286 9*
10-21-80

MASTER

NO STOCK

DOE/ET/20611-11

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

Quarterly Technical Report for November 1, 1979—January 31, 1980

By

Yong K. Ahn
Yung C. Chen
Herbert T. Chen
Richard W. Helm

Eric T. Nelson
Kevin J. Shields
Richard P. Stringer
Richard C. Bailie

Work Performed Under Contract No. ET-78-C-02-5022

Gilbert Associates, Inc.
Reading, Pennsylvania

and

West Virginia University
Environmental Energy Engineering, Inc.
Morgantown, West Virginia

U.S. Department of Energy

Solar Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

"This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been printed directly from copy supplied by the originating organization. Although the copy supplied may not in part or whole meet the standards for acceptable reproducible copy, it has been used for reproduction to expedite distribution and availability of the information being reported.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$9.00
Microfiche \$3.50

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

QUARTERLY TECHNICAL PROGRESS REPORT

FOR THE PERIOD

November 1, 1979 to January 31, 1980

WORK PERFORMED UNDER

DOE CONTRACT DE-AC0278ET20611
(Formerly Contract No. ET 78-C-02-5022)

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

of

Gilbert Associates, Inc.
Reading, Pennsylvania 19603

and

Richard C. Bailie

of

Environmental Energy Engineering, Inc. &
West Virginia University
Morgantown, West Virginia 27505

CONTENTS

	<u>Page</u>
A. INTRODUCTION	1
B. SUMMARY OF SIGNIFICANT PROGRESS	2
C. SCHEDULE STATUS	3
D. TECHNICAL STATUS	
1. Allocation Model Development	5
2. Market Analysis	13
3. Modeling Biomass Reactions	16
4. Process Economics	36
5. Process Development Unit Studies	44
6. Biomass Characterization	73

A. INTRODUCTION AND OBJECTIVES

The objective of this study is to develop an initial base of information and a computer-based planning aid which will be capable of generating optimum allocations of biomass feedstocks resources to meet given market fuel demands.

The primary feature of this work as opposed to previous studies is that an emphasis has been placed on the integration of:

1. Experimental characterizations and PDU tests
2. Engineering design and economics
3. Information storage and information processing

Previous studies have tended to concentrate on one of two of these areas rather than on integrating all three areas simultaneously under a single project.

Gilbert Associates, Inc., of Reading, Pennsylvania, the prime contractor, is performing the engineering and information processing tasks, and Dr. Richard Bailie of West Virginia University and Environmental Energy Engineering is managing the feedstock characterization and PDU testing tasks.

It is generally recognized that biomass feedstock availability information, biomass production demand information and biomass conversion process design information is not sufficient in quantity or quality to enable commercial plants to be constructed without building prototype plants. However, upon conclusion of the biomass conversion studies which have been initiated already by the Department of Energy (some of which are market-oriented, some engineering-oriented and some of which are laboratory studies) it would be desirable if there existed a system into which this research and development information can flow. The biomass allocation system being developed under this project will not provide all the answers; however, it will provide an initial information base and an organized structure in which biomass feedstock availability, conversion and utilization information can be accumulated. This project will create a model which can be used by the energy planner to make an initial assessment of the most profitable routes to follow to satisfy his regional fuel needs from available biomass resources.

B. SUMMARY OF SIGNIFICANT PROGRESS

o Allocation Model Development

The biomass allocation model has been developed and is undergoing testing. Data bases for biomass feedstock and thermochemical products are complete. Simulated data on process efficiency and product costs are being used while more accurate data are being developed.

o Market Analyses

Market analyses data are required for the biomass allocation model. Information now stored in the biomass feedstock data base includes for each biomass type: feedstock amount by region and season in Btu's/year; heating values in Btu/lb for those feedstocks for which published data are available, and; feedstock costs in \$/MM Btu. Information now stored in the product data base includes for each product: product amount by region in Btu/year and product cost in \$/MM Btu.

o Modeling Biomass Reactions

The modeling activity will assist in providing process efficiency information required for the allocation model. Process models for entrained bed and fixed bed gasifiers based on coal have been adapted to biomass.

o Process Economics

Fuel product manufacturing costs will be used as inputs for the data banks of the biomass allocations model. Conceptual economics have been generated for seven of the fourteen process configurations via a biomass economic computer program.

o Process Development Unit Studies

The PDU studies are designed to demonstrate steady state thermochemical conversions of biomass to fuels in fluidized, moving and entrained bed reactor configurations. Pulse tests in a fluidized bed to determine the effect of particle size on reaction rates and product gas composition have been completed.

Two hour shakedown tests using peanut hulls and wood as the biomass feedstock and the fluidized bed reactor mode have been carried out. A comparison was made of the gas composition using air and steam - O₂.

o Biomass Characterization

Biomass thermal profiles and biomass composition information shall be provided. To date approximately 70 biomass types have been collected. Chemical characterization of this material has begun. Thermal gravimetric, pyrogaschromatographic and effluent gas analysis has begun on pelletized samples of these biomass species.

C. SCHEDULE

Since the November, 1979 thermochemical contractor's review meeting in Rolla, Missouri, project personnel concerned with the systems tasks have concentrated their efforts on developing process efficiency and product cost data for the biomass to fuels processes being considered.

As scheduled, the biomass resource and biomass derived fuels market analysis has been completed.

As scheduled, the biomass allocation model has been designed and is undergoing testing.

As scheduled, the data storage system has been designed and utilized for storage of the marketing data. Storage files for process efficiency data and biomass derived fuel costs now contain arbitrary values which will be replaced with more precise values when the process efficiency data and fuel costing data development is complete by the next contractor's meeting in May.

Since the Rolla meeting, project personnel responsible for the biomass characterization tasks continue to concentrate their efforts on perfecting the analytical procedures and on carrying out the Process Development Unit runs.

Approximately 70 biomass samples have been collected. Chemical characterization of the biomass is now underway. Laboratory characterization of the biomass samples by effluent gas analysis, thermal gravimetric analysis and pyro-gas-chromatography has begun but is behind schedule. Process Development Unit runs are on schedule.

Figure C-1 graphically depicts the current status of the project.

**FIGURE C-1
PROJECT SCHEDULE**

KEY
 | - PLANNED
 ▲ - ACTUAL

TECHNICAL DISCUSSION

D1. ALLOCATION MODEL DEVELOPMENT

Scope

The allocation model is designed to provide information on the most profitable pathways required to satisfy fuel needs based on the biomass feedstock available in a given region and season. Data banks inputting the allocation model include those from the market analysis (cost and availability of the biomass feedstock and products), and the conversion processes (efficiencies and manufacturing costs for fifteen processes used to convert biomass to fuel).

Progress to Date

During the past reporting period all programs and data files were completed in the sense that they generate correct results for all tests which have been run to date. Some clean-up work has been done on the program listing, but this clean-up work is only about 20% complete.

The biomass allocation model is functional and has been tested using the marketing data available together with simulated values for process efficiencies and product manufacturing costs. Printouts from two typical runs are shown in Figures D1-1 and D1-2. A graphical representation of the D1-2 solution is shown in Figure D1-3.

Program testing has continued at a low level of effort pending the completion of the engineering economic study. Simulated efficiencies and manufacturing costs are still being used. Programs exist for reading the efficiency and manufacturing cost information as soon as it becomes available, but some changes to these programs may be required after carrying out tests with actual data.

When the original program design document was generated in May, 1978 it was recognized that changes would be necessary. As a result of continued program testing, many changes have been made to the programs. During the past reporting period some of these changes have been incorporated into the program description, but much more documentation work needs to be carried out to bring the early document up to date.

A users manual has been completed in preliminary form.

Future Plans

During the next reporting period work will continue at a low level effort on improving the users manual and documenting the programs. Program testing will continue at an accelerated rate when efficiencies and manufacturing costs become available.

READY
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/FL/MS
3. IN/IL/IA
4. OR/KA

=
1

C. SELECT SEASON
1. SPRING
2. SUMMER
3. AUTUMN
4. WINTER

Figure D1-1 A TYPICAL COMPUTER RUN FOR A BIOMASS ALLOCATION SOLUTION

K.SELECT FEELSTOCKS

=

47,2,6,8,14,17,18,28,30,46,49,52,67,9,82,50

H.SELECT MARKET SECTOR

1.TRANSPORTATION

2.RESIDENTIAL

3.CHEMICALS

4.ELECTRIC UTILITY

SELECT PPRODUCT

1.AMMONIA

2.SNG

3.LOW BTU GAS

4.MED BTU GAS

5.CASOLINE

6.CHEMICALS

7.METHANOL

8.FUEL OIL

9.STEAM

10.ELECTRICITY

ENTER "SECTOR", "PPRODUCT"

=

1,3

INVALID COMBINATION

=

1,5

=

3,2

=

3,10

=

2,9

INVALID COMBINATION

=

3,1

=

3,6

=

4,3

=

4,4

=

4,5

INVALID COMBINATION

=

4,7

=

4,8

=

4,9

=

4,10

=

T

Figure D1-1 A TYPICAL COMPUTER RUN FOR A BIOMASS ALLOCATION SOLUTION
(Continued)

DEMAND SATISFIED BY BIOMASS= 1.1 PERCENT OF TOTAL DEMAND
IS THIS O.K. ? (Y/N)

=

N

NEW PCT

=

1.15

SOLUTION FOUND

FEEDSTOCK NUMBER	FEEDSTOCK AVAILABLE (MMETU/YR)	FEEDSTOCK USED (MMETU/YR)	PRODUCT NUMBER	INTERMEDIATE PROCESS	PRODUCT DEMAND (MMETU/YR)	SELLING PRICE (\$/MMETU)
2	0.1622E+07	0.1622E+07	45	11	0.3019E+07	0.3332E+01
6	0.3140E+06	0.3140E+06	45	13	0.3019E+07	0.3332E+01
8	0.2342E+07	0.1835E+07	45	26	0.3019E+07	0.3332E+01
9	0.5000E+06	0.2485E+06	5	4	0.4025E+07	0.9408E+01
14	0.7267E+06	0.1758E+06	40	16	0.5462E+06	0.4312E+01
17	0.1069E+07	0.1069E+07	5	12	0.4025E+07	0.9408E+01
18	0.1119E+07	0.1060E+07	14	28	0.4140E+07	0.7056E+01
22	0.9820E+06	0.8820E+06	14	23	0.4140E+07	0.7056E+01
30	0.7589E+05	0.7588E+05	14	8	0.4140E+07	0.7056E+01
19	0.1119E+07	0.5689E+05	39	28	0.5462E+06	0.3920E+01
46	0.3362E+07	0.3362E+07	14	7	0.4140E+07	0.7056E+01
9	0.5000E+06	0.1437E+06	30	4	0.3050E+05	0.1117E+02
14	0.7263E+06	0.6105E+06	39	16	0.5462E+06	0.3920E+01
2	0.2342E+07	0.5139E+06	40	26	0.5462E+06	0.4312E+01
9	0.5000E+06	0.5078E+06	45	4	0.3019E+07	0.3332E+01

Figure D1-1 A TYPICAL COMPUTER RUN FOR A BIOMASS ALLOCATION SOLUTION
(Continued)

REGION=NY/PA/WV
 SEASON=AUTUMN
 NUMBER OF ITERATIONS= 23
 TAILEND SIZE=11616 BYTES
 PROFIT FOR ITERATION 23= -0.14645E+07
 PROFIT FOR ITERATION 22= -0.14645E+07

FEEDSTOCK NUMBER/NAME	PRODUCT NUMBER/SECTOR/PRODUCT	EFFICIENCY	MANUFACTURING COST	PROFIT
2.OAKS,WHITE(O,E)	45. ELEC/STEAM	0.706E+00	0.288E+01	-0.627E+06
6.BIRCH,YELLOW(E)	45. ELEC/STEAM	0.706E+00	0.387E+01	-0.119E+06
8.MAPLE,SOFT(E)	45. ELEC/STEAM	0.706E+00	0.387E+01	-0.696E+06
9.BEECH(E)	5. TRANS/GASOLINE	0.560E+00	0.919E+01	0.304E+05
14.POPLAR,YELLOW(E)	40. ELEC/MED BTU GAS	0.792E+00	0.425E+01	0.835E+04
17.CHERRY,BLACK(E)	5. TRANS/GASOLINE	0.560E+00	0.919E+01	0.131E+06
19.HARDWOODS(O,E)	14. RES/ENG	0.784E+00	0.707E+01	-0.877E+04
25.PENLOCK(E)	14. RES/ENG	0.784E+00	0.707E+01	-0.730E+04
30.SOFTWOOD(O,E)	14. RES/ENG	0.784E+00	0.707E+01	-0.628E+03
18.HARDWOODS(O,E)	39. ELEC/LOW BTU GAS	0.816E+00	0.390E+01	0.100E+04
46.CORN,GRAIN	14. RES/ENG	0.784E+00	0.707E+01	-0.270E+05
9.BEECH(E)	30. CHEM/CHEMICALS	0.560E+00	0.109E+02	0.204E+05
14.POPLAR,YELLOW(E)	39. ELEC/LOW BTU GAS	0.816E+00	0.390E+01	0.104E+05
8.MAPLE,SOFT(E)	40. ELEC/MED BTU GAS	0.792E+00	0.425E+01	0.244E+05
9.BEECH(E)	45. ELEC/STEAM	0.706E+00	0.390E+01	-0.204E+06

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

FEEDSTOCK NUMBER/NAME	PRODUCT NUMBER/SECTOR/PRODUCT	DATA MISSING
47.SOYBEANS	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
48.CATS	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
50.PAPLEY	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
55.PYE	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
62.SUNIFER	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT
87.ARTICHOKE, JERUS.	ALL PRODUCTS(ABOVE)	FEEDSTOCK AMOUNT

Figure D1-1 A TYPICAL COMPUTER RUN FOR A BIOMASS ALLOCATION SOLUTION
 (Continued)

READY
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. SELECT SEASON

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

=
2

K. SELECT FEEDSTOCKS

=
3, 5, 8, 9, 11, 13, 14, 24, 25, 46, 51

H. SELECT MARKET SECTOR

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

SELECT PRODUCT

1. AMMONIA
2. SNG
3. LOW BTU GAS
4. MED BTU GAS
5. GASOLINE
6. CHEMICALS
7. METHANOL
8. FUEL OIL
9. STEAM
10. ELECTRICITY

ENTER "SECTOR", "PRODUCT"

=
1, 5
=
1, 7
=
1, 8
=
3, 8
=
4, 8
=
3, 3
=
4, 3
=
T

Figure D1-2 A TYPICAL COMPUTER RUN

DEMAND SATISFIED BY BIOMASS= 0.75 PERCENT OF TOTAL DEMAND
IS THIS O.K. ? (Y/N)

=
Y

SOLUTION FOUND

FEEDSTOCK NUMBER	FEEDSTOCK AVAILABLE (MMBTU/YR)	FEEDSTOCK USED (MMBTU/YR)	PRODUCT NUMBER	PRODUCT DEMAND (MMBTU/YR)	SELLING PRICE (\$/MMBTU)
25	0.6194E+06	0.6194E+06	8	0.1500E+07	0.6120E+01
3	0.2045E+07	0.1892E+07	44	0.1500E+07	0.6120E+01
8	0.2348E+07	0.3389E+06	5	0.2625E+07	0.8640E+01
9	0.9000E+06	0.9000E+06	8	0.1500E+07	0.6120E+01
11	0.9203E+05	0.9203E+05	8	0.1500E+07	0.6120E+01
13	0.3794E+06	0.3794E+06	8	0.1500E+07	0.6120E+01
14	0.7863E+06	0.7863E+06	5	0.2625E+07	0.8640E+01
24	0.2997E+06	0.2997E+06	5	0.2625E+07	0.8640E+01
5	0.8132E+06	0.8132E+06	44	0.1500E+07	0.6120E+01
8	0.2348E+07	0.4973E+06	8	0.1500E+07	0.6120E+01
46	0.3262E+07	0.3262E+07	5	0.2625E+07	0.8640E+01
3	0.2348E+07	0.4596E+06	7	0.2625E+06	0.9360E+01
3	0.2045E+07	0.1525E+06	8	0.1500E+07	0.6120E+01
8	0.2348E+07	0.9088E+05	27	0.7125E+05	0.3600E+01
8	0.2348E+07	0.5252E+06	32	0.3000E+06	0.6120E+01
8	0.2348E+07	0.4366E+06	39	0.3562E+06	0.3600E+01
51	0.1000E+06	0.6503E+05	8	0.1500E+07	0.6120E+01

Figure D1-2 A TYPICAL COMPUTER RUN (CONTINUED)

FIGURE D1-3
GRAPHICAL REPRESENTATION OF A TYPICAL SOLUTION

D2. MARKET ANALYSIS

Scope

The biomass feedstock information will include:

- o Feedstock amount by region and season in Btu/year
- o Heating values in Btu/lb for those feedstocks for which published data are available
- o Feedstock cost in \$/MM Btu

For the products, the primary information to be obtained will be:

- o Product amount by region in MM Btu/year
- o Product cost in \$/MM Btu

Progress to Date

During the past reporting period, work on the initial data base was completed. This feedstock data base consists of relative availability and price information by species for each region and season. Four regions were selected on the basis of an overlap between a high demand for biomass derived fuels and availability of biomass materials. The regions, selected on a state basis, are as follows:

Region I	NY/PA/WV	(silviculture, some agriculture)
Region II	LA/AL/MS	(silviculture)
Region III	IN/IL/IA	(agriculture)
Region IV	OR/WA	(silviculture)

The data are presently contained in a disk file in card image form. A typical printout from this file showing cost and availability information for the sixty-one biomass resources in region during the summer season is shown in Table D1-1.

The product data base consists of the current demands and product costs projected to 1985 for fuels derived from biomass. Typical data taken from the product file for a region is shown in Table D1-2.

A document describing the market analysis approach was prepared in a preliminary form.

Future Plans

During the next reporting period the market analysis document will be improved, but the level of effort for this work will remain small until such time that the document must be prepared in final form.

TABLE D1-1
FEEDSTOCK COST AND AVAILABILITY

REGION=2
SEASON=1

SPECIES		COST (\$/MMBTU)	AVAILABILITY FOR REGION-SEASON (TRILLIONS BTU/YR)
1.	OAKS, WHITE (S,E)	2.02	3.782
2.	OAKS, WHITE (O,E)	2.19	3.458
3.	OAKS, RED (S,E)	2.19	1.540
4.	OAKS, RED (O,E)	1.93	10.373
5.	HICKORY (E)	2.02	4.084
6.	BIRCH, YELLOW (E)	2.02	0.0
7.	MAPLE, HARD (E)	1.58	0.044
8.	MAPLE, SOFT (E)	2.14	1.433
9.	BEECH (E)	2.14	0.317
10.	SWEETGUM (E)	2.04	7.610
11.	TUPELO/8.GUM (E)	2.09	5.902
12.	ASH (E)	2.14	1.192
13.	BASSWOOD (E)	2.14	0.095
14.	POPLAR, YELLOW (E)	1.69	2.949
15.	COTTONWOOD/ASP.	1.62	0.231
16.	WALNUT, BLACK (E)	2.19	0.035
17.	CHERRY, BLACK (E)	2.19	0.151
18.	HARDWOODS (O,E)	1.62	4.002
19.	ALDER, RED (W)	2.02	0.0
20.	OAK (W)	1.70	0.0
21.	HARDWOODS (O,W)	2.02	0.0
22.	LONGLEAF/SP (E)	1.84	15.491
23.	SHORTLEAF/LOB, E	1.75	41.303
24.	PINE, YELLOW (O,E)	2.02	2.865
25.	PINE, R/W (E)	2.02	0.309
26.	PINE, JACK (E)	1.98	0.0
27.	SPRUCE/8.FIR (E)	2.02	0.0
28.	HEMLOCK (E)	2.19	0.031
29.	HEMLOCK (W)	2.02	0.0
30.	SOFTWOOD (O,E)	2.02	0.278
31.	PONDEROSA/J.PINE	1.64	0.0
32.	FIR, DOUGLAS (W)	2.02	0.0
33.	FIRS, TRUE (W)	1.83	0.0
34.	CYPRESS (E)	2.02	1.719
35.	PINE, SUGAR (W)	2.02	0.0
36.	PINE, WHITE (W)	2.02	0.0
37.	REDWOOD (W)	2.27	0.0
38.	SPRUCE, SITKA (W)	1.88	0.0
39.	ENGELMANN (+O,W)	2.18	0.0
40.	LARCH (W)	2.02	0.0
41.	CEDAR, RED (W)	1.25	0.0
42.	CEDAR, INCENSE (W)	1.73	0.0
43.	PINE, LODGEPOLE (W)	2.02	0.0
44.	SOFTWOOD (O,W)	2.02	0.0
45.	WHEAT	0.27	1.070
46.	CORN, GRAIN	0.35	4.387
47.	SOYBEANS	0.27	6.126
48.	OATS	0.27	0.227
49.	POTATOES	0.27	0.647
50.	BARLEY	0.27	0.108
51.	SUGARBEET, FIELD	0.27	0.0
52.	SORGUM, GRAIN	0.27	0.167
53.	RICE, STRAW	0.17	0.208
54.	SUGARCANE, FIELD	0.35	1.422
55.	COTTON	0.27	0.627
56.	PEANUTS	0.35	0.864
57.	BAGASSE	0.44	0.311
58.	RYE	0.27	0.088
59.	GRASSES, SEED	0.34	0.0
60.	HULLS, RICE	0.40	0.0
61.	SUGARBEET, PULP	0.35	0.0

TABLE D1-2
PRODUCT DEMAND AND PRICE

PRODUCT NUMBER	PRODUCT NAME	PRODUCT DEMAND MMBTU/YR	PRODUCT COST \$/MMBTU
1	CHEM/AMMONIA	0.1000E+07	0.2610E+02
2	RES/SNG	0.5000E+09	0.5897E+01
3	ELEC/SNG	0.6250E+09	0.5897E+01
4*	CHEM/LOW BTU GAS	0.2500E+08	0.3312E+01
5*	ELEC/LOW BTU GAS	0.1250E+09	0.3312E+01
6*	CHEM/MED BTU GAS	0.2500E+08	0.3643E+01
7*	ELEC/MED BTU GAS	0.1250E+09	0.3643E+01
8	TRANS/GASLINE	0.3625E+09	0.7449E+01
9	CHEM/CHEMICALS	0.7500E+07	0.8611E+01
10*	TRANS/METHANOL	0.3750E+08	0.9266E+01
11*	CHEM/METHANOL	0.7500E+07	0.9266E+01
12*	ELEC/METHANOL	0.3750E+08	0.9266E+01
13	TRANS/FUELOIL	0.1250E+09	0.5141E+01
14	RES/FUELOIL	0.1000E+09	0.5141E+01
15	CHEM/FUELOIL	0.2500E+08	0.5141E+01
16	ELEC/FUELOIL	0.1250E+09	0.5141E+01
17*	ELEC/STEAM	0.3750E+08	0.2509E+01
18	RES/ELECTRICITY	0.1680E+09	0.1236E+02
19	CHEM/ELECTRICITY	0.4200E+08	0.1236E+02
20	ELEC/ELECTRICITY	0.2100E+09	0.1236E+02
21		0.0	0.0
22		0.0	0.0
23		0.0	0.0
24		0.0	0.0

D3. MODELING BIOMASS REACTIONS

Scope

The original scope of work for Task 7 stated that "The kinetics of both catalytic and noncatalytic biomass conversion will be developed in this task based on the experimental data obtained in Tasks 2 through 5 and stored in the data bank tape created in Task 6 and that the kinetic studies will be performed for combustion, steam-air or steam-oxygen gasification, hydrogasification and pyrolysis."

Successful development of a gasifier reactor model requires not only a good understanding of chemical kinetics but also the hydrodynamics. A wealth of information exists on coal conversion. However, very little information exists on the complex structure changes of biomass/char particles during reactions and on rates of gasification for various biomass materials. For this reason we have proceeded to modify the existing coal conversion reactor model to simulate the biomass gasification process.

Due to delay in obtaining experimental data, the major effort thus far has been focused on investigating the importance of the operating parameters on the entrained bed gasifier performance by using rate equations from coal gasification.

Progress to Date

1. Entrained Bed Gasifier

The complex hydrodynamics of an entrained bed gasifier have been successfully approximated by the compartment-in-series approach in a recent study of Texaco Gasifier Model by Dr. Wen of West Virginia University Dept. of Chemical Engineering. This approach selects a large compartment size (about 1/20 of the effective reactor length) for the mixing zone immediately following the inlet. Smaller compartment sizes (about 1/100 of the effective reactor length each) are employed in the model for the following plug flow (with dispersion) zones.

Material and energy balance equations can be set up for each compartment as shown in Figure D3-1. The calculation procedures of the computer program to solve these set of simultaneous equations is shown in Figure D3-2.

Parameter studies are made to provide a better understanding of the reactor performance for various operating conditions utilizing this model. In particular, the carbon conversion, the product gas distribution, temperature profiles along the reactor and the thermal efficiency are studied. The types and ranges of the variables investigated include:

FIGURE D3-1
HEAT AND MASS BALANCES
IN n -th COMPARTMENT

FIGURE D3-2
COMPUTER FLOW DIAGRAM FOR THE ENTRAINED BED MODEL

Reactor Operating Pressure	21.4 atm and 1 atm
Biomass Feed Temperature	480°K
Average Particle Size	500 μ m
Biomass Feed Rate	200 and 500 g/sec.
Water-Fuel Weight Ratio	0.3 - 0.6
Oxygen-Fuel Weight Ratio	0.2 - 0.9

The proximate and ultimate analysis of the biomass considered in this study are:

<u>Ultimate Analysis</u>	<u>Dry Maple, Wt. Percent</u>
C	50.6
H	6.0
O	41.7
N	-
Ash	<u>1.6</u>
Total	99.9

<u>Proximate Analysis</u>	<u>Wet Basis Wt. Percent</u>	<u>Dry Basis Wt. Percent</u>
Moisture Content	25.0	--
Volatile Matter	57.1	76.1
Fixed Carbon	14.7	19.6
Ash	<u>3.2</u>	<u>4.3</u>
Total	100.0	100.0
Heating Value	8190 Btu/lb	

In all pressurized (21.4 atm) cases, carbon conversion is almost complete (99%). This is due to the high volatile matter content of the biomass (76.1%). Fixed carbon (19.6%) is for all practical purposes totally gasified (more than 99%) within 6 feet of the reactor after the fuel being fully devolatilized. The reactor length required for the devolatilization is usually about one foot from the top of the reactor. Figure D3-3 shows an example of the carbon conversion as well as the temperature profiles for the solids and gas along the reactor. The product gas distribution from the same run is also shown in Figure D3-4.

The effects of oxygen-fuel ratio on the major gaseous products (CO, H₂ and CO₂) in terms of the gas distribution and the thermal efficiency are shown in Figure D3-5, 6, 7, and 8 for a biomass feed rate of 200 g/sec. Water-fuel ratios are varied as 0.3, 0.4, 0.5, and 0.6 are found to be quite sensitive to this parameter. It appears that an optimum range of oxygen-fuel ratio (0.5-0.6) exists at which the thermal efficiency is a

FIGURE D3-3
CALCULATED TEMPERATURE PROFILES AND
CARBON CONVERSION PROFILE IN A
CO-CURRENTLY DOWN FLOW ENTRAINED BED GASIFIER

FIGURE D3-4
CALCULATED PRODUCT GAS COMPOSITION
PROFILES (WET BASIS) A CO-CURRENTLY
DOWN FLOW ENTRAINED BED GASIFIER

FIGURE D3-5
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION AT WATER/FUEL
= 0.3 g/g IN A CO-CURRENTLY DOWN FLOW ENTRAINED BED GASIFIER

FIGURE D3-6
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

FIGURE D3-7
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

FIGURE D3-8
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

maximum. Beyond the optimum range, the amount of oxygen supplied to the gasifier appears to be excessive and the gas product becomes mainly of CO_2 and H_2O decreasing the thermal efficiency considerably. Below this range, the amount of oxygen is not sufficient and tar produced during devolatilization emerges with other gaseous products. This decreases the amount of gas produced and the thermal efficiency if tar is excluded from calculation of efficiency. The outlet solid (ash) temperature depends strongly on the oxygen-fuel ratio. A large amount of oxygen fed, means a high solid temperature. Figures D3-9 and 10 show that the outlet temperature increases linearly for the oxygen-fuel ratio greater than 0.6 for the feed rates of 200 and 500 g/sec.

Figures D3-11, 12, 13, and 14 are for 500 g/sec. solid feed rate. The optimum range of oxygen-fuel ratio seems to be the same for both flow rates studied. The change in the outlet temperature is clearly related to the amount of solids fed to the reactor. High outlet temperatures are obtained for small solids feed rates.

The amount of water-fuel ratio will also affect the temperature. The water fed into the reactor, as discussed previously is slightly below the saturation temperature. It takes a large amount of energy to bring the water to the gas temperature. Therefore, feeding a large amount of water means a low outlet temperature.

Although the proposed model can provide some insight into the operation of an entrained-bed gasifier, experimental data are needed to verify and refine the model developed. Especially, the chemical kinetics of biomass devolatilization and biomass char gasification reaction which is to be derived from experimental laboratory data. Additional information is also needed regarding the experimental data on temperature and concentration profiles for different types of biomass.

2. Fixed Bed Gasifier

There have been several fixed bed gasifier models developed based on coal gasification. All of these models were of the updraft type in which coals move downward while coming into contact with gases flowing upward countercurrently. The bed consists of a preheating zone at the top followed by a pyrolysis zone, a gasification zone, a combustion zone and an ash zone at the bottom. Most of these published mathematical models assume that drying and devolatilization reactions are instantaneous. Although this assumption may be justified for coal gasification, it is certainly not applicable to biomass gasification because biomass loses about two-thirds of its dry weight during pyrolysis. The pyrolysis process must be well understood if we are to model biomass gasification properly.

Unfortunately, the literature contains little quantitative information on biomass pyrolysis. The Effluent Gas Analysis Experiment at West Virginia is still yet to develop experimental results. Again, we are forced to use available coal pyrolysis data. Here the effective kinetic parameters (activation energy and frequency factor) determined from the experimental work in

FIGURE D3-9
TEMPERATURE OF THE SOLID AS A
FUNCTION OF OXYGEN/FUEL RATIO

FIGURE D3-10
TEMPERATURE OF THE SOLID AS A FUNCTION
OF OXYGEN/FUEL RATIO

FIGURE D3-11
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

FIGURE D3-12
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

FIGURE D3-13
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

FIGURE D3-14
EFFECT OF OXYGEN/FUEL RATIO ON THE THERMAL EFFICIENCY
AND THE MAJOR PRODUCT GAS COMPOSITION IN THE
ENTRAINED BED GASIFIER

Lawrence Livermore Laboratory on Wyoming Subbituminous coal were used to model pyrolysis zone in fixed-bed gasifier.

The mathematical model developed by Dr. Wen is adapted here to model the gasification zone in a fixed bed gasifier.

Several simplifying assumptions are made in the model as follows:

1. Volumetric reaction is assumed for all gas-solid reactions except combustion for which shrinking core model is assumed.
2. Gas temperature is the same as solid temperature at every point in the gasifier, i.e. heat transfer between gas and solid is instantaneous.
3. Temperature at the bottom of the gasifier is equal to the inlet temperature of the gas mixture.
4. All the volatile matter as determined by proximate analysis is released in the devolatilization zone and therefore the amount of char formed is the same as the amount of fixed carbon plus ash as determined by proximate analysis.
5. Drying zone is not included in the model.
6. Devolatilization reaction is thermally neutral.
7. Gasifier pressure is constant.

To simulate the gasification-combustion zone, differential equations with respect to distance along the height of the gasifier are set up for each of the eight variables considered in the gasification-combustion zone, namely, temperature, and the flow rates of fixed carbon, CO, CO₂, O₂, H₂, CH₄ and H₂O. For example, the temperature profile and the molar flow rate of CO can be represented by the differential equations which have the following form:

$$\frac{dT}{dz} = \sum_{i=2}^8 H_i R_i - h \pi D (T - T_w)$$

$$\frac{dW_{CO}}{dz} = aR_1 + R_2 - R_3 + 2R_5$$

These simultaneous first order non-linear differential equations are solved using Runge-Kutta with fixed length integration scheme. Initially, the value of carbon conversion is assumed and is used to estimate the solids concentration at the bottom of the gasifier. The integration is started at the point above the grate ($Z = 0$) using gas and solid concentration as the initial values. The integration is continued over the entire length of the bed. The value of carbon flow rate at $Z = L$ (where L = height of bed) is compared with the carbon feed rate. If the difference is found to be more than 1.0 gm/sec, the assumed carbon conversion is changed and the entire procedure is repeated.

To date, the preliminary results of the test run indicated that the modification made to the original computer program have been successfully debugged. The numerical method used to solve the set of differential equations is reasonably quick to converge. Generally, with a step size of 2 cm in gasification zone (total number of steps ~ 50) and a step size of 1 to 4 cm in devolatilization zone (total number of steps ~ 100), convergence can be obtained within five to eight iterations.

The preliminary results of a sample run are summarized in Table D3. The high carbon and steam conversions are achieved by using a bed height of about 18 feet. Again, as stated earlier, these results are based on the kinetic rate from coal conversion reactions. Compared to coal, biomass is significantly more reactive. If we keep the kinetic rates of char gasification the same and just increase the devolatilization rate ten times, the same carbon and steam conversion can be achieved within a bed height of 6.1 ft. as shown in Table D3. The result further demonstrated that good kinetic data are essential for accurate mathematical modeling of various processes. The computer program will need considerable refinement before it can be used with confidence.

Future Plans

As soon as the experimental data is available, the effective kinetic parameters for different biomass conversion will be determined. These kinetic data instead of the data from coal conversion will be used in the biomass modeling process.

Parameter studies, e.g. oxygen or air/biomass, steam/biomass effects, will be made to provide a better understanding of the fixed bed gasifier performance for various operating conditions. Mathematical models for fluidized bed biomass gasifier shall begin.

TABLE D3

SAMPLE RESULTS OF FIXED BED GASIFIER

Feed rates: Biomass = 35325 lb/hr

Steam = 13084 lb/hr

Oxygen = 5029 lb/hr

Feed temperatures: Biomass = 70°F

Steam = 700°F

Oxygen = 700°F

Pressure: 344 psig

Bed diameter: 10 ft.

	A	B
Height of gasification zone, ft.	4.0	4.0
Height of devolatilization zone, ft.	14.0	2.1
Total bed height, ft.	18.0	6.1
Exit gas temperature, °F	695	985
Maximum bed temperature, °F	2200	2200
Amount of exit steam, lb/hr	7527	7901
Amount of tar formed, lb/hr	6445	7445
Amount of product gas (lb mole/hr - dry & tar free)	1839	1952
Composition of product gas (mole %)		
CO	22.5	30.5
CO ₂	23.1	16.1
H ₂	30.5	36.8
CH ₄	23.1	16.1
N ₂	0.5	0.5
Higher ² H.C. (C ₂ & C ₃)	0.1	-
HHV of product gas, Btu/SCF	390	365
Carbon conversion, % of FC	98.1	98.1
Thermal Efficiency = $\frac{\text{HHV of product gas}}{\text{HHV of coal feed}}$	89.4%	88.8%
Steam Conversion, % of steam feed	62.5%	59.6%

A = Use Campbell's reaction rate in devolatilization zone

B = Use ten times the reaction rate in Case A in devolatilization zone

D4 PROCESS ECONOMICS

Scope

The objective of this task is to perform economic analyses of selected processes for conversion of biomass to marketable products such as low or medium-Btu gas, SNG, and methanol. Thermal efficiencies will also be determined for each of the processes. The process efficiencies and product manufacturing costs will be used as inputs for the data bank of the biomass allocation model.

Progress to Date

Conceptual economics have been generated for seven of the fourteen process configurations listed in Table D4-1 via a biomass economic computer program. Features of the economics program include: Generation of an expandable computer data bank for the storage of biomass conversion plant capital and operating cost data obtained from various published literature sources. The economic data will be classified by plant type, biomass type, plant size, capacity factor, etc.; Procedure for extracting information from the data bank for specified plant type, plant size, and biomass type; Input options for reviewing and adjusting the economic data in the computer data bank. The user has the option of varying plant size, capacity factor, efficiency, biomass feed rate, biomass type (high heating value and density), biomass cost, and inflation factors; Calculation procedure for determining factored plant capital costs, net operating costs, and total capital; Calculation of product cost in \$/MM Btu using the discounted cash flow and utility financing method procedures.

Two cases originally considered for evaluation, production of chemical grade methanol from medium-Btu gas, and production of gasoline, fuel oil and chemicals via Fischer-Tropsch processing of medium-Btu gas, have been deleted. The biomass allocation model does not differentiate between fuel and chemical grade methanol; hence the chemical grade methanol case has been deleted. Minimal economic data are available for Fischer-Tropsch processing. Available data suggest that application of this coal-based technology to biomass feedstocks is probably economically infeasible. A new case, production of fuel oil via pyrolysis of biomass, has been added to the list shown in Table D4-1. The process configurations completed to date include medium-Btu gas, SNG, fuel grade methanol from medium-Btu gas, ammonia from medium-Btu gas, gasoline from methanol via the Mobil-M process, power generation from direct combustion of biomass, and production of fuel oil by pyrolysis of biomass. A preliminary analysis of low-Btu gas production was also performed. However, additional information shall be added to the data bank before completion of this case.

Parametric evaluations of these process configurations were made by varying the plant size, biomass cost, process thermal efficiency, biomass higher heating value, and biomass bulk density. The parametric evaluation of each process configuration will be utilized to estimate the average product cost (DCF financing basis) for each of the 61 biomass species listed in Table D1-1. Figures D4-1, D4-2, and D4-3 are representative samples of the results of the parametric evaluation of medium-Btu gas production. Figure D4-1 illustrates

TABLE D4-1

PROCESS CONFIGURATIONS FOR WHICH ECONOMIC DATA ARE BEING DEVELOPED

- o Low-Btu gas
- o Medium-Btu gas
- o High-Btu gas (SNG)
- o Fuel grade methanol from medium-Btu gas
- o Ammonia from medium-Btu gas
- o Gasoline from medium-Btu gas via Mobile-M process
- o Power generation from direct combustion of biomass via conventional boiler (baseload)
- o Fuel oil via pyrolysis
- o Power generation from low-Btu gas via combined cycle (baseload)
- o Power generation from low-Btu gas via conventional boiler (baseload)
- o Power generation from medium-Btu gas via combined cycle (baseload)
- o Power generation from medium-Btu gas via conventional boiler (baseload)
- o Power generation from fuel grade methanol via combined cycle (intermediate service)
- o Power generation from fuel grade methanol via gas turbine (peaking service)

FIGURE D4-1
PRODUCT COST VS. PLANT SIZE FOR MEDIUM-BTU GAS
(HHV= 7800 BTU/LB, CAPACITY FACTOR= 0.9, THERMAL EFFICIENCY =
70%, BIOMASS COST= \$2.00/10⁶ BTU)

FIGURE D4-2
PRODUCT COST VS. PLANT THERMAL EFFICIENCY FOR MEDIUM-BTU GAS
(HHV= 7800 BTU/LB, CAPACITY FACTOR= 0.9, BIOMASS COST =
\$2.00/10⁶ BTU, PLANT CAPACITY= 10.0 X 10⁶ BTU/DAY)

FIGURE D4-3
PRODUCT COST VS. BIOMASS HIGHER HEATING VALUE FOR MEDIUM-BTU GAS
(CAPACITY FACTOR= 0.9, THERMAL EFFICIENCY=
70%, BIOMASS COST= \$2.00/10⁶ BTU, PLANT CAPACITY= 10.0 X 10⁹ BTU/DAY)

FIGURE D4-4
PRODUCT COST VS. BIOMASS UNIT COST FOR MEDIUM-BTU GAS
(HHV= 7800 BTU/LB, CAPACITY FACTOR= 0.9, THERMAL EFFICIENCY=
70%, PLANT CAPACITY= 10.0×10^9 BTU/DAY)

the effect of plant size on the average product cost (DCF financing basis). The most reasonable plant size for a particular region and season will be selected for each biomass type. Near-term plant sizes are expected to fall in the range of about 300-750 ton/day of biomass feedstock. Figure D4-2 shows the effect of plant thermal efficiency on product gas cost. Plant thermal efficiency has been defined as the product energy value divided by the feedstock biomass energy values, all energy values based on reported higher heating values. Plant thermal efficiencies utilized in this task have been generated from available literature sources. Variations in plant thermal efficiencies attributable to processing feedstocks from Table D4-2 will be estimated by correlation of biomass ultimate analysis data.

Figure D4-3 illustrates the effect of biomass heating value on the average product cost for medium Btu gas. The higher heating value of most hardwoods and softwood species are similar. Anticipated variations in heating value will not have as significant an effect on the average product cost of medium-Btu gas as will plant size and process thermal efficiency. Figure D4-4 shows the effect of varying biomass unit costs on the cost of the medium-Btu gas product. Increasing the cost of biomass increases plant operating costs without effecting capital costs, resulting in the linear relationship.

A representative sample of output data is summarized in Table D4-3. As one would expect, the production cost of an end product such as medium-Btu gas is lower than for end products which are created from additional processing of gasified biomass such as SNG, methanol, and gasoline. The high cost of producing electricity by direct combustion of electricity is attributed to high capital costs and low process thermal efficiency.

Future Plans

The process economics model will be used to develop cost data for the six remaining processing schemes. The completed data sets will be analyzed to determine product manufacturing costs and thermal efficiencies for each of the fourteen process configurations. This information will then be used in operating of the biomass allocation model.

TABLE D4-3
RESULTS OF ANALYSIS OF PROCESS ECONOMICS

<u>Product Type</u>	<u>Medium-Btu Gas</u>	<u>SNG</u>	<u>Methanol</u>	<u>Ammonia</u>	<u>Gasoline</u>	<u>Electricity, 200 MW (Direct Combustion)</u>	<u>Fuel Oil (Pyrolysis)</u>
<u>Process Summary</u>							
Product Capacity, 10 ⁹ Btu/day	11.70	9.36	7.02	10.14	6.24	16.38	9.36
Biomass Feedrate, ^{ton/day} (bone dry)	1000	1000	1000	1000	1000	3003	1000
Biomass Cost, \$/10 ⁶ Btu	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Biomass HHV Btu/lb	7800	7800	7800	7800	7800	7800	7800
Plant Capacity Factor	0.9	0.9	0.9	0.9	0.9	.07	0.9
43 Thermal Efficiency	0.75	0.60	0.45	0.65	0.40	.035	0.60
<u>Economic Summary</u>							
Capital Cost, 10 ⁶ \$	27	32	44	56	159	100	25
Net Operating Cost, 10 ⁶ \$/yr	14	15	16	19	25	33	24
Product Cost, \$/10 ⁶ Btu, DCF Financing Basis	4.91	6.57	10.39	8.61	30.05	12.28	9.49

D5. PROCESS DEVELOPMENT UNIT STUDIES

Scope

The Process Development Unit studies at Environmental Energy Engineering are designed to demonstrate steady state thermochemical conversions of biomass to fuels in fluidized, moving and entrained bed reactor configurations.

Progress To Date

Section D5 consists of a portion of a project report prepared for a recent project review meeting.

INDEX

I. EXECUTIVE SUMMARY

II. CONTRACT EXECUTION

II-A. Pulse Tests (Task 5)

II-B. Steady State Tests (Tasks 9, 10 & 11)

I. EXECUTIVE SUMMARY

SCOPE OF CONTRACT:

Environmental Energy Engineering, Inc. as a subcontractor to Gilbert Associates, Inc. is charged with the responsibility of performing the large scale reactor testing and the generation of data for incorporation into the overall Gilbert process model developed for the Department of Energy on this project. Specifically E.E.E. is responsible for the following tasks on the overall project schedule.

- TASK 5 - Evaluation of the effect of biomass particle size on fluidized bed runs.
- TASK 9 - Verification of process models selected for non catalytic runs.
- TASK 10 - Verification of process models for selected catalytic runs.
- TASK 11 - Demonstration of sustained PDU Runs.

CONTRACT TECHNICAL ORGANIZATION:

The four tasks listed in the contract have been grouped into two major operating categories as follows:

- Pulse Tests - Fluidized bed tests to determine the effect of particle size on reaction rate and product gas composition (TASK 5).

- Steady State Tests - Packed bed, Entrained bed and Fluidized bed tests to determine the effects of material on reaction rate and product gas composition (TASKS 9,10,11)

Additionally a third series of tests (above the contract requirements) will be added without exceeding the allowed time schedule or original contract estimate. This series will provide information as follows:

- Parametric Tests - Fluidized bed tests will be utilized to duplicate steady state test conditions and selectively vary operating parameters to provide information on unit capacity, and the effects of variations in temperature, fuel/O₂ ratio, moisture content etc. for materials previously run.

CONTRACT STATUS:

Pulse Tests (Task 5)

- Pulse tests were initiated in April 1979 and completed in late August 1979 with the report submitted in September 1979.
- Tests were made in the E.E.E. two (2) foot diameter fluidized bed modified to provide for uniform sample mixing, program timed sampling and rapid withdrawal and cooling of the product sample.

- Tests demonstrated that the reaction time was directly proportional to cross-sectional area of the particle, however, the gas composition as a function of particle size could not be accurately determined. In all cases the material balance did not close well. It is theorized that the rapid withdrawal of the sample required by the timed sample system resulted in gas existing with substantial quantities of higher hydrocarbons which were not measured by the chromatograph (GC limited to methane). Additional test verification of this is planned for the parametric runs.

Steady State Tests (Tasks 9,10 & 11)

- E.E.E. reactor modified to provide an indirectly fired fluidized bed, fixed bed or entrained bed reactor with the capacity to utilize steam, C_2 or air as a reactant gas with variable inlet temperatures from ambient to 900°F and a zoned external heat source to provide profile heating as required.
- Engineering for the modifications commenced in February 1979 and was completed in August 1979 with equipment purchasing fabrication and delivery commencing in April 1979 and being substantially complete in September 1979.
- Modifications were installed commencing in August 1979 with completion and start up in November 1979.

- Preliminary shakedown runs were made between mid November 1979 and late December 1979 to adjust the equipment. All equipment functions well at constant rate, however, feed system does not have sensitivity to permit small incremental changes during operation. This capability is presently being acquired in a sensitive weigh belt feeder system.
- Preliminary operating test runs commenced January 1, 1980 in the fluidized bed mode. Summary results for the first three test runs are listed below:

Preliminary Test Results
Two Hour Tests
Fluidized Bed

MATERIAL	MEDIA	HHV BTU/SCFI	Yield SCF/LB. (DRY)	COMPOSITION (% VOL. DRY)			
				H ₂	CO ₂	CH ₄	CO
Peanut Hulls	Air	162	35.6	14.2	15.4	4.7	22.3
Peanut Hulls	Steam-O ₂	248	21.4	23.2	40.5	8.7	27.9
Wood	Air	165	32.9	12.6	15.9	5.6	22.5

- Steady state runs will continue in the fluid bed mode utilizing both catalytic and non catalytic beds to complete the two hour short term verification runs by March 1, 1980.
- The unit will be converted to the fixed bed and entrained bed modes and verification runs made commencing March 1, 1980 and extending to May 1, 1980.

FIGURE 1 Equipment Set-up for Particle Size Effect Tests

II-A. PULSE TESTS

TASK 5 - PARTICLE SIZE EFFECTS

Task Description: Determine the effect of particle size on pyrolytic thermal treatment of biomass using a fluidized bed.

FIRST SERIES OF TESTS

Equipment Description:

- o Figure 1 is a sketch of the equipment setup for the particle size effect tests.
- o The feed material was dropped into the bed through a two valve system to maintain a gas seal in the pipe.
- o A truncated cone was installed about one foot above the bed. This cone provided rapid mixing of the gases so that representative samples could be taken.
- o The gas samples were pulled from the bed by a compressor. This compressor was a 16Hp Briggs and Stratton engine which was driven by an electric motor.
- o The sample gas passed through a condenser to remove most of the water vapor.
- o The gas passed through a sample manifold. The sample manifold consisted of eleven solenoid valves. Ten of the valves were for filling gas sample bags and the other valve was on the manifold exhaust.
- o The opening and closing of the solenoid valves was controlled by a microprocessor which was preprogrammed with sampling times.
- o Long duration runs will be made in the fluidized bed mode commencing May 1, 1980 and completing June 15, 1980.

Parametric Studies:

Parametric studies will be initiated at the conclusion of the long duration runs on June 15, 1980 and will be conducted in the fluidized bed mode to determine the effects of variation in temperature, feed gas mixture, capacity, etc. A separate report supplement will be issued on these studies in October 1980.

TEST PROCEDURE:

- The feed materials were prepared by cutting to the desired lengths and oven drying at 105°C. In a few cases the feed materials were either submerged in water or stored in an oven which was maintained at 27°C with a water reservoir.
- A test was made by
 - weighing the feed material
 - programming the microprocessor
 - dropping the feed material into the fluidized bed
 - starting the microprocessor
 - analyzing the bag samples with a gas chromatograph
- The gas sampling times were measured starting 2 seconds after the material was dropped. This is the time required for the material to reach the bed, and for the gas to leave the cone.

RESULTS:

- Twenty eight runs were made in this first series of tests.
- A number of replicate tests were made. The values obtained for the gas yield, gas heating value, carbon efficiency, and energy efficiency did not appear to be reproducible.
- Figure 2 is a typical plot comparing the results for a set of replicate tests.

- It appeared that the replicates differed by a constant value. This would be the case if the steady state gas analysis shifted. The steady state gas analysis was taken at the start of the day and a new sample was taken whenever the operating conditions were changed.

SECOND SERIES OF TESTS

EQUIPMENT MODIFICATIONS:

- Smaller valves were placed on the air and gas streams to obtain better control.
- The cooler-condenser was moved so that the gas leaving the top of the fluidized bed unit was immediately cooled. This was to quench any gas phase reactions that might be taking place and to give larger gas sample volumes.

TEST PROCEDURE MODIFICATIONS:

- The gas sample manifold was evacuated before starting each test.
- The gas flow through the bed was checked by:
 - Carbon dioxide tracer in the air line.
 - An air rotameter.
 - Argon tracer in the bed.
- Before each test, care was taken to obtain a steady state with the following conditions:
 - No oxygen
 - Low hydrogen
 - Low methane
 - Low carbon monoxide

FIGURE 2 Comparison of Replicate Tests - Carbon Monoxide

RESULTS AND CONCLUSIONS:

- The effect of particle size on reaction time is shown in Figure 3. The time required for complete reaction was found to be proportional to the cross-sectional area of the particles.
- The conversion efficiencies of green wood were found to be between 50 and 80% of the efficiencies of oven dry wood.
- The tests had lower carbon and energy efficiencies than the previous tests. Some of the reasons for this could be:
 - The placement of the cooler-condenser before the compressor may have reduced the cracking of higher hydrocarbons which were not measured. It also could have increased the absorption of the hydrocarbons in the compressor oil because of the lower temperature of the oil.
 - Checks on the air orifice meter found it to be about 20% higher than the argon tracer or the air rotameter indicated. The argon tracer and air rotameter were considered to be more accurate than the orifice meter and were used in the analyses of these tests.
- The low efficiencies are probably the result of not measuring any hydrocarbon other than methane. The occurrence of higher hydrocarbons would increase the energy and carbon yields both from themselves and from increased yields of methane, carbon monoxide, carbon dioxide, and hydrogen as calculated from the nitrogen balance.

FIGURE 1 Effect of Particle Size on Total Reaction Time.

- The residence time will effect the amount of cracking of higher hydrocarbons that takes place. To follow the transient response of a pulse test, the gases were removed quickly from the reaction zone and cooled. This shortened the gas residence time.
- The cone used to promote gas mixing also acted as a radiation shield. This reduced the temperature that the gas sample passed through and as a result help to retard higher hydrocarbon cracking.

II-B. STEADY STATE TESTS

TASKS 9,10 & 11

Task Description: Fluidized Bed, Entrained Bed, Fixed Bed, Steady State Tests to evaluate the effect of material composition on reaction rate and product gas composition.

EQUIPMENT DESCRIPTION AND MODIFICATIONS:

- A large number of modifications have been made to the system. Figure 4 is a sketch of the equipment layout. Figure 5 is a processing and instrumentation diagram.
- Oxygen is supplied from liquid oxygen tanks. The oxygen flow rate is measured with a rotameter.
- Steam is supplied from a 9.5 horsepower Parker Industrial Boiler. The steam rate is measured with an orifice meter.
- Air is supplied by a Spencer Turbo-Compressor. The air rate is measured with an orifice meter.
- The reactant gases pass through a 34KW General Electric circulation heater which is controlled by an Athena 1200 controller.
- The reactor was modified as follows:
 - An 18" O.D. RA-330 Tube was installed in the reactor. This tube serves as the reaction chamber. Figure 6 is a sketch of this tube. This tube reduced the capacity of the fluidized bed by 50%. It also provides a method to add heat to the reaction chamber or to negate the heat losses from the reaction chamber.

FIGURE 4
Equipment Layout

FIGURE 5
Process and Instrumentation Diagram

FIGURE 6
Reaction Chamber Tube

- Heat can be supplied to the reaction chamber by four burners which are fired tangentially into the annulus space around the reaction chamber. Figure 7 shows a sketch of the burner system.
 - Figure 8 shows the reactor set-up for the fluidized bed mode of operation. A detail of the distributor insert is shown in Figure 9. The distributor has 392 holes with a diameter of 1/16 inch. The holes are on a square pattern with 3/4 inch centers.
 - Figure 10 shows the reactor set-up for the packed bed mode of operation. This set-up is exactly the same as the fluidized bed except that a coarse sand bed is placed on the distributor.
 - Figure 11 shows the reactor set-up for the entrained bed tests. For this system the distributor is removed and the fuel is fed into the inlet gas stream with an ejector.
- In all cases a rotary air lock is used to feed the fuel to the reactor. This rotary valve is only used as an air lock. Initially the feed rate was controlled by a vibrator feeder. The feed rate was found to vary when the vibrator was used so a screw conveyor is now being used. The feed material is supplied to the screw conveyor hopper with an air lift. Figure 12 shows the feed system for the fluidized bed and the packed bed tests. For the entrained

Note: Top burners are
rotated 90° from the
bottom burners.

Figure 1 Burner System

FIGURE 3
Fluidized Bed Reactor System

FIGURE 9
Distributor Insert

Figure 10
Moving Bed Reactor System

Figure 11
Entrained Bed Reactor System

FIGURE 12
Feed System

bed tests the screw conveyor, hopper and rotary air lock will be moved so that the system can be fed from the bottom.

- After the product gases leave the reaction chamber they pass through a cyclone for carbon removal and then they pass through an afterburner where the combustible gases are burned.
- Gas samples are taken from the duct between the reactor and the cyclone. Sampling systems are described in the next section.
- The exhaust gases from the afterburner pass through a scrubber and then an exhaust fan.

SAMPLING SYSTEM:

- A Bendix on-line gas chromatograph is used to analyze the gases for hydrogen, carbon dioxide, oxygen plus argon, methane, and carbon monoxide. The gases are analyzed every five minutes. The sample for this gas chromatograph passes through a cooler-condenser. This gas sampling system is shown in Figure 15.
- Higher hydrocarbons will be determined by passing the column vent and backflush vent through an activated carbon trap. These traps will then be analyzed at WU.
- A third sample system is planned. This system is shown in Figure 14. The first trap will be used to collect the tars. The second trap will be used to collect the rest of the gases and the third trap will be used to insure that all of the gases have been collected.

PRELIMINARY TESTS:

- Originally the feed tube was extended into the bed so that the fuel was fed to the bed. The system was heated and wood pellets were fed. Large amounts of pyrolysis gases were found to be leaking from the rotary air-lock valve. It was concluded that the

FIGURE 13
Gas Sample System

FIGURE 14

Sample Trap System

feed material was not leaving the feed tube. The feed tube was shortened so that it ended about 6 inches above the bed.

- The system was tested again by feeding wood pellets. The leak problem at the rotary air-lock valve had been solved. It was found that some of the pyrolysis gases were leaking through the joint in the 18 inch reactor tube. This leak is a result of the inability to balance the draft between the center bed and the annulus. A four inch orifice was installed in the annulus exhaust duct. This reduced the gas leakage. No attempt has been made to eliminate the leakage since it is better to have some of the pyrolysis gases leaking out instead of annulus gases leaking in.
- The feed tube was initially water cooled. The tube plugged with pellets after about 15 hours of testing. The tube was cleaned out by turning the cooling water off and removing the rotary air lock valve. This allowed gases to pass up through the tube and eventually burn the tube clean. When the cooling water was restarted a leak developed so now the unit is being operated without the feed tube being cooled.

D6. BIOMASS CHARACTERIZATION

Scope

Over the life of the project the laboratory analyses being conducted at West Virginia University will provide the following characterization information for representative biomass feedstocks:

1. Biomass Thermal Profiles
2. Biomass Composition Information

Progress to Date

Section D6 consists of portions of a project report prepared for a recent project review meeting.

**Table of Conditions For
Pyro Analysis**

	Inert Gas	Reactive Gas	Large Sample	Small Sample	Temp. Variable
T.G.A.	X	X	X		X
E.G.A.	X	X			X
T.G.A./PA	X			X	
Thermogram	X			X	
PG-C	X			X	

**Non-Catalytic
Studies on Biomass
(Atmospheric)**

	Original Plan	Present Plan
1. Large T.G.A. (Pellets) N ₂ , CO ₂ , H ₂ O, H ₂ atm. a) Pyrolysis curves b) Gasification of Char	X	X X
2. Ultimate Analysis	X	X
3. Proximate Analysis (A.S.T.M.)	X	X
4. Proximate Analysis - P & E T.G.A.		X
5. Thermogram		X
6. Pyro-gas chromatograph		X
7. Analysis of Ash		X
8. Analysis of Mineralogy		X
9. Surface Area Measurements of Char		X
10. Wood Chemistry		X
11. E.G.A.	X	X

Catalytic Studies

	Original Plan	Present Plan
1. Large T.G.A. (Pellets)		
a) Pyrolysis	X	X
b) Gas-Char Reactivity		X
2. Thermogram		X
3. Pyrogaschromatograph		X

Non-Catalytic Atmospheric

System: Thermal Gravimetric Analyzer (TGA)

Brief Description of System: The Thermal Gravimetric Analyzer, TGA, allows for a solid sample to be placed in a region of high temperature and the mass of the sample to be accurately recorded as a function of time. A flow of a selected gaseous atmosphere is passed by the sample. For the system used in these studies, the solid sample was rapidly immersed into a constant temperature.

Work Statement: The original contract provided the following scope for the TGA work:

TGA data

- Task 2 is limited to atmospheric runs.
- Initially use the following TGA experimental design for the 5 samples selected for proximate analysis.

Temperature, °F: 700, 1350, 2000 (These temperatures serve as guidelines only.)

Oxidant:	Air (combustion)	1 flow rate
	Air/Steam (Low-Btu)	2 ratios
	O ₂ /Steam (Med-Btu)	2 ratios
	Hydrogen (Hydrogasification)	1 flow rate
	Inert (Pyrolysis) N ₂	2 flow rates
	CO ₂	1 flow rate
	Total	9 flow rates

A total of 5 samples x 3 temp. levels x 9 flow rates =
135 TGA runs.

For each run gas analysis will be made for H₂, CO₂, CO, CH₄ and others, except for hydrogasification for which only gas volume shall be measured.

- All runs will be without added catalyst.
- Expected outputs
 - * Weight loss curves - see Appendix A, Figure 2 in the clarification proposal.
 - * Conversion data and composition profiles - see Pages 30 and 31 of the clarification proposal, Appendix D, Table 1.
- Develop experimental design for the remaining 95 species and perform experiments for the selected additional species which will be determined by a mutual agreement between GAI and WVU.

One major change has been made in this program. The original contract called for the analysis of the gas produced during the reaction as well as weight loss curves. It was learned from the preliminary studies that it was not possible to obtain both of these types of data from the TGA run. Whenever it was necessary to provide the conditions that gave reasonable results for the effluent gas analysis, it interfered with the thermo-gravimetric analysis. Therefore, it was decided to divide into two separate steps. In one program the weight loss curves would be determined and in a separate unit the effluent gas analysis would be determined. There was no reduction in the samples to be analyzed. There was no change in the size of samples to be used for the two separate experiments.

Description of Experimental Output: The attached figure shows a typical output curve from the TGA. When the sample is surrounded by reactive gases the curve provides two separate regions. The first region is the pyrolysis region where the weight loss is due to the thermal destruction of the biomass sample. This is rapid and the characteristic curve varies somewhat between biomass species but is not greatly affected by the atmospheric gases surrounding the sample. The major effect on the curve is the temperature of the reactor. The second region is a result of the gasification of the char. The reaction rate is much slower than the pyrolysis reaction and is affected by the surrounding gas. The temperature is again the major variable that affects this curve.

Work Status: About 50 runs were made in the TGA using N₂, hydrogen, CO₂, and steam as the carrier gas. Temperatures ranged from 900°F to 1700°F. The trends in this initial data are briefly discussed in the previous paragraph. The curves obtained while showing important trends are tainted because the tube carrying the gas to the hot reactor failed during the runs and the gas flow rate through the system was not assured. Additional problems resulted from the sample pan swaying somewhat and touching the sides of the reactor during the run. This influenced the weight readings.

The TGA unit used in these initial studies was not the unit that was described in the original proposal. At the time the original proposal was written a TGA with all the auxiliary equipment needed to carry out this study was available. Between the time that the proposal was written, until the time that it was funded (well over 1 year) this equipment went out of service and many of the components were cannibalized for other purposes. In particular, many of the components went into the construction of the pressurized TGA unit that was to be used in these studies as well as other work being performed for the Department of Energy. As a result, when the contract became effective this unit and the trained operators for this unit were not available. For this reason a supplemental unit that was available was pressed into service. It was this unit that provided operational problems. The location on the fourth floor added to the swaying of the pan in the balance during the run.

Last month it was decided to abandon the present pressurized unit. This meant that the parts that were cannibalized for the pressurized unit were now available for the original TGA. This old unit has been recommissioned and put back into service for the biomass studies. It is now dedicated to this service and scheduling problems associated with the sharing of the supplemental unit are no longer a curtailment to this study.

While there were unexpected delays, the delays have had some positive benefits to the program. The components were borrowed in order to develop a study on char reactivities (coal). This study will allow some additional experimental work to determine the activity of biomass chars. This would not have been done had it not been for the Department of Energy contract on char reactivation that is being carried out at WVU.

Supplemental Work: The original program called for the study of the pyrolysis portion of the TGA curve with no emphasis on the gasification portion of the curve. The early results have shifted the emphasis toward an understanding of the char gasification as the important study region. The current plan calls for the analysis of the char gasification region. Whereas the pyrolysis region takes only a few minutes to obtain the region of char gasification requires rather long time periods for analysis.

Grey Powder remaining
some shape retained

2061°F

100%

-100%

1360°F

Temp. 1370 °F
Cht. Sp. 10 min/in
Bal. Rng. 100 micrograms
Der. Spn. 5 MV

ATGA DATE: 5/1/52 Temp. 1360 °F
Material & No. 1-1
Carrier Gas 1-1
Flow Carrier Gas 1-1
Varian Settings 1-1

Wt. Suppression (Initial) 75.116
Wt. Recorder Span 1.0
Derivative Recorder Span 1.0
Filter No. 1
Range 1 (mg/min)
Notes: 1-1

Non-Catalytic Atmospheric

System: Effluent Gas Analyzer (EGA)

Brief Description of System: The EGA consists of a hot reactor tube through which a gas flows. A biomass sample is inserted into the hot reactor and the gas produced is quickly cooled in a condenser to prevent further reaction, then sent to a series of time sequenced gas holders. The gases collected are then analyzed to provide a measure of the composition of gas produced as a function of the reaction time.

The EGA is essentially a modification of a combustion train that is used to obtain ultimate analysis of fuels. The reactor consists of a quartz tube passing through electrical heaters. This tube is brought up to temperature and then the biomass sample which has been placed in a ceramic boat is inserted into the quartz tube. The gas evolved is then collected and analyzed for its components.

Work Statement: The original contract did not call for EGA measurements to be made separately. They were to be included as part of the TGA experiments. It was found that this was not effective and it was necessary to provide a separate set of conditions and experimental apparatus for each of these two experiments. The EGA experiments are covered in the TGA section of the original work contract.

Description of Experimental Output: The attached figure shows a typical output from the EGA. It is companion data to the results from the TGA. While the TGA provides the weight of the remaining sample as a function of time when the sample pellet is exposed to various reactive and non-reactive atmospheres, the EGA attempts to provide a measure of the product produced from the decomposition of the biomass. The factors that affect the EGA are the same that were found to be effective in modifying the product occurring from the TGA unit. The temperature is the major variable that affects these curves.

Work Status: EGA curves have been obtained for only a limited number (3) biomass samples. The results may be considered only as preliminary values and it remains necessary to do some more work with the TGA to better resolve some of the data. Trouble is encountered when the major portion of the gas is essentially one component with only traces of other materials. This results in the major curve masking the smaller ones when used as output from the gas chromatograph.

Supplemental Work: There is no supplemental activity planned for this analysis system.

Non-Catalytic Atmospheric

System: Thermal Gravimetric Analyzer/Proximate Analysis (TGA/PA)

Brief Description of System: The Perkin Elmer TGA unit is used to provide values similar to those reported for the proximate analysis using the ASTM standard method described in another activity in this program. A small sample of biomass (3-5 mg) is sent through a series of heating cycles on the Perkin Elmer TGA unit. This provides a value for moisture, volatile matter, fixed carbon, and ash that compares to the standard ASTM. In addition, it provides a rate curve for the decompositions that occur.

Work Statement: There was no work planned under this activity in the original work plan.

Description of Experimental Output: The Perkin Elmer TGA/PA unit provides outputs that are represented by the attached figures. The heating cycle used during this was one that heated the sample from 110°C to 960°C at a heating rate of 100°C per minute. It was then held at this temperature for 15 minutes. The difference in weight between the initial weight and the weight after this temperature plateau is reached is the volatile matter. The carrier gas is then switched from nitrogen to air and the carbon is allowed to burn off. The remaining material is the ash.

Work Status: The procedure for obtaining the proximate analysis using the TGA by Perkin Elmer is a standard procedure and these can be run off in about 2 hours, a modest time period. The curves are not difficult to obtain.

Supplemental Work: None.

Bagasse # 1211811

5.21 mg wet 5.14 dry
 89.5 % Val
 9.4 % FC
 1.1 % Ash

2-11-11

87

Change in
 flow rate
 being recorded
 while

2.0
 2.0

2.0
 2.0

PERKIN-ELMER CHART NO 056-7300

Hamlock #12/17/3
 4.18 wt 4.12 dry mg
 84.0 70 vol
 15.0 90 FC
 1.0 90 ash

Non-Catalytic Atmospheric

System: Thermogram (Pyrogram)

Brief Description of System: The thermogram is a plot of the production of combustible gaseous products produced from the heating of a biomass sample. The biomass sample is placed in a reactor through which helium is flowing. The temperature of the reactor is increased linearly. The gases evolved are sent to a detector and there they are continuously monitored for combustible gases.

Work Statement: These studies were not included in the original work proposed.

Description of the Experimental Output: The figures attached show the curves obtained when a flame ionization detector is used to monitor the gas being evolved. This gives a measure of the combustible hydrocarbon gases being generated by the decomposition of the biomass. It is clear that the behavior of the biomass is different. Some of the material gives a single peak while others give multiple peaks when decomposing. The print out also provides the time the peak comes out. Differences in these times were found significant in the evaluation of coal characteristics for liquifaction.

Work Status: Thermograms for 15 biomass materials have been obtained and the other materials could be run at any time. They are not difficult to obtain.

Supplemental Work: Although the curves described above are useful, they have shortcomings. The flame ionization detector used for monitoring the gas evolution does not monitor hydrogen or CO_2 which are both important products. The present system has been modified to allow the gas produced to be monitored by two detection systems rather than the single system used. This is done by adding a thermal conductivity cell prior to the flame ionization chamber. The thermal conductivity cell will include both the CO_2 and H_2 in the trace. The output from this system will be a dual trace thermogram. As far as is known this approach to the characterization of the biomass will be a new development and provide a stronger data base than the single trace.

ANAL 1 DET 1 METH 1 1 FILE 21

RUN 14 STILLER WOOD SAMPLES HICKORY

SENSITIVITIES 400 4

ANAL 1 DET 1 METH 1 1 FILE 21

RUN 14 STILLER WOOD SAMPLES 21 : 38.4 10 / 21 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	PRT	RF	C	NAME
11.14	6161.6947		1.114	1.000	100.0000	!

ANAL 1 DET 1 METH 1 1 FILE 11

RUN 24 STILLER WOOD SAMPLES HEM LOCK

SENSITIVITIES 400 4

25. - full
Pent

ANAL 1 DET 1 METH 1 1 FILE 11

RUN 24 STILLER WOOD SAMPLES 17 : 2.9 10 / 22 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
10.57	1318.2976	T	1.057	1.000	27.9389	!
11.39	899.6864	T	1.139	1.000	19.0672	!
11.69	2500.5260		1.169	1.000	52.9940	!

ANAL 1 DET 1 METH 1 1 FILE 13

RUN 22 STILLER WOOD SAMPLES BAGASSE

SENSITIVITIES 400 4

ANAL 1 DET 1 METH 1 1 FILE 13

RUN 22 STILLER WOOD SAMPLES 15 : 38.5 10 / 22 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
10.41	2403.7785	T	1.041	1.000	38.5193	!
11.29	1130.3731	T	1.129	1.000	18.1136	!
11.58	2706.3091		1.158	1.000	43.3671	!

Non-Catalytic Atmospheric

System: Pyrogaschromatogram (PGC)

Brief Description of System: The PGC traps the gaseous products produced when a sample of biomass is heated. The biomass sample is placed in a reactor through which helium is passed. The temperature is increased in a linear manner. The gases collected are then sent to a partition column where they are separated into components and analyzed.

Work Statement: These studies were not included in the original work plan.

Description of the Experimental Output: The figures attached show the output from the PGC. It is clear that there are many components observed and the curves differ, i.e., the biomass breaks down differently. These curves are referred to as the biomass fingerprint.

Work Status: PGC curves have been obtained for 15 biomass samples. It is a routine test and the remaining samples can be run at any time.

Supplemental Work: Although the curves show the variation in the biomass product output they have short-comings. The peaks shown are for high molecular weight products and the lower molecular weight materials of interest in gasification are not resolved in the present system. New partitioning columns are installed to provide this resolution. The peaks in the fingerprint have not been identified. The detector used to obtain the trace does not measure hydrogen or CO₂ (see thermogram). To obtain additional data that includes these components the unit is modified to obtain dual curves as was done with the thermogram studies. This will provide a stronger data base.

ANAL 1 DET 1 METH 1 1 FILE 7
 RUN 1 STILLER WOOD SAMPLES CELLULOSE
 SENSITIVITIES 400 4

PERKIN-ELMER PART No. 3321910

ANAL 1 DET 1 METH 1 1 FILE 7
 RUN 1 STILLER WOOD SAMPLES 11 : 25.4 18 / 1 / 79
 SENSITIVITIES 400 4

TIME	AREA	BC	RT	RF	C	NAME
1.68	98.4729	T	0.168	1.000	14.6847	!
2.03	74.4089	T	0.203	1.000	11.0962	!
2.54	68.2137	T	0.254	1.000	10.1723	!
3.42	7.0976	T	0.342	1.000	1.0584	!
3.77	16.4592	T	0.377	1.000	2.4843	!
3.90	28.6922	T	0.390	1.000	4.2772	!
4.54	43.1001	T	0.454	1.000	6.4273	!
5.22	23.2844	T	0.522	1.000	3.4723	!
5.94	41.5360	T	0.594	1.000	6.1940	!
6.68	52.8000	T	0.668	1.000	7.8738	!
7.23	29.6972	T	0.723	1.000	4.4286	!
8.09	15.8444	T	0.809	1.000	2.2435	!
8.63	8.2595	T	0.863	1.000	1.2317	!
8.88	11.9891	T	0.888	1.000	1.7879	!
9.29	18.5856	T	0.929	1.000	2.7716	!
9.64	8.8502	T	0.964	1.000	1.3198	!
9.92	8.0572	T	0.992	1.000	1.2015	!
10.35	15.4316	T	1.035	1.000	2.3012	!
11.02	20.1593	T	1.102	1.000	3.0063	!
11.96	12.5990	T	1.196	1.000	1.8788	!
12.49	21.4195	T	1.249	1.000	3.1942	!
13.40	5.3910	T	1.340	1.000	0.8039	!
13.89	11.8188	T	1.389	1.000	1.7625	!
14.07	11.1382	T	1.407	1.000	1.6598	!
16.33	7.7372	T	1.633	1.000	1.1538	!
17.72	2.5939	T	1.772	1.000	0.3868	!
18.38	2.3874	T	1.838	1.000	0.3560	!
19.07	3.7075	T	1.907	1.000	0.5529	!
20.52	0.5575	T	2.052	1.000	0.0831	!
24.63	0.2107	T	2.463	1.000	0.0314	!
28.33	0.6990	T	2.833	1.000	0.1042	!

ANAL 1 DET 1 METH 1 1 FILE 10

RUN 2 STILLER WOOD SAMPLES RED PINE

SENSITIVITIES 400 4

ANAL 1 DET 1 METH 1 1 FILE 10

RUN 2 STILLER WOOD SAMPLES 12 : 29.9 10 / 1 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
1.58	21.4374	T	0.158	1.000	5.2971	
1.69	20.4665	T	0.169	1.000	5.0572	
2.04	36.7705	T	0.204	1.000	9.0859	
2.53	14.3270	T	0.253	1.000	3.5402	
2.86	4.4886	T	0.286	1.000	1.1091	
3.18	20.8870	T	0.318	1.000	5.1611	
3.78	15.5424	T	0.378	1.000	3.8405	
4.03	38.5779	T	0.403	1.000	9.5325	
4.89	7.4300	T	0.489	1.000	1.0360	
5.28	14.7776	T	0.528	1.000	3.6515	
5.72	34.7737	T	0.572	1.000	8.5925	
6.67	16.2873	T	0.667	1.000	4.0246	
7.21	6.9529	T	0.721	1.000	1.7181	
7.42	10.7520	T	0.742	1.000	2.6568	
8.39	7.0944	T	0.838	1.000	1.7530	
8.50	6.4009	T	0.850	1.000	1.6014	
8.85	4.8472	T	0.885	1.000	1.1977	
9.30	9.8246	T	0.930	1.000	2.4276	
9.52	9.4560	T	0.952	1.000	2.3366	
10.04	4.1809	T	1.004	1.000	1.0331	
10.34	9.6099	T	1.034	1.000	2.3746	
10.95	19.3126	T	1.095	1.000	4.7721	
12.02	4.9424	T	1.202	1.000	1.2213	
12.35	3.9217	T	1.235	1.000	0.9691	
12.68	24.7283	T	1.268	1.000	6.1103	
13.99	6.4593	T	1.399	1.000	1.5961	
14.55	7.7545	T	1.455	1.000	1.9161	
15.07	6.5366	T	1.507	1.000	1.6152	
15.89	2.9737	T	1.589	1.000	0.7348	
16.67	7.0326	T	1.667	1.000	1.7377	
28.33	6.0713	T	2.833	1.000	1.5002	

ANAL 1 DET 1 METH 1 1 FILE 11

RUN 3 STILLER WOOD SAMPLES RICE STRAW

SENSITIVITIES 400 4

012

PERKIN-ELM

ANAL 1 DET 1 METH 1 1 FILE 11

RUN 3 STILLER WOOD SAMPLES 13 : 55.9 10 / 1 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
1.63	15.4636	T	0.163	1.000	3.7791	!
1.74	19.9308	T	0.174	1.000	4.8708	!
2.09	31.3241	T	0.209	1.000	7.6551	!
2.33	15.2338	T	0.233	1.000	3.7234	!
2.96	5.6848	T	0.296	1.000	1.3893	!
3.39	28.0179	T	0.339	1.000	6.8471	!
3.78	14.5081	T	0.378	1.000	3.5456	!
4.10	33.8316	T	0.410	1.000	8.2679	!
4.93	9.3180	T	0.493	1.000	2.2772	!
5.33	10.5280	T	0.533	1.000	2.5729	!
5.77	11.0988	T	0.577	1.000	2.7124	!
6.04	14.4268	T	0.604	1.000	3.5257	!
6.70	21.1379	T	0.670	1.000	5.1658	!
7.21	22.2668	T	0.721	1.000	5.4417	!
8.38	12.8972	T	0.838	1.000	3.1519	!
8.70	3.0332	T	0.870	1.000	0.7413	!
8.91	6.9763	T	0.891	1.000	1.7049	!
9.50	17.8937	T	0.950	1.000	4.3730	!
10.08	10.2422	T	1.008	1.000	2.5030	!
10.50	7.4730	T	1.050	1.000	1.8141	!
10.99	14.9260	T	1.099	1.000	3.6477	!
11.99	11.8508	T	1.199	1.000	2.8962	!
12.70	16.2336	T	1.270	1.000	3.9672	!
13.47	4.8137	T	1.347	1.000	1.1764	!
14.06	6.7660	T	1.406	1.000	1.6535	!
14.61	14.1817	T	1.461	1.000	3.4658	!
15.75	4.9454	T	1.575	1.000	1.2086	!
16.54	11.2262	T	1.654	1.000	2.7435	!
17.51	5.6108	T	1.751	1.000	1.3712	!
18.96	2.2164	T	1.896	1.000	0.5417	!
19.52	1.3678	T	1.952	1.000	0.3343	!
20.16	1.0370	T	2.016	1.000	0.2534	!
20.95	0.6383	T	2.095	1.000	0.1560	!
20.38	2.1384	T	2.838	1.000	0.5226	!

ANAL 1 DET 1 METH 1 FILE 12
 RUN 4 STILLER WOOD SAMPLES BAGASSE

SENSITIVITIES 400 4

ANAL 1 DET 1 METH 1 FILE 12

RUN 4 STILLER WOOD SAMPLES 15 : 7.5 10 / 1 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
0.17	0.0000		0.017	1.000	0.0000	!
1.61	16.6656	T	0.161	1.000	3.6232	!
1.74	9.5107	T	0.174	1.000	2.0677	!
1.85	11.0750	T	0.185	1.000	2.4079	!
2.09	29.3926	T	0.209	1.000	6.3901	!
2.57	16.8550	T	0.257	1.000	3.6644	!
3.35	60.9094	T	0.335	1.000	13.2594	!
3.80	18.8614	T	0.380	1.000	4.1006	!
4.12	47.6288	T	0.412	1.000	10.3548	!
5.34	16.8704	T	0.534	1.000	3.6677	!
5.77	40.2560	T	0.577	1.000	8.7519	!
6.69	24.0735	T	0.669	1.000	5.4081	!
7.23	8.6790	T	0.723	1.000	1.8869	!
7.48	12.0710	T	0.748	1.000	2.7902	!
8.11	4.4200	T	0.811	1.000	0.9620	!
8.37	5.1734	T	0.837	1.000	1.1247	!
8.69	4.5056	T	0.869	1.000	0.9795	!
8.87	6.3875	T	0.887	1.000	1.3887	!
9.51	27.0579	T	0.951	1.000	5.8025	!
10.00	6.7904	T	1.000	1.000	1.4763	!
10.42	7.5075	T	1.042	1.000	1.6496	!
10.99	10.5139	T	1.099	1.000	2.2850	!
11.63	4.9836	T	1.163	1.000	1.0835	!
11.97	5.3744	T	1.197	1.000	1.1684	!
12.42	10.5011	T	1.242	1.000	2.2830	!
12.69	16.3230	T	1.269	1.000	3.5409	!
14.03	7.9072	T	1.403	1.000	1.7191	!
14.59	10.6006	T	1.459	1.000	2.3064	!
15.10	7.8600	T	1.510	1.000	1.7107	!
16.34	1.3563	T	1.634	1.000	0.2949	!
16.75	4.5132	T	1.675	1.000	0.9812	!
18.42	0.2941		1.842	1.000	0.0640	!
20.36	0.0000		2.036	1.000	0.0000	!
28.42	3.2625		2.842	1.000	0.7093	!

ANAL 1 DET 1 METH 1 1 FILE 13

RUN 5 STILLER WOOD SAMPLES WHITE OAK

SENSITIVITIES 400 4

ANAL 1 DET 1 METH 1 1 FILE 13

RUN 5 STILLER WOOD SAMPLES 16 : 30.6 10 / 1 / 79

SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
1.71	31.4764	T	0.171	1.000	5.3624	!
1.79	67.6582	T	0.179	1.000	11.5264	!
2.56	18.6131	T	0.256	1.000	3.1710	!
3.67	118.1030	T	0.367	1.000	20.1203	!
4.31	48.0537	T	0.431	1.000	8.1866	!
5.32	9.6764	T	0.532	1.000	1.6485	!
5.53	9.6480	T	0.553	1.000	1.6437	!
5.86	43.4886	T	0.586	1.000	7.7496	!
6.73	33.9878	T	0.673	1.000	5.7902	!
7.25	11.7836	T	0.725	1.000	2.0075	!
7.51	20.1568	T	0.751	1.000	3.4340	!
8.13	7.9622	T	0.813	1.000	1.3565	!
8.39	6.4025	T	0.839	1.000	1.0908	!
8.91	12.2726	T	0.891	1.000	2.0908	!
9.35	14.9670	T	0.935	1.000	2.5498	!
9.69	21.5385	T	0.969	1.000	3.6694	!
10.51	7.6172	T	1.051	1.000	1.2977	!
11.01	10.7315	T	1.101	1.000	3.1911	!
11.98	18.1324	T	1.198	1.000	3.0891	!
12.76	18.0966	T	1.276	1.000	3.0830	!
14.07	5.5577	T	1.407	1.000	0.9468	!
14.38	2.7483	T	1.438	1.000	0.4602	!
14.68	6.1107	T	1.468	1.000	1.0410	!
15.23	10.6048	T	1.523	1.000	1.8067	!
16.76	12.7481	T	1.676	1.000	2.1718	!
18.47	1.6287	T	1.847	1.000	0.2775	!
18.87	2.2515	T	1.887	1.000	0.3036	!
19.33	1.2341	T	1.933	1.000	0.2102	!
20.34	1.4994	T	2.034	1.000	0.2554	!
28.42	2.2346	T	2.842	1.000	0.3807	!

ANAL 1 DET 1 METH 1 1 FILE 9
 RUN 6 STILLER WOOD SAMPLES HEMLOCK
 SENSITIVITIES 400 4

ANAL 1 DET 1 METH 1 1 FILE 9
 RUN 6 STILLER WOOD SAMPLES 11 : 1.9 10 / 2 / 79
 SENSITIVITIES 400 4

TIME	AREA	BC	RRT	RF	C	NAME
0.21	0.0125		0.021	1.000	0.0018	
1.73	27.0694	T	0.173	1.000	3.8220	
1.83	19.8700	T	0.183	1.000	2.8055	
2.02	36.7052	T	0.202	1.000	5.1025	
2.58	26.0454	T	0.258	1.000	3.6774	
3.64	39.4393	T	0.364	1.000	5.5686	
3.78	20.7571	T	0.378	1.000	2.9308	
4.12	6.4915	T	0.412	1.000	0.9166	
4.38	69.7395	T	0.438	1.000	9.0467	
5.32	18.5196	T	0.532	1.000	2.6148	
5.91	77.0608	T	0.591	1.000	10.8816	
6.77	30.7264	T	0.677	1.000	4.3383	
7.26	14.8518	T	0.726	1.000	2.0970	
7.54	21.0048	T	0.754	1.000	2.9657	
8.16	7.1971	T	0.816	1.000	1.0162	
8.43	6.5769	T	0.843	1.000	0.9286	
8.71	8.1686	T	0.871	1.000	1.1534	
8.92	11.6281	T	0.892	1.000	1.6418	
9.36	35.2908	T	0.936	1.000	4.9828	
10.28	8.4115	T	1.028	1.000	1.1876	
10.51	12.4454	T	1.051	1.000	1.7572	
11.05	37.1609	T	1.105	1.000	5.2469	
12.14	11.2979	T	1.214	1.000	1.5952	
12.44	8.4784	T	1.244	1.000	1.1971	
12.78	43.2051	T	1.278	1.000	6.1002	
14.09	14.1292	T	1.409	1.000	1.9950	
14.68	23.8297	T	1.468	1.000	3.3646	
15.19	17.9763	T	1.519	1.000	2.5381	
16.01	10.5811	T	1.601	1.000	1.4948	
16.76	43.1846		1.676	1.000	6.0974	
28.42	0.3884		2.842	1.000	0.0540	

Non-Catalytic Atmospheric

System: Ultimate Analysis (ASTM)

Brief Description of System: The ultimate analysis is to be run using the ASTM standard method.

Work Statement:

Ultimate Analysis

- Run ultimate analysis for each of 5 representative samples selected in the proximate analysis and compare with literature data.
- If the comparison is good, use the literature ultimate analysis data for other samples.

HHV

- Measured for each sample.

Description of Experimental Output: The ultimate analysis was run using ASTM method. The output from this is ash, fixed carbon, hydrogen, and oxygen.

Work Status: About 20 ultimate analyses have been run on various biomass samples.

Supplemental Work: While the original analysis suggested that only 25 biomass samples be run for the ultimate analysis, the program presently will have all 100 samples of biomass run for the ultimate analysis.

Non-Catalytic Atmospheric

System: Proximate Analysis

Brief Description of the System: The proximate analysis will be run according to ASTM standards as modified to provide for the high volatile materials.

Work Statement:

Proximate Analysis

- Group feedstocks based on literature data to make a total of 5 specific feedstocks for initial evaluation.
- Need for proximate analysis on remaining 95 species to be evaluated following completion of initial five.

Description of Experimental Output: The experimental system is the one specified by ASTM.

Work Status: About 20 proximate analyses have been run to date. Arrangements have been made for a complete 100 samples to be run.

Supplemental Work: The program now calls for all 100 samples to be analyzed by the proximate analysis rather than the limited number suggested in the original scope of work.

Non-Catalytic Atmospheric

System: Wood Chemistry

Brief Description of System: The wood will be analyzed for cellulose, lignin, hemi-cellulose, and extractables using ASTM methods.

Work Statement: This material was not covered in the original scope of work.

Description of the Experimental Output: The experimental output will provide for the biomass materials to be broken down into the constituent parts, A - cellulose, B - hemi-cellulose, C - lignin, D - extractables.

Work Status: The procedures have been worked out and a limited number of materials have been analyzed.

Supplemental Work:

Non-Catalytic Atmospheric

System: Other Physical Measurements--Analysis of Ash, Mineralogy of Ash, Surface Area Measurements of Char.

Brief Description of System: These represent standard procedures that have been developed at WVU, largely through the State of West Virginia Geological Survey which provides these analyses for a wide range of coal materials. These facilities have been developed for coal, but the Survey has agreed to work with us as coal analytical investigators to provide this additional information on biomass samples.

Pressurized Work

System: Pressurized TGA

Brief Description of System: The principles are the same as for the atmospheric TGA.

Work Statement: The work statement for the pressurized TGA is given below.

Pressurized TGA Runs: Evaluation of Effects of Temperature and Pressure

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, oxygen, and in inert atmospheres. 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).

Specifically, this task consists of the following scope of work:

1. Use three samples, probably the same three used in Task 4.
2. Run TGA at approximately 500 psig for the three samples at the best temperature using one flow rate each of air/steam, O₂/steam, inert, (N₂ and CO₂) and air.
 - * A total of 3 samples x 1 pressure x 1 temp. x 5 flow rates = 15 runs.
 - * Expected output should be the same as atmospheric TGA runs made in Task 2.
 - * All runs without catalyst.
3. Compare the above results with those of atmospheric TGA of Task 2. Are there pressure effects?
4. If there are significant pressure effects, further meetings will be arranged to specify experimental design and to perform experiments accordingly.
5. If there are no significant pressure effects, do not repeat any more runs. Total runs for Task 3 will be from the minimum 15 to the maximum of 150 runs.

Description of Experimental Output: None obtained.

Work Status: The original system has been scrapped when found inoperable. A new system is being fabricated (see attached sketch) and is to be delivered by the end of January. This unit is being built for another contract but will be available to the biomass studies on a limited basis. The system should be operational by March 15, 1980.

Supplemental Work: None.

PRELIMINARY RELEASE

NOTES

- 1) LINEAR DIMENSIONS:
Shown on drawing all $\pm 0.063"$
- 2) PENETRATIONS:
a) Those indicated with $\odot$ locate
90° behind the plane of paper
b) Indicated $\circ$ locate in the
plane of paper
All $\pm 10^\circ$ horizontal rotation
- 3) PERPENDICULARITY:
 $C_L \perp A$ 0.125"/ft
- 4) TRUE POSITION:
 R_2 vs R_1 within 0.063"
- 5) The ID of the Grayloc hub and the lip OD of the seal ring are precisely finished sealing surfaces. They are to be protected at all times from mechanical damage, foreign matter, arc strikes, etc. The Grayloc connectors are to be assembled in accordance with the manufacturers installation and maintenance procedures. Should any damage occur, it must be repaired by Gray Tool Co. or an authorized licensee.
- 6) All exterior surfaces, except the Grayloc hub lips and the face of the flanges shall be painted with an aluminum pigment paint suitable for exposure to 700°F prior to painting, the surface shall be cleaned per the paint manufacturers recommendations. All surfaces not painted shall be coated with Dow Corning's molykote metal protector or approved equal.
- 7) The entire vessel shall be hydrostatically tested to the pressure required by ASME BPV Code, Section VIII, Division I per psi standard 1977 edition. After hydrostatic testing, dry and protect spools against corrosion.

LIST OF MATERIALS

- 1 - nominal lifting ring for 1000# load
 - 1 - 6" nominal elliptical head - Carbon Steel A105
 - 6" - 6" sch 40 pipe Carbon Steel A106 Grade B
 - 1 - 6" Grayloc supplied by WVU
 - 1 - 2" Grayloc supplied by WVU
 - 6" - 2" sch 80 A106 pipe
 - 1 - 8" nominal 900# class blind flange A105
 - 1 - 8" nominal flexitalic gasket
 - 1 - 8" nominal 900# weld neck flange A105
 - 12 - 1 3/8" studs with nuts
 - 10.5" - 8" nominal sch 80 pipe Carbon Steel A106 Grade B
 - 1 - 8" nominal elliptical head Carbon Steel A105
 - 1 - 2" support leg
 - 2 - 2" adjustable (leveling) legs
- Or equivalent items subject to approval.

Catalytic Studies

System: T.G.A.
E.G.A.
Thermogram
Pyrogaschromatograph

Brief Description of System: Same as those described for non-catalytic work.

Work Statement: The work statement for the catalytic work is given below.

Catalyst Testing by Atmospheric TGA Runs

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.

Specifically, this task will consist of the following scope of work:

1. Select three biomass samples out of 5 representative samples analyzed in Task 2. Selection criteria will be:
 - * Highest gas and lowest char yield
 - * High H₂/CO ratio (CH₃OH, NH₃, FT, etc.)
 - * High CH₄ content (SNG application)
2. Select the best temperature level and the best reaction gas ratios and flow rates for air/steam, O₂/steam and hydrogen using the results of Task 2. There will be no catalytic pyrolysis (inert) or combustion runs (air). For the selected operating conditions, run for each of three samples at two levels of catalyst concentrations for each of the following five catalysts:
 - * Ni-base * Metal Oxide
 - * Limestone * Ash from Biomass Conversion
 - * Dolomite
3. A total of 3 samples x 1 temperature x 3 reaction gas compositions, 2 catalyst concentrations x 5 catalysts = 90 runs.

4. Compare the results with Task 2. Any catalytic effects? If not, forget the rest. If yes, select two of the five best catalysts. Repeat runs with two additional temperatures (700 and 2000°F) and 2 additional feedstocks.
5. A minimum of 90 to maximum of 150 runs will be needed.
6. The expected output will be the same as in Tasks 2 and 3.

Description of Experimental Output: Same as non-catalytic study.