for biomass conversion by -

1. Combustion - Oxygen containing environment
2. Pyrolysis - Inert environment
3. Gasification - Steam environment

The reactor configurations to be verified will include -

1. Fluidized solid system
2. Entrained solid system
3. Fixed solid system
4. Falling solid system

Both catalytic (only in fluid bed) and non-catalytic systems will be studied.

The work will be done at the test facility in Morgantown, WV that is used for commercial testing of industrial wastes. The basic unit is a two foot reactor system normally run as a fluid bed. It includes a process gas generator that allows gas atmospheres of widely varying compositions and temperatures to be used in the reactor. The system includes an on-line gas chromatograph.

The conditions to be tested will be predicted by the process modeling and be tested in the P.D.U. A large number of studies of 2-3 hrs. in duration using 300-400 lbs. of biomass will be made. For a few conditions selected as most significant testing will continue 24-40 hrs. and will consume 2-5 tons of biomass. Energy and material balances will be made.

Task Descriptions

Task 2: Fuel Characterization by Atmospheric TGA Runs

Task Objection: To characterize the behavior of various biomass materials in an inert and in a reactive thermal environment. The characteristic parameters are to be useful in prediction of the behavior in commercial size equipment.

FIGURE B.2
BASIC SCHEMATIC OF THERMAL GRAVIMETRIC ANALYZER

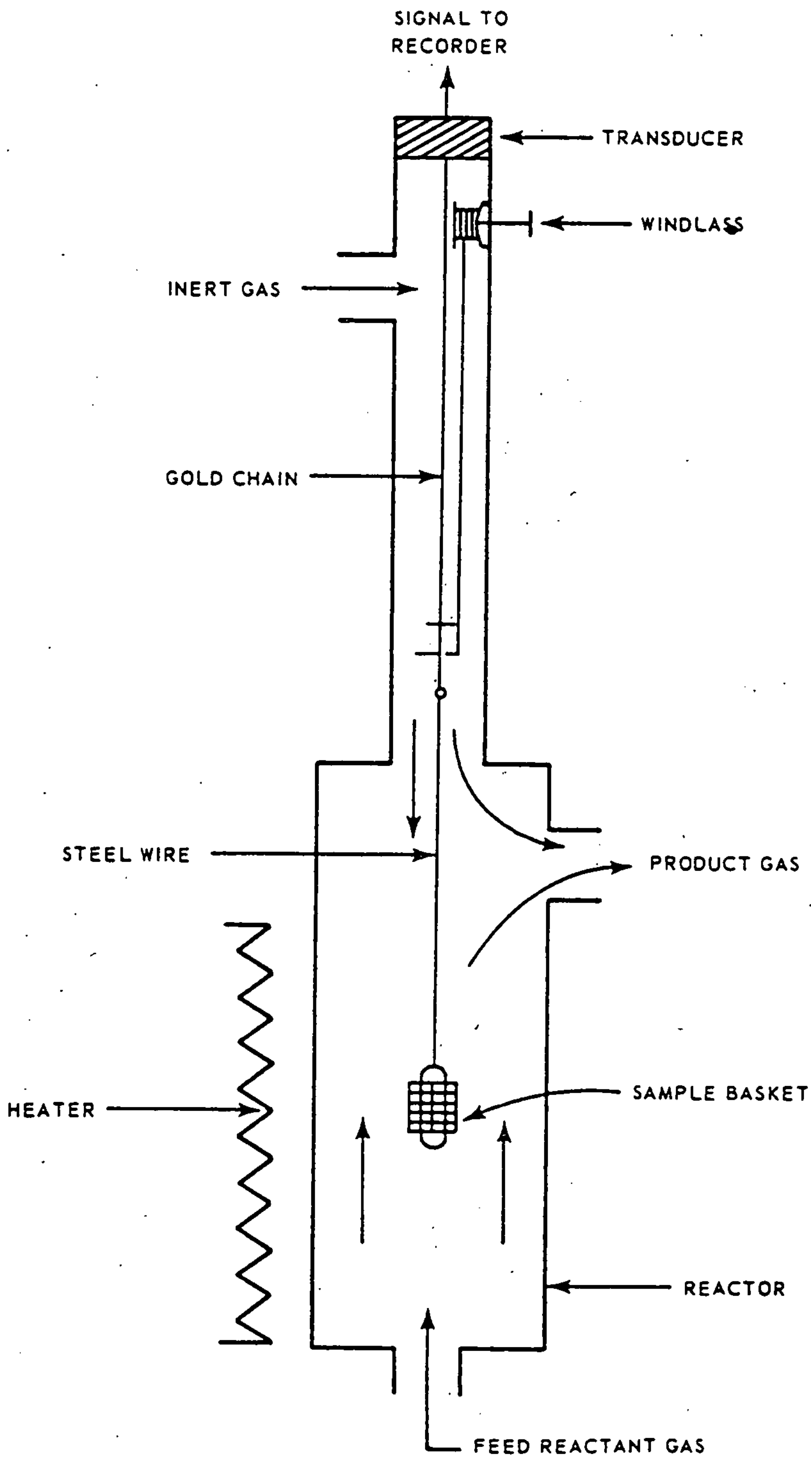
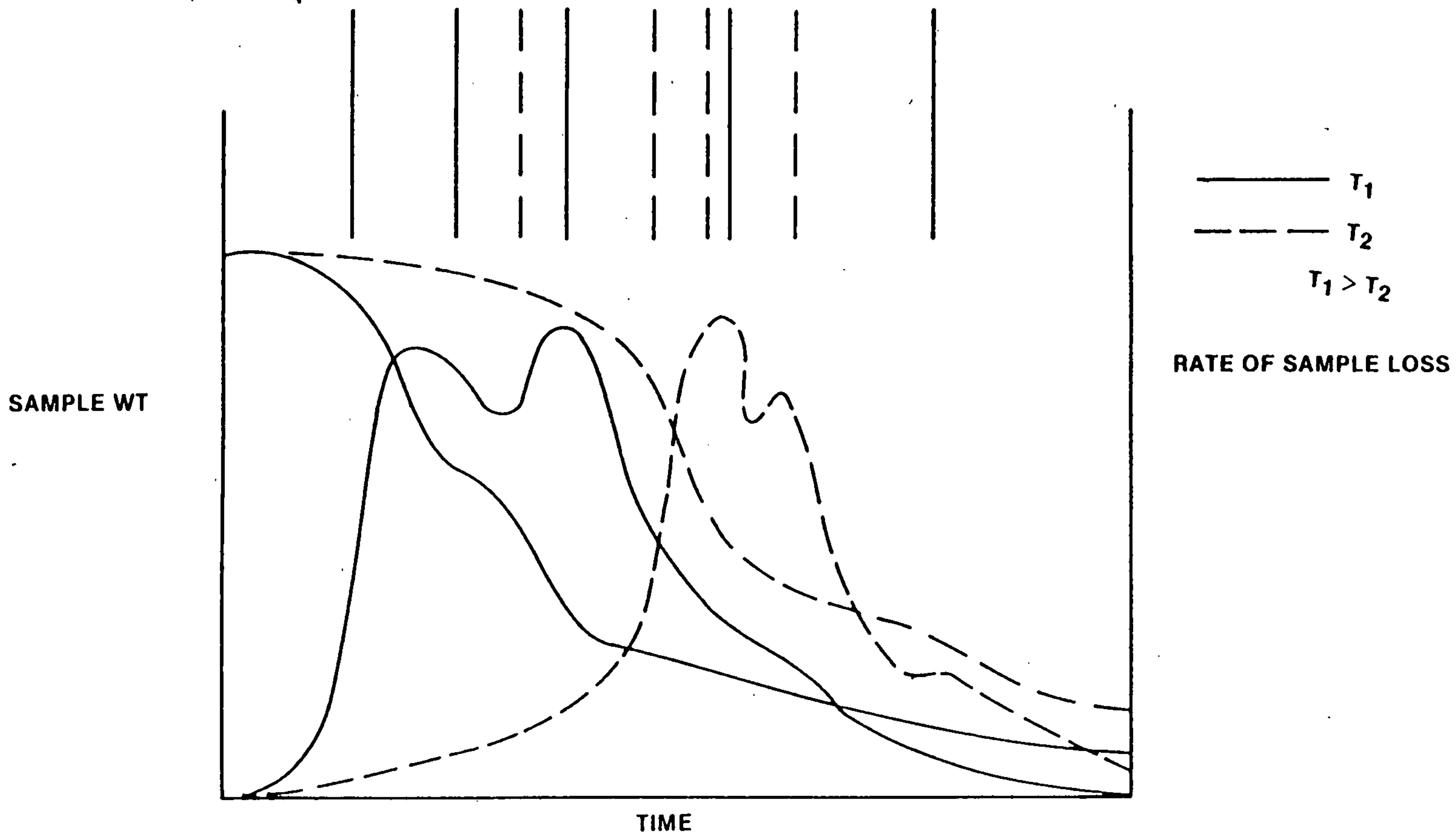


FIGURE B.3

GAS COMPOSITION									
CO_2	8	8	-	10	-	-	14	-	20
CO	18	20	-	14	-	-	8	-	14
H_2	14	14	-	10	-	-	8	-	10
CH_4	6	2	-	1	-	-	0	-	0



HYPOTHETICAL BIOMASS THERMAL PROFILE

Facilities: Several Thermo-Gravimetric analysers are available at W.V.U. which have been commissioned for several coal studies. They are all of the Thompson type shown in Figure B.2.

Discussion: Different biomass materials behave differently when exposed to a thermal environment. The present methods for characterization of biomass fuels include:

1. Ultimate Analysis - C, H, O, S, N, Ash
2. Proximate Analysis: Volatile Matter, fixed C, Moisture, Ash
3. Constituent Analysis: Hemi-cellulose, Cellulose, Lignin.

None of these analyses provides information that can be used to predict how the biomass will behave when exposed to a high temperature environment. For example, one type of Eucalyptus tree has thermal properties which allow it to be used in fireplaces. This behavior could not be predicted from the present characterization behavior.

In humans, medical doctors have been successful in interpreting the EKG to predict the patient's behavior under physical stress. The TGA runs provide a profile of the weight loss and the rate of weight loss of the solid when exposed to a high temperature environment. These profiles will be characteristic of each biomass and should be useful in predicting the relative behavior of the biomass when subjected to thermal stress.

The characteristic profiles will be obtained for an extremely large variety of biomass samples selected both for their widespread availability, and for variety based on the characteristic analysis given above (for example, high and low amount of volatile material).

Data to be Obtained:

1. Total weight as a function of time
2. Rate of weight loss as a function
3. Gas analysis as a function of time.

Figure B.3 shows a hypothetical curve of the type of results sought.

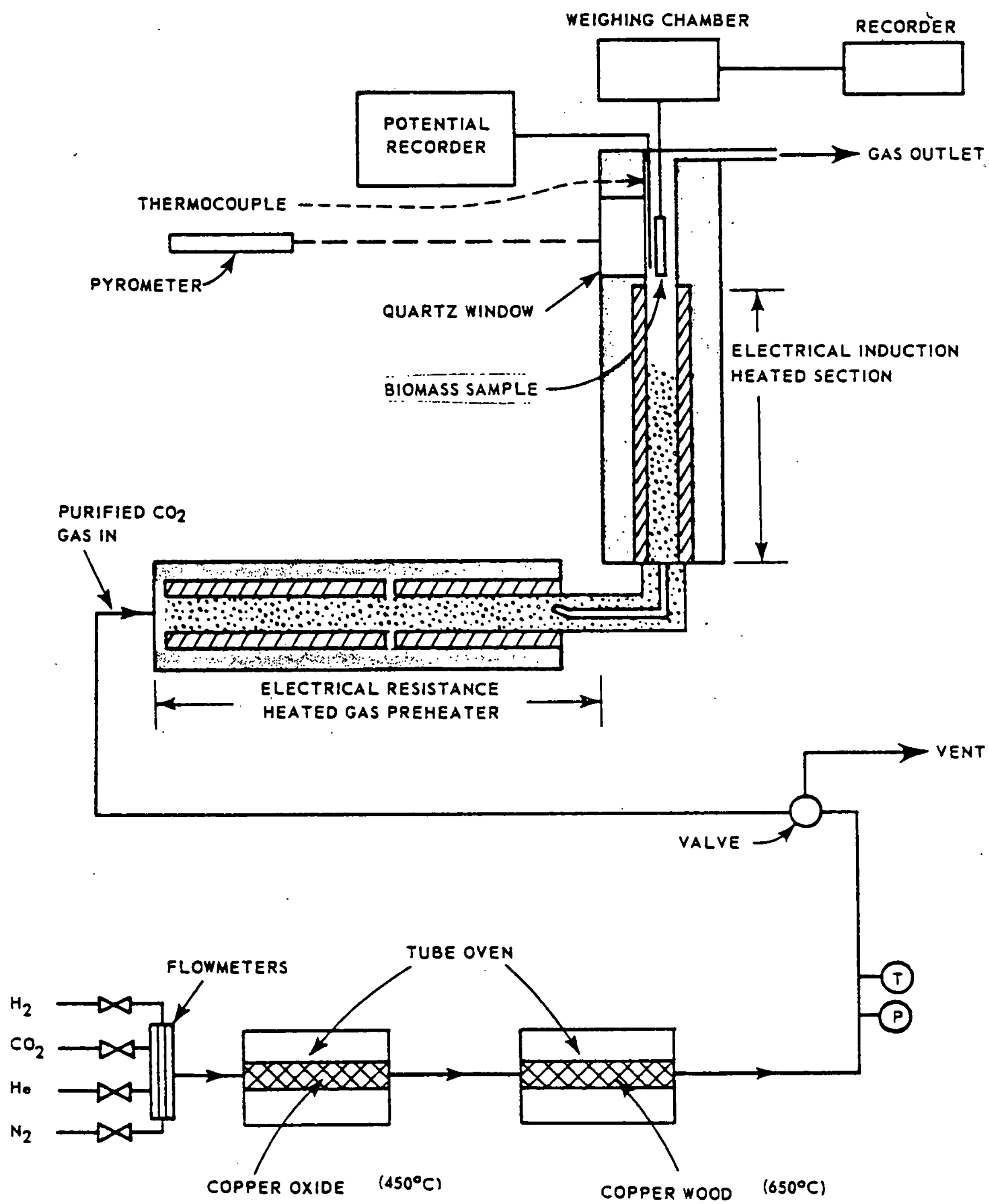
Task 3: Evaluation of the Temperature and Pressure Effects by TGA Runs

Task Objective: To determine how the biomass behavior in a thermal environment is altered by temperature, pressure and reactive environments.

Facilities: In addition to the atmospheric TGA used for the task "Fuel Characterization by Atmospheric TGA Runs" the high pressure, high temperature unit will be used. A schematic diagram of this unit is shown in Figures B.4. This unit was designed to operate at temperatures to 2000^{o}C and pressures to 600 psi.

FIGURE B.4

SCHEMATIC DIAGRAM OF THE PRESSURIZED TGA



Data to be Obtained: Under this task the following environments will be used:

1. Steam
2. Air
3. Hydrogen
4. CO_2
5. Mixtures of above
6. Pyrolysis gas

The pressures will range up to 500 psig and temperatures to 2000^{o}C. The characteristic profiles will be obtained as described in Task 2. The level of detail for this study will be dictated by early results. Dramatic shifts in the behavior of the biomass will call for a more detailed study and complete matrix. The complete matrix is shown in Table B.1. The completed matrix is planned for only one or two selected materials.

The following table shows a matrix for TGA experiments described above to study temperature and pressure effects. In combustion mode of operation, a series of runs will be made with varying biomass sample weight and air flow rate for each run so that the effect of air-to-biomass ratio, in addition to temperature and pressure, on combustion can be studied. Hydrogen will be used instead of air for the hydrogasification studies. In the gasification studies, a fixed amount of sample will be charged for each run, but varying steam-to-air or steam-to-oxygen ratios will be used. In pyrolysis, the reaction rate will be affected by biomass particle size variations as well as by temperature and pressure changes. The size effect, however, cannot be investigated in the TGA apparatus and will be studied separately in Task 5 using pilot plant facilities.

Task 4: Catalyst Testing by Atmospheric TGA Runs

Task Objectives: To determine the quantitative influence of various catalysts on the product split of gaseous components determined in Task 2.

Facilities: See Tasks 2 and 3.

Discussion: The effort will be to evaluate the effect of added catalyst (as opposed to in-situ catalyst such as wood ash) on the gas product split. The normal candidates such as

1. Nickel based catalyst
2. Limestone
3. Dolomite
4. Metal oxides

will be run in the atmospheric TGA and the characteristic profiles compared to those obtained in Task 2. If it is found that gas yield modifications are significant and can be controlled by catalyst addition and temperature, the studies will be extended to the high pressure TGA.

TABLE B.1

EXPERIMENTAL PROGRAM MATRIX FOR TGA RUNS — BOTH WIDTH AND WITHOUT CATALYSTS

G_i = Ratio of sample weight to air flow; d_i = Ratio of sample weight to H_2 flow; r_i = Steam-to-air or steam-to-oxygen ratio; S_i = Weight of samples charged to inert gas flow system.

	COMBUSTION			HYDROGASIFICATION			GASIFICATION			PYROLYSIS		
PRESSURE: PSIG	150	300	400	150	300	500	150	300	500	150	300	500
TEMPERATURE: °C												
500	G_1 G_2 G_3	G_1 G_2 G_3	G_1 G_2 G_3	d_1 d_2 d_3	d_1 d_2 d_3	d_1 d_2 d_3	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3	S_1 S_2 S_3	S_1 S_2 S_3	S_1 S_2 S_3
1000	G_1 G_2 G_3	G_1 G_2 G_3	G_1 G_2 G_3	d_1 d_2 d_3	d_1 d_2 d_3	d_1 d_2 d_3	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3	S_1 S_2 S_3	S_1 S_2 S_3	S_1 S_2 S_3
1500	G_1 G_2 G_3	G_1 G_2 G_3	G_1 G_2 G_3	d_1 d_2 d_3	d_1 d_2 d_3	d_1 d_2 d_3	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3	S_1 S_2 S_3	S_1 S_2 S_3	S_1 S_2 S_3
2000	G_1 G_2 G_3	G_1 G_2 G_3	G_1 G_2 G_3	d_1 d_2 d_3	d_1 d_2 d_3	d_1 d_2 d_3	r_1 r_2 r_3	r_1 r_2 r_3	r_1 r_2 r_3	S_1 S_2 S_3	S_1 S_2 S_3	S_1 S_2 S_3

If gas compositions may be altered it will be possible to select a biomass, catalyst, temperature and pressure to produce a product gas to meet consumer specifications where this is advantageous.

Data to be Obtained: See Task 2. The characteristic curves discussed in Task 2 will be obtained for catalyst biomass mixtures. This will be done at atmospheric pressure and extended to pressure if strong effects are obtained.

Task 5: Evaluation of the Effect of Biomass Particle Size by Fluidized Bed Runs

Task Objectives: To determine the effect of biomass particle size on the gas product produced from thermal treatment of biomass.

Facilities: Figure B.5 shows the basic elements of the base fluidized bed facility. The fluid bed is 2 feet in diameter and can accept particle sizes up to 3 feet.

Discussion: The fluid bed is an ideal system for study of the behavior in a thermal environment. It provides a large thermal flywheel and large quantities may be introduced into the bed without affecting the temperature. Figure B.6 shows a typical example of coal injected as a pulse into a fluid bed.

Data to be Obtained: Curves such as those shown in Figure B.7 will be obtained for

1. temperatures between 500 - 1000^{o}C
2. biomass feeds
3. particle sizes to 3 inches.

Task 9: Verification of Process Models for Selected Non-Catalytic Runs

Task Objective: To provide experimental verification of process models developed under Task 7.

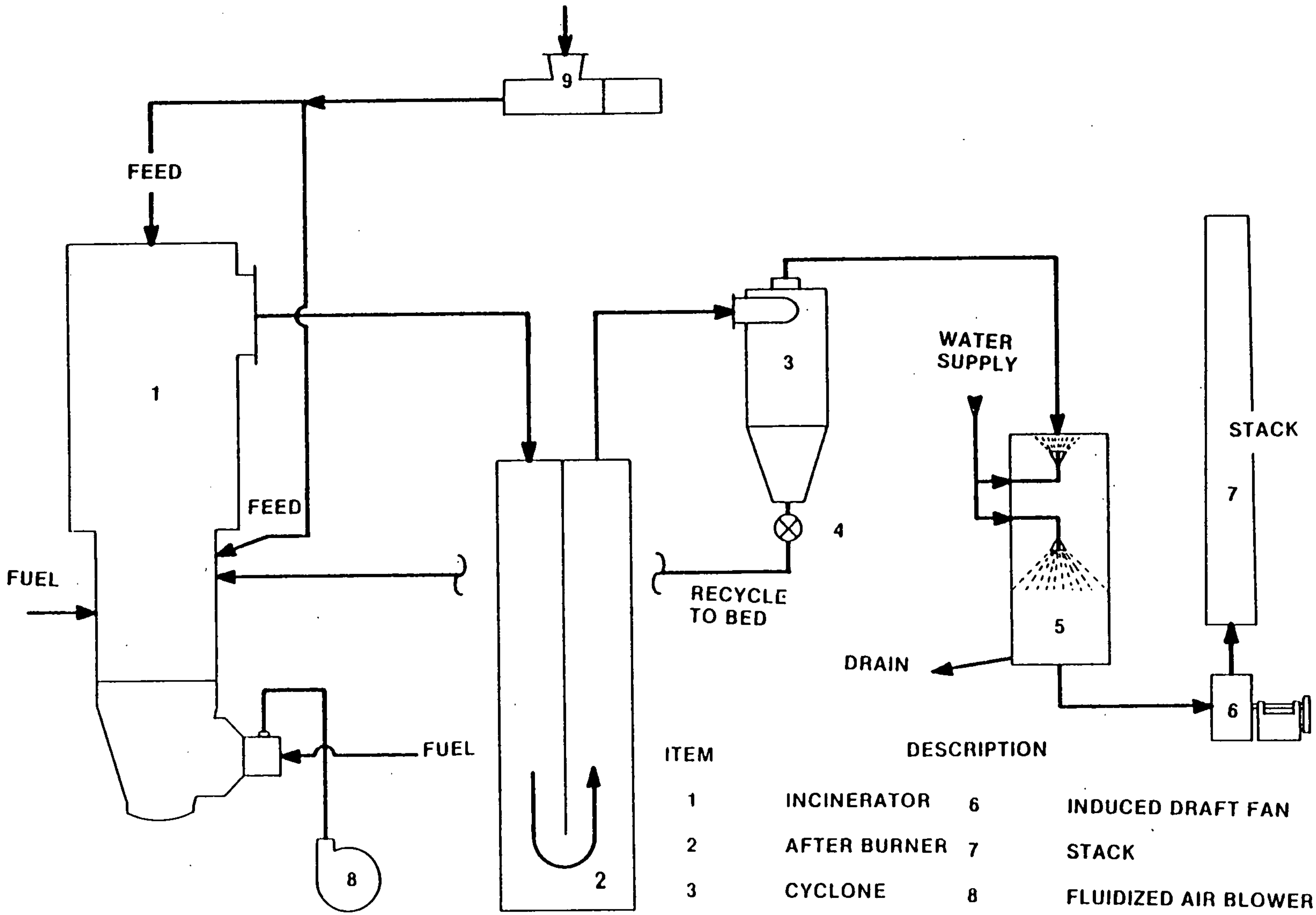
Facilities: In addition to the facilities described in Task 5 the process gas generator and steam generator described in Figure B.7 will be used to provide a wide variety of gas compositions for the reactors. The present facilities will be modified to provide gas recycle and allow the unit to be operated as a fixed bed system, entrained bed system, and free fall bed system as well as the fluid bed system.

Discussion: The PDU unit will be operated as

1. Combustion Unit - Gas oxygen
2. Pyrolysis Unit - Gas inert
3. Gasification - Gas O_2/Steam

to provide experimental runs to verify the predictions of the process models - Task 7.

FIGURE B.5



ITEM	DESCRIPTION	ITEM	DESCRIPTION
1	INCINERATOR	6	INDUCED DRAFT FAN
2	AFTER BURNER	7	STACK
3	CYCLONE	8	FLUIDIZED AIR BLOWER
4	ROTARY VALVE	9	WASTE FEED PUMP
5	SCRUBBER		

FIGURE B.6

DEVOLATILIZATION OF WYOMING SUBBITUMINOUS C COAL

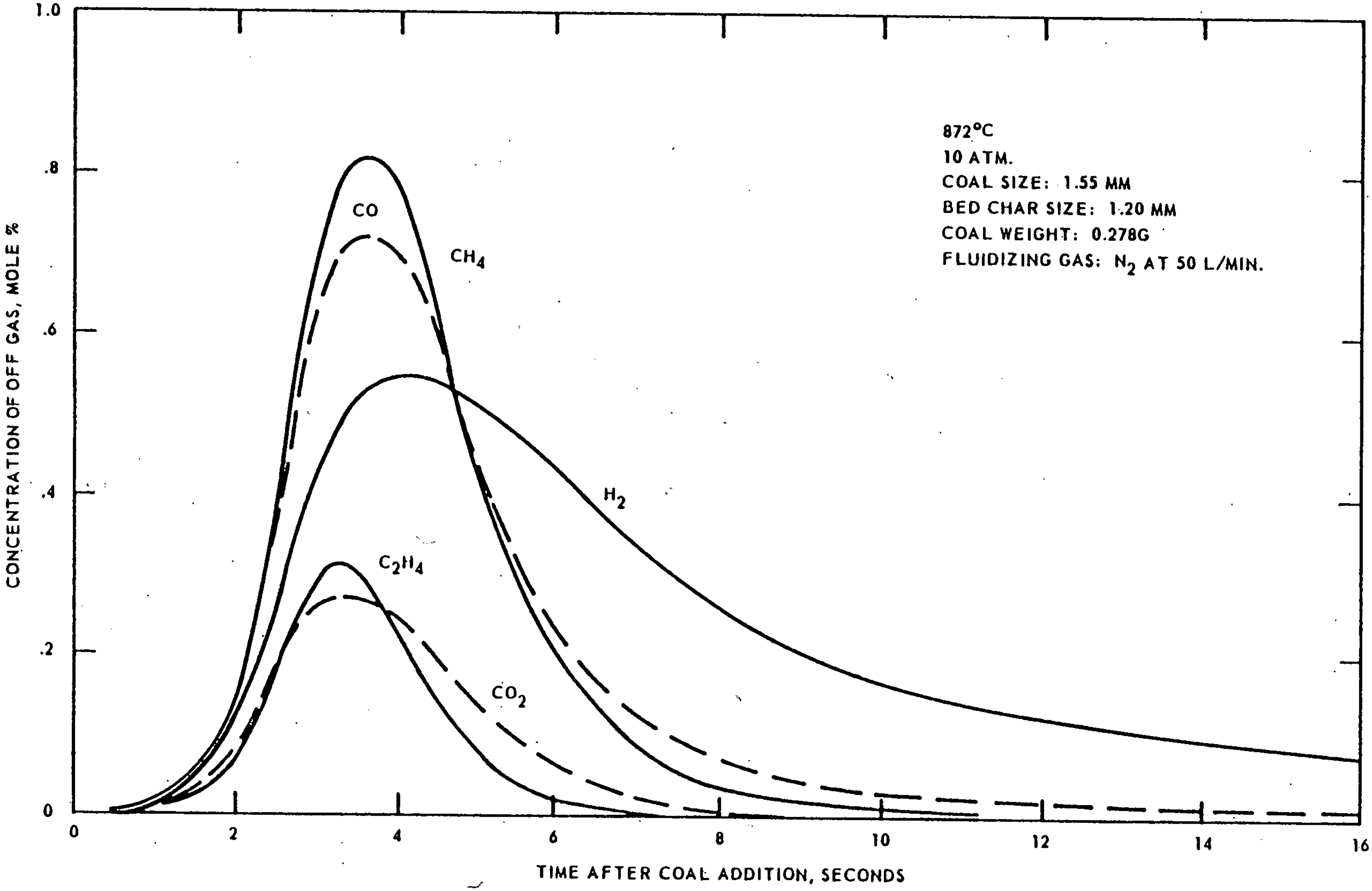
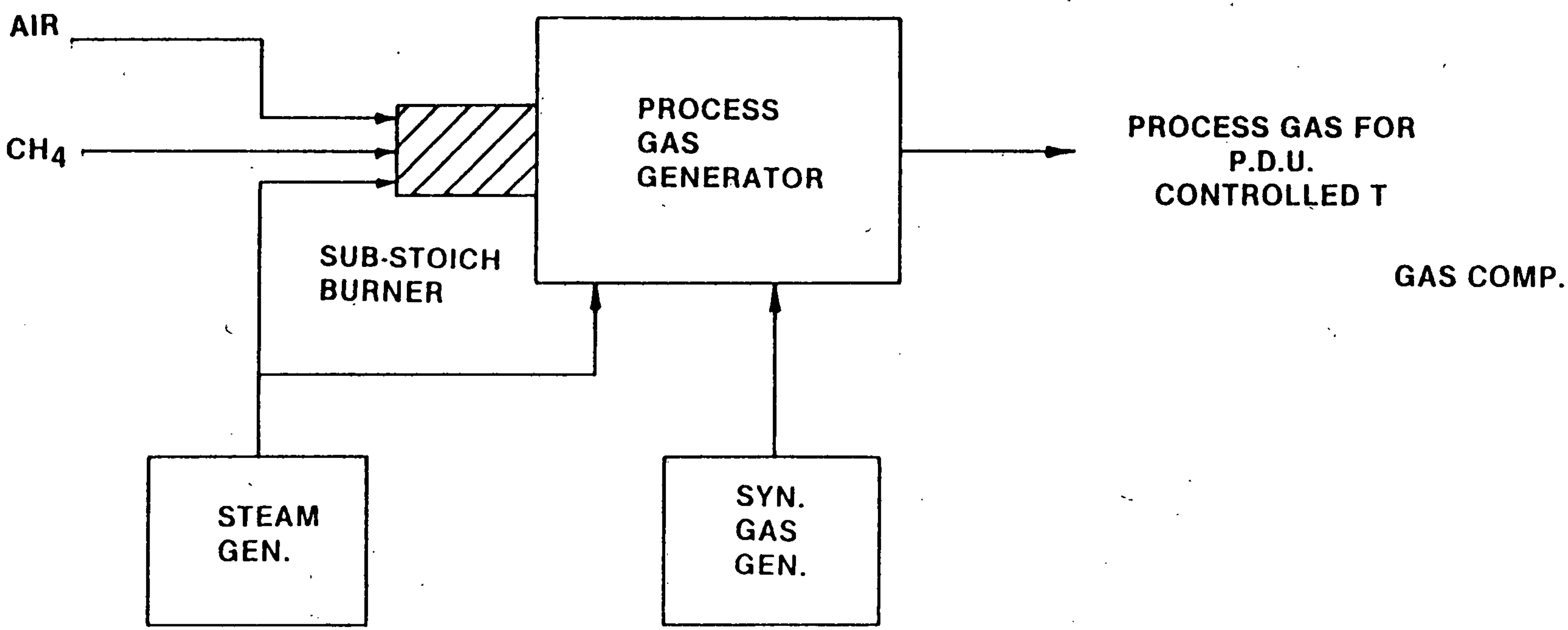


FIGURE B.7



PROCESS GAS GENERATOR

Data to be Obtained: The gas yeild and compositions will be obtained for the following situations:

Reactor Type	Operational Mode		
	Combustion	Pyrolysis	Gasification
Fluid Bed	X	X	X
Entrained Bed	X	X	X
Free Fall Bed	X	X	X
Packed Bed		X	

Task 10: Verification of Process Models for Selected Catalytic Runs

Task Objectives: To verify the process models developed in Task 7 by running tests in the P.D.U.

Existing Facilities: See Task 7.

Discussion: The P.D.U. will be operated as a fluid bed mode only. The inert solid will be replaced by selected catalyts. The runs will be similar to Task 7 and the results of the catalytic runs compared to non-catalytic runs to see if the predicted gas splits are achieved.

Data to be Obtained: See Task 7.

Task 11: Verification of Process Models for Selected Catalytic Runs

Task Objectives: To determine accurate material and energy balances under equilibrium conditions.

Discussion: These runs are scheduled to be made in the fluid bed mode. Seven runs are tentatively planned. Two will be using a catalyst in the fluidized bed, and at least one run will be made with wood, corn stover, and bagasse, as shown in the following experimental program matrix:

No. of Demonstration Runs to be Made in Sustained Pilot Plant Runs

Reactor Configuration: Fluidized Bed (Tentative)

	Combustion	Pyrolysis	Gasification
Non-catalytic Runs:			
Wood	1		
Corn Stover		2 (Two temperature levels at 540° & 1000°C	
Bagasse			1
Catalytic Runs:			
Wood			1
Corn Stover	1		
Bagasse		1	

However, the number of runs will be limited to seven, and they will be conducted in the following manner:

- One run will be made in a high temperature pyrolysis range (1000°C) and one in the low temperature pyrolysis range (500°C)
- One run will be made in a combustion mode and one run to be made in the gasification mode.
- Three runs will be provided for catalytic pyrolysis using a solid catalyst in the bed in place of the inert bed used in the other run.

The system will process between one to three tons of biomass material during a run.

B.2 MARKET ANALYSIS

Scope

The purpose of the market analysis is to develop a data base which will include information regarding the regional and seasonal availability of biomass materials. These materials will include woody biomass species and selected grasses and grains produced as agricultural commodities. Some of the criteria employed in selecting the materials are: quantities produced, qualtities available and proximity to conversion facilities, transportation and marketplace.

The markets for biomass derived fuels are to be identified. To date, most of the biomass resource analyses have emphasized identification of biomass materials suitable for conversion to specific fuels and the conversion technologies available. This work will supplement these studies by examining the problem from the perspective of market demand. The question posed would be: What demands exist in the market for the fuels derived from biomass resources and what are the characteristics of these fuels? While this study cannot address the total biomass market problem, it will identify and examine the major market issues for fuels that can be produced from biomass materials via thermochemical conversion:

In summary, the purpose of this phase of the study is to develop the data base required to match the market sector demands with the biomass resource supplies. See Table B.2.

Progress To Date

During the first two months (Oct. 15 - Dec. 15) the following work was conducted:

- o Previous biomass market studies were reviewed for the purpose of assisting in the selection of biomass samples.
- o Major woody and agricultural biomass materials were identified as candidates for laboratory TGA analysis.
- o A plan was developed for collecting the first "batch" of biomass samples.

In selecting the biomass samples, primary consideration is being given to materials based on the following factors:

- o Regional availability of material
- o Seasonal availabliity of material
- o Collectability
- o Options for on or near site use
- o Proximity to market
- o Location/availability of conversion technology/hardware
- o Composition and characteristics of materials
  - bark/wood rations (silvaculture)
  - density
  - moisture

TABLE B.2

TASK 1 — MARKET ANALYSIS

- OBJECTIVE:
  - — DEVELOP REGIONAL AND SEASONAL DATA FOR BIOMASS MATERIALS (SUPPLY) AND MARKETS FOR BIOMASS DERIVED FUELS (DEMAND)
- SCOPE OF WORK:
  - — REVIEW EXISTING MARKET DATA
  - — IDENTIFY — LOCATE — COLLECT LARGE NUMBER OF BIOMASS SAMPLES FOR LABORATORY ANALYSIS
  - — DEVELOP REGIONAL ANALYSIS
  - — ASSESS REGIONAL AND SEASONAL SUPPLY FOR THE BIOMASS MATERIALS SELECTED
  - — DEVELOP COST DATA FOR FEEDSTOCKS AND SELLING PRICES FOR FUELS
  - — DETERMINE DEMANDS FOR THE BIOMASS DERIVED FUELS FOR THE FOLLOWING MARKET SECTORS
    - — TRANSPORTATION
    - — SNG (RESIDENTIAL)
    - — ELECTRIC UTILITY
    - — CHEMICAL AND ALLIED PRODUCTS

TABLE B.2 (CONT'D)

TASK 1 — MARKET ANALYSIS (Continued)

- SCHEDULE:
  - — INITIATED FOURTH QUARTER 1978 FOR A PERIOD OF 12 MONTHS
- PRESENT STATUS AND ACCOMPLISHMENTS:
  - — LITERATURE SEARCH — PLUGGING GAPS AND INTEGRATION WITH OTHER CONTRACTORS
  - — ACQUIRING BIOMASS SAMPLES
  - — CONSTRUCTING SUPPLY/DEMAND DATA BANK AND REGIONS
- OUTPUT:
  - — PROVIDE REGIONAL AND SEASONAL SUPPLY/DEMAND DATA BANK FOR SELECTED BIOMASS MATERIALS AS INPUT TO BIOMASS ANALYSIS LINEAR PROGRAM

USDA data are being collected and analyzed in order to rank biomass materials by quantities available in various regions. (See Table B.3)

Future Plans

The first quarter of Calendar 1979 will see a significant portion of the market analysis conducted. The following work elements will be undertaken:

- o Collect biomass samples for laboratory analysis.
- o Develop regional and seasonal supply/demand data bank for selected biomass materials as required for the biomass analysis linear program.
- o Construct biomass supply and demand regions.
- o Determine regional and seasonal markets for the biomass derived fuels on the following sectors: (See Figure B.8)
    - transportation
    - electric utility
    - SNG (Residential)
    - chemical and allied products

TABLE B.3

BIOMASS MATERIAL SOURCES

EASTERN FRESH TYPES

WHITE - RED - JACK PINE
SPRUCE - FIR
LONGLEAF - SLASH PINE
LOBLOLLY - SHORTLEAF PINE
OAK - PINE
OAK - HICKORY
OAK - GUM - CYPRESS
ELM - ASH - COTTONWOOD
MAPLE - BEECH - BIRCH
ASPEN - BIRCH

WESTERN FRESH TYPES

DOUGLAS FIR
PONDOROSA PINE
WESTERN WHITE PINE
FIR SPRUCE
HEMLOCK-SITKA SPRUCE
LARCH
LODGEPOLE PINE
REDWOOD
CHAPARRAL
PIHYON - JUMPER

AGRICULTURAL PRODUCTS

WHEAT STRAW
RICE STRAW
BAGASSE
CORN STOVER
SUNFLOWER STALKS
SUGAR BEETS
SUGAR CANE
SWEET SURGHUM

FIGURE B.8

MARKET ANALYSIS

DEVELOP MARKET DATA BASE

ANALYZE SEASONAL/REGIONAL APPLICATIONS

COLLECT BIOMASS SAMPLES

DETERMINE AVAILABILITY/APPLICATION OF BIOMASS DERIVED FUELS FOR THE FOLLOWING MARKET SECTORS:

LABORATORY ANALYSIS

- SNG (RESIDENTIAL)
- CHEMICAL & ALLIED PRODUCTS
- TRANSPORTATION
- ELECTRIC UTILITY

B.3 THE BIOMASS SYSTEM OPTIMIZATION PROGRAM

Scope

The scope of the system optimization program is defined by the following linear programming formulation in mathematical form.

Let D_j = energy demand for project j

S_j = selling price for project j

M_{ij} = manufacturing cost for product j from feedstock i

N_{ij} = efficiency of converting feedstock i to product j

f_{ij} = feedstock i (of total amount F_i) which is converted to product j

Maximize the profit function

$$P = \sum_{j=1}^{jmax} D_j S_j - \sum_{j=1}^{jmax} \sum_{i=1}^{imax} M_{ij} N_{ij} f_{ij} \qquad \text{——— 1}$$

Subject to the constraints

$$\sum_{j=1}^{jmax} f_{ij} = Fi \qquad \text{——— 2}$$

$$\sum_{i=1}^{imax} N_{ij} f_{ij} = D_j \qquad \text{——— 3}$$

$$\sum_{j=1,\ i=1}^{jmax,\ imax} f_{ij} \geq 0 \qquad \text{——— 4}$$

The objective of the computer programming work is to develop a system of the type shown in Figure B.9.

The block on the lower right of this figure represents the linear programming algorithm specified by equations 1 through 4. However, in order to execute that algorithm for different sets of feedstocks and products, a number of supporting programs must be generated. First, a matrix set up program must be developed which is capable of building an initial matrix for any values of imax and jmax - that is, for an optimization problem of any practical size. Second, that matrix must be supplied with input information from a system data base which must contain interconnected files of supply and demand, experimental and conversion process information. Finally, a subsystem must be provided by means of which information from the system data base can be selected for use in specifying the optimization run to be executed.

Progress To Date

Linear Programming Algorithm

The first step in writing the linear programming program was to solve a simple problem by hand.

The next step was to write a linear programming algorithm and a generalized matrix set up program and to check out these two programs by duplicating the hand calculated results.

The resulting programming system is shown in Figure B.10, and the results generated by this system are shown in Table B.4 and B.5. These tables are of a preliminary nature, and are only intended for program development use, therefore, they have not been provided with captions. Table B.4 is the initial matrix corresponding to the following problem.

$$F = 36.9 \times 10^6,\ 7.5 \times 10^6,\ 69.615 \times 10^6 \text{ MMBtu/yr}$$

$$D = 32.45 \times 10^6,\ 14.449 \times 10^6,\ 0.8053 \times 10^6 \text{ MMBtu/yr}$$

$$S = 6.37,\ 10.45,\ 10.75 \quad \text{\$/MMBtu}$$

$$M = \begin{matrix} 11.65, & 12.03, & 12.38 \\ 7.33, & 7.5\ , & 7.71 \\ 8.32, & 8.54, & 8.78 \end{matrix} \qquad N = \begin{matrix} .217, & .47, & .46 \\ .217, & .47, & .46 \\ .205, & .443, & .433 \end{matrix}$$

and Table B.5 is the final matrix from which the following four values were obtained -

$$f_{22} = 5.7493 \times 10^6 \quad \text{MMBtu/yr}$$
$$f_{23} = 1.7507 \times 10^6 \quad \text{"}$$
$$f_{31} = 15.829 \times 10^6 \quad \text{"}$$
$$f_{32} = 26.516 \times 10^6 \quad \text{"}$$

which result in a profit of 26.528 \$ MM/yr.

FIGURE B.9

PRELIMINARY WORK

STEP 1: HAND CALCULATION (3 X 3) PROBLEM

STEP 2:

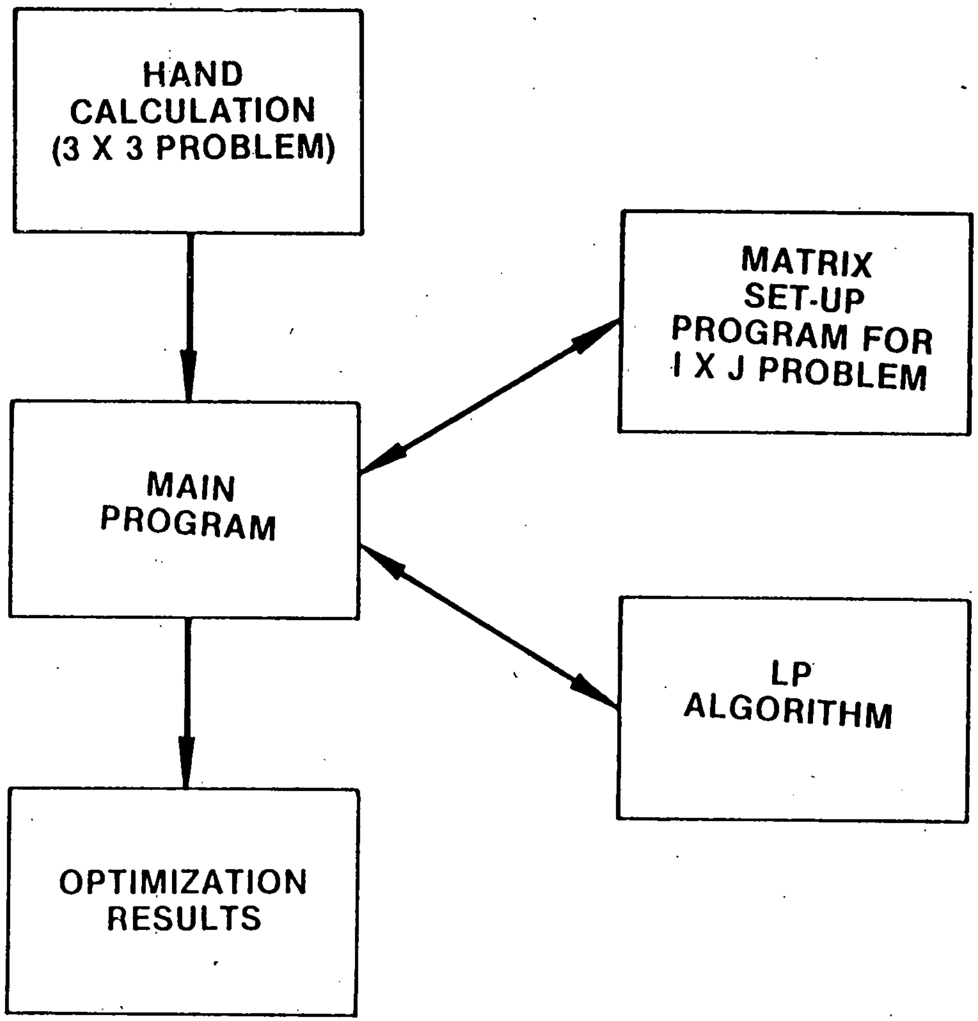


FIGURE B.10

PRELIMINARY SYSTEM

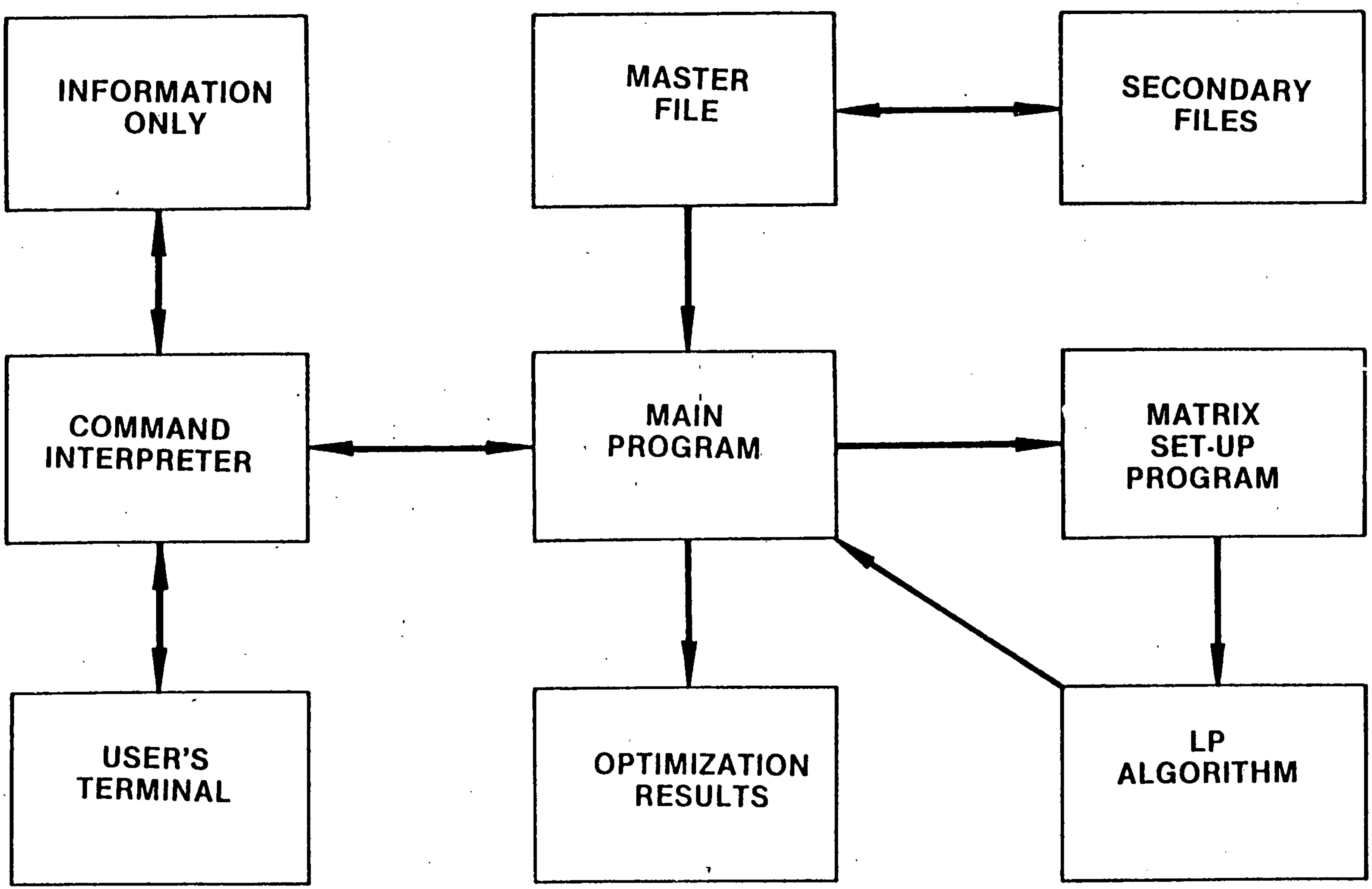


TABLE B.4

INITIAL MATRIX CORRESPONDING TO HAND CALCULATION

```
READY
ex biomass2
J=  1
  .0           -1.1458     -.74260     -.74980     -.20832     1.3865      1.3984
  .36900E+08   1.0000      1.0000      1.0000      .0          .0          .0
  .75000E+07   .0          .0          .0          1.0000      1.0000      1.0000
  .69615E+08   .0          .0          .0          .0          .0          .0
  .13499E+08   .21700      .47000      .46000      .21700      .47000      .46000
  .14449E+08   .0          .47000      .0          .0          .47000      .0
  .80530E+06   .0          .0          .46000      .0          .0          .46000
  .0           .0          .0          .0          .0          .0          .0
J=  8
 -.39975       .84613      .85301      .0          .0          .0          .0
  .0           .0          .0          .0          .0          .0          .0
  .0           .0          .0          .0          .0          .0          .0
  1.0000       1.0000      1.0000      .0          .0          .0          .0
  .20500       .44300      .43300      .0          .0          .0          .0
  .0           .44300      .0          .0          .0          .0          .0
  .0           .0          .43300      .0          .0          .0          .0
  .0           .0          .0          .0          .0          .0          .0
J= 15
  .0           .0
  .0           .0
  .0           .0
  .0           .0
  .0           .0
  .0           .0
  .0           .0
  .0           .0
```

TABLE B.5

FINAL MATRIX CORRESPONDING TO HAND CALCULATION

*** 9 14 15 8 1

J= 1

.0	-1.1458	-.74260	-.74980	-.20832	1.3865	1.3984
.15829E+08	1.0585	.0	.0	1.0585	.0	.0
.57493E+07	.0	.0	-1.0000	1.0000	1.0000	.0
.27269E+08	-1.0585	-1.0609	-1.0609	.24137E-02	.0	.0
.26516E+08	.0	1.0609	1.0609	-1.0609	.0	.0
.36900E+08	1.0000	1.0000	1.0000	-.23842E-06	.0	.0
.17507E+07	.0	.0	1.0000	.0	.0	1.0000
-.26528E+08	-.72261	-1.6403	-1.6594	-.27397	.0	.0
1.0625	.0	.0	.0	.0	.0	.0

J= 8

-.39975	.84613	.85301	.0	.0	.0	.0
1.0000	.0	.0	.0	.0	.0	4.8781
.0	.0	-.94130	.0	1.0000	.0	.0
.0	.0	.13248E-02	.0	1.0609	1.0000	-4.8780
.0	1.0000	.99368	.0	-1.0609	.0	.0
.0	.0	.0	1.0000	.0	.0	-.95367E-06
.0	.0	.94130	.0	.0	.0	.0
.0	.0	-.32000E-02	.0	-.48880	.0	1.9500
.0	.0	.0	.0	.0	.0	-1.0000

J= 15

.0	.0
-4.8780	-4.8781
.0	-2.1739
2.6207	2.5716
2.2573	2.3064
.95367E-06	.95367E-06
.0	2.1739
-3.8600	-3.9274
-1.0000	-1.0000

Data Base

Most of the data base programming work which has been carried out to date has been system-oriented rather than user-oriented. A masterfile of simulated data has been generated. At the present time this master file can support up to 100 feedstocks and up to kmax processes and jmax demands such that jmax kmax $\leq$ 64.

Sufficient data base work has been carried out to enable development work on the remainder of the optimization system to continue. Additional work on the data base will be carried out when the first input information from the other tasks becomes available.

The User Interface

It is beyond the scope of the present project to provide a highly sophisticated user interface. On the otherhand, it has become evident that some interactive capability must be provided.

Originally, it was assumed that it would be possible to use an available general purpose programming package.[1] However, this has not proven to be practical. Due to the fact that the matrix set-up program had to be flexible in order to handle problems of different sizes, it was easier and better to add a new linear programming algorithm to the set-up program than to add a matrix set-up program to a standardized linear pgoramming algorithm. Also, as a result of the flexibility required in the set-up program, it was decided that a more interactive approach must be employed than was originally anticipated.

Although additional matrix set-up logic must be developed and implemented (in order to handle the situation of having several processes each capable of supplying several projects) a preliminary estimate of the maximum size of the overall problem may be estimated as follows.

Assuming only one manufacturing cost per product and assuming jmax = 8 (products) and imax = 32 (feedstocks), then the tableau for the linear programming problem will require (imax + jmax + 1) (imax jmax + 1 + imax + jmax) or 12,177 words of memory.

Although some linear programming problems handle hundreds of variables, the cost and scope of this development project would be unreasonably increased by including a large number of variables in all runs. Therefore, for the purpose of this study it will be assumed that the user of the optimization system would prefer to interactively screen the data base for practical combinations of feedstocks, processes and products, and to restrict each initial matrix to a reasonable size in terms of both memory requirement and execution time. However, at this state in the development of the optimization system, no matrix size, software, machine transportability or hardware restrictions are being placed on the optimization package other than those imposed by the fact that

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1 Simplex, a Code for the Solution of Linear Programming Problems, UCRL-51820 prepared for U.S. Energy Research and Development Administration under Contract No. W-7405-Eng-48.

the optimization system is presently being coded in FORTRAN IV on an IBM MVS system which uses 3330 disk storage units.

A preliminary command interpretation and report generation system to achieve the above objectives has been designed and is in the process of being checked out.

Future Plans

During the first few months of the project the preliminary system shown in Figure B.9 was designed and the more important programs coded and checked out.

Throughout much of 1979 the objective will be to check out the preliminary system and to gradually replace the simulated data with actual data. During this period a lower level of effort will be needed.

Finally, after all programs have been thoroughly checked using actual data, the level of effort will be increased in order to package and document the system in final form.

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