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AN OVERVIEW OF BIOMASS THERMOCHEMICAL CONVERSION ACTIVITIES FUNDED BY THE BIOMASS ENERGY SYSTEMS BRANCH OF DOE

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Abstract

The U.S. Department of Energy (DOE) is actively involved in the development of renewable energy sources through research and development programs sponsored by the Biomass Energy Systems Branch. The overall objective of the thermochemical conversion element of the Biomass Energy Systems Program is to develop competitive processes for the conversion of renewable biomass resources into clean fuels and chemical feedstocks which can supplement fuels from conventional sources. An overview of biomass thermochemical conversion projects sponsored by the Biomass Energy Systems Branch is presented in this paper.

1. INTRODUCTION

The purpose of this paper is to provide an overview of thermochemical conversion technology development activities within the Biomass Energy Systems Branch of the U.S. Department of Energy (DOE). The Biomass Energy Systems Branch (BESB) is a part of DOE's Division of Distributed Solar Technology. Thermochemical conversion technology development activities sponsored by the Biomass Energy Systems Program can be catagorized into four main areas: direct combustion, direct liquefaction, gasification, and indirect liquefaction via synthesis gas.

Pacific Northwest Laboratory (PNL) and Lawrence Berkeley Laboratory (LBL) have been selected to provide program management services to the Biomass Energy Systems Program. Lawrence Berkeley Laboratory is responsible for the technical management of development activities on the direct liquefaction of biomass feedstocks. Pacific Northwest Laboratory is responsible for the technical management of development activities directed toward the thermochemical conversion of biomass feedstocks by direct combustion, gasification and indirect liquefaction via synthesis gas.

Biomass comprises all plant growth, both terrestrial and aquatic and includes renewable resources such as forests and forest residues, agricultural crop residues, animal manures, and crops grown on energy farms specifically for their energy content.

Thermochemical conversion processes employ elevated temperatures to convert biomass materials to more useful energy forms. Process examples include:

(1) Combustion to produce heat, steam, electricity, or combinations of these;

(2) Direct liquefaction to produce heavy oils, or with upgrading, lighter boiling liquid products such as distillates, light fuel oils and gasoline;

(3) Gasification to produce low or intermediate BTU fuel gas;

(4) Pyrolysis to produce gases (low or intermediate BTU), pyrolytic liquids and char;

(5) Gasification to produce synthesis gas for the production of synthetic natural

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gas (SNG), ammonia, methanol, alcohol fuels, or Fischer-Tropsch liquids and gasoline via catalytic processes.

2. PROGRAM OBJECTIVE

The objective of the thermochemical conversion technology development activities of the Biomass Energy Systems Program is to develop competitive processes for the conversion of biomass feedstocks to fuels and other energy intensive products. This objective can be accomplished by the direct combustion of biomass materials and the substitution of biomass derived fuels and chemical feedstocks for those produced from conventional sources.

3. PROGRAM ORGANIZATION

The thermochemical conversion technology development activities sponsored by the Biomass Energy Systems Program can be divided into the following four categories:

(1) Direct Liquefaction

(2) Direct Combustion

(3) Gasification

(4) Indirect Liquefaction Via Synthesis Gas

In the remainder of this paper we will outline the ongoing activities in each of these catagories.

3.1 DIRECT COMBUSTION SYSTEMS

The direct combustion of biomass feedstocks is already widely practiced by several industries, especially the forest products industry. Many types of direct combustion equipment are commercially available for this purpose.

Two projects are currently being funded by the Biomass Energy Systems Program in the area of direct combustion technology. These projects are shown in the organization chart illustrated in Figure 1. The Aerospace Research Corporation project is directed toward developing a wood fueled combustor which can be directly retrofitted to existing oil or gas fired boilers. Direct retrofit requires that heat release rates equivalent to those obtained when firing oil or gas be obtained in the wood fired combustor. Heat release rates on this order have been achieved when firing wood by preheating the combustion air to 800-1100°F.

The Wheelabrator Cleanfuel Corporation project is a demonstration of large scale co-generation based on wood feedstock. The scope of this project includes the design of the plant plus additional tasks such as preparation of an environmental impact statement, demonstration of large tree harvesting equipment and determination of feedstock availability for a large facility.

3.2 GASIFICATION-INDIRECT LIQUEFACTION SYSTEMS

Biomass gasification technologies can be divided into processes which produce a low BTU gas and those which produce a medium BTU gas.

Low BTU gasification technology is commercially available for many types of biomass feedstocks and can be expected to have an impact on energy supplies by 1985. Several of these commercial processes are based on low BTU coal gasification technologies and the gas produced can best be used as fuel for supplying process heat, process steam, or for electrical power generation.

The versatility of low BTU gas is somewhat limited and its use is subject to the following limitations:

(1) The low heating value of the gas usually requires that it be consumed on or near the production site in a close coupled process.

(2) Substitution of low BTU gas for natural gas as a boiler fuel usually requires boiler derating and/or extensive retrofit modifications.

(3) The high nitrogen content of low BTU gas precludes its use as a synthesis gas for most chemical commodities which can be produced from synthesis gas.

Medium BTU gas has the following advantages over low BTU gas:

(1) Boiler derating may not be required or is usually less severe when substituting medium BTU gas for natural gas.

(2) Medium BTU gas can be transported moderate distances by pipeline at a reasonable cost.

(3) Medium BTU gas is required for the synthesis of derived fuels and most chemical feedstocks and commodities which can be produced from synthesis gas.

The versatility of medium BTU gas (MBG) is illustrated in Figure 2. The major disadvantage of MBG is that its production from coal usually requires the use of an oxygen blown gasifier which is expensive to operate due to the cost of the oxygen.

In this respect biomass gasification may have an advantage over coal gasification. Biomass is more reactive than coal. It has the potential for gasification at lower temperatures, without the addition of oxygen, to produce medium BTU gas. Several of the gasification process development activities sponsored by the Biomass Energy Systems Program are attempting to exploit this advantage.

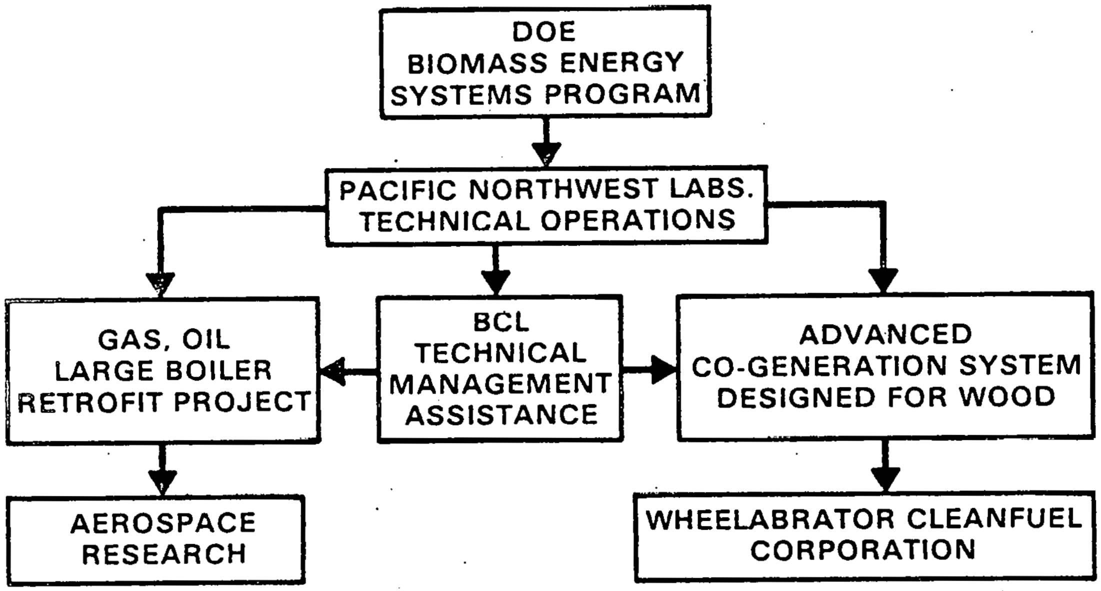

FIGURE 1. Direct Combustion Development Activities

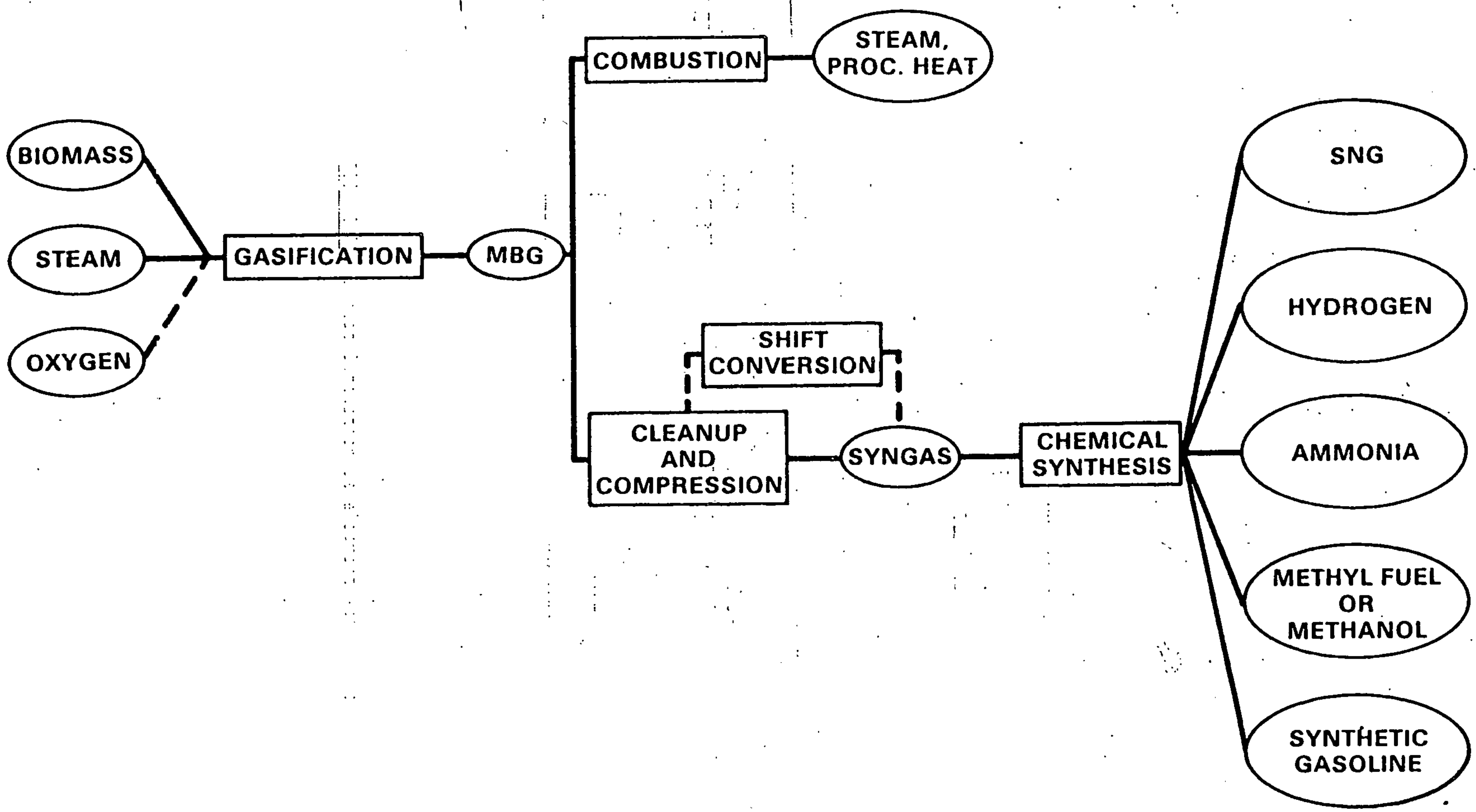

FIGURE 2. Medium BTU Gasification (MBG) Indirect Liquefaction Technology

If the thermochemical conversion of biomass is to achieve its maximum potential for supplementing existing U.S. energy supplies it will have to be environmentally and economically competitive with synthetic fuels produced from coal and it will have an impact on the availability of liquid fuels and chemical feedstock supplies. The gasification development activities sponsored by the Biomass Energy Systems Program are also directed toward improving the competitiveness of biomass gasification through the use of catalysts and unique gasification reactors to produce, directly, specific synthesis gases for the production of SNG, methanol or methyl fuels, ammonia and hydrogen. Success in these efforts could eliminate the necessity for external water gas shift or methanation steps when producing these commodities. The potential elimination of the oxygen requirement and the water gas shift step are indicated by the dashed lines in Figure 2.

Gasification and indirect liquefaction technology development projects currently sponsored by the Biomass Energy Systems Program are depicted on the organization chart shown in Figure 3. Projects with operational process development units (PDUs) include the following.

(1) The Garrett Energy Research and Engineering Company is operating a multihearth gasification reactor at Hanford, California. This PDU, with a capacity of approximately 3 oven dried tons per day (odt/d), is being developed for converting difficult-to-handle feedstocks, such as cotton gin thrash and corn stover, into medium BTU gas.

(2) The University of Arkansas has been working with two rotary kiln pyrolysis PDUs; a small 0.5 odt/d unit located on campus at Fayetteville and a 28 odt/d unit located at Jonesboro, AR.

(3) Texas Tech University is operating a 0.5 odt/d counter current (top feed) fluidized bed gasifier with a variety of biomass feedstocks to produce medium BTU gas.

(4) Pacific Northwest Laboratory is operating a 0.5 odt/d fluidized bed gasifier in a catalytic mode utilizing a variety of catalysts to produce specific products and synthesis gases directly.

(5) The University of Missouri - Rolla is operating the largest fluidized bed gasifier PDU in the thermochemical conversion program. This unit, with a capacity of 2.4 to 24 odt/d, is currently operating in the low BTU gas mode. Future plans call for this unit to operate in the medium BTU gas mode both with and without catalysts.

Gasification PDUs are in the construction stage at Wright Malta Corporation and Battelle Memorial Institute. A brief description of each gasification PDU in the program is given in Table 1.

3.3 SUPPORTING STUDIES

Supporting systems studies are being conducted by Gilbert/Commonwealth, Inc., Gorham International, Inc., Science Applications, Inc., and Catalytica Associates, Inc.

The Gilbert/Commonwealth project is aimed at the development of a biomass resource allocation model based on linear programming. The model, which will integrate regional/seasonal biomass feedstock availability, conversion process efficiencies and economics and regional/seasonal end product demand projections, is intended for use as a planning tool by the Department of Energy. It will provide an organized structure for evaluating the potential economic and regional impact of new biomass conversion technologies. Experimental data on biomass feedstock characteristics and conversion efficiencies is being supplied by West Virginia University and Environmental Energy Engineering Company under subcontract to Gilbert/Commonwealth.

Gorham International is conducting a study to determine the potential for retrofitting coal gasifiers to operate with wood feedstocks.

Science Applications, Inc. has recently completed a comprehensive technical and economic assessment of producing methanol from biomass feedstocks employing conventional gasification technology. This study also includes an assessment of biomass availability and the distribution and markets for methanol fuels.

Catalytica Associates, Inc. is conducting a study to produce a systematic assessment of the role of catalysis in thermochemical conversion via gasification and liquefaction. Catalytica is also examining the potential impact of catalytic concepts under development in other areas, such as coal conversion, and new reactor technology on biomass conversion.

Included on the organization chart is a proposal for a large experimental facility (LEF) for the gasification of biomass. This facility, which would have a projected capacity of 300 oven dried tons per day of biomass, is still in the planning stage and has not been formally approved.

The LEF would serve as a demonstration unit for the gasification processes currently being developed at the PDU stage and would provide process information that could be used for the design of a commercial sized facility.

3.4 DIRECT LIQUEFACTION SYSTEMS

The Biomass Energy Systems branch is sponsoring efforts to develop a direct liquefaction process for the thermochemical conversion of biomass to liquid fuels. Lawrence Berkeley Laboratory (LBL)

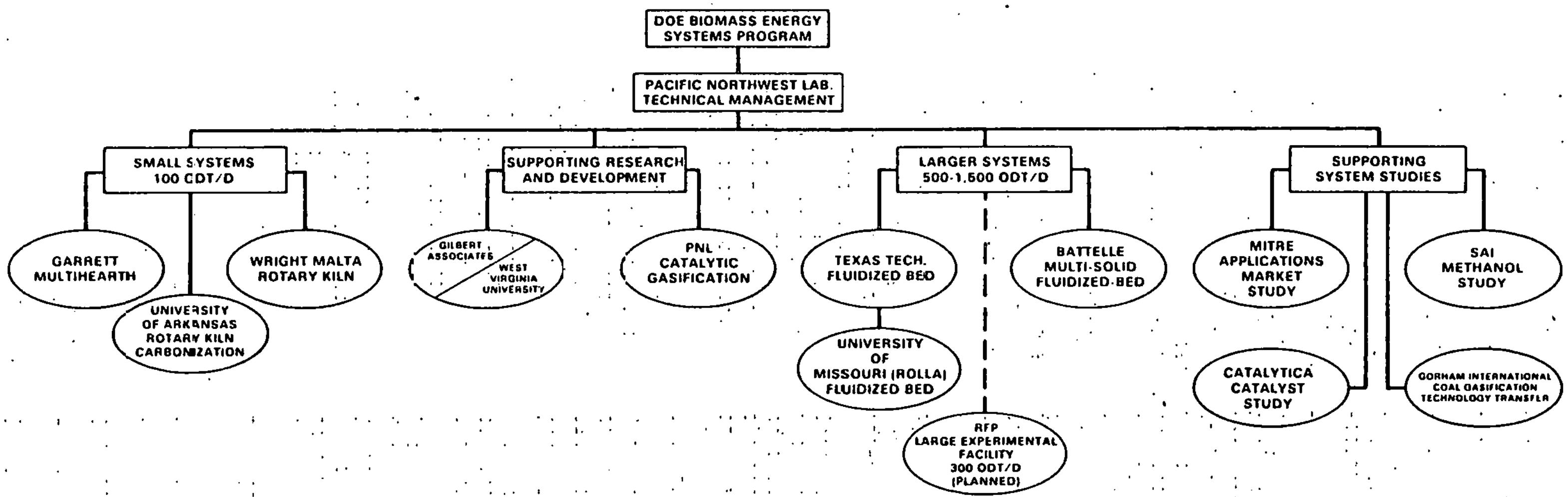

FIGURE 3. Gasification - Indirect Liquefaction Systems

TABLE 1. Biomass Gasification-Indirect Liquefaction Process Development Units (PDUs)

Project	Reactor Type	PDU Size	Potential Feedstocks	Product(s)	Potential Applications	Status
Garrett Energy Research and Engineering Hanford, CA	• Multihearth • Non-Catalytic • Low Pressure • No Oxygen Required	3 ODT/D*	Manure Cotton Gin Thrash Wood Corn Stover	MBG (~400 BTU/scf)	Small industrial applications (under 100 ODT/D)	Operational
Wright-Malta Corporation Ballston Spa, NY	• Rotary Kiln • Soda Ash Catalyst • High Pressure • No Oxygen Required	3 ODT/D	Wood Chips	MBG (~450 BTU/scf) Methanol synthesis gas	Small industrial plants, pulp/paper mills	PDU designed startup mid 1980
University of Arkansas Fayetteville, AK	• Rotary Kiln • Non-Catalytic • Low Pressure • No Oxygen Required	0.5 ODT/D laboratory unit at Fayetteville 28 ODT/D PDU at Jonesboro Arkansas	Wood Chips, Saw Dust, Rice Hulls, Cotton Gin Thrash, Nut Hulls, and Other Agricultural Residues	Low BTU gas and char	Small industrial and agricultural applications	Operational
Pacific Northwest Laboratory Richland, WA	• Fluidized Bed • Catalytic-Various Catalysts • Pressure (1-10 atm) • No Oxygen Required	0.5 ODT/D	Wood Various others	Methane, hydrogen, and synthesis gases for ammonia, methanol and liquid hydrocarbons	Current PDU for catalyst screening studies - concept applicable to various gasifiers	Operational
Battelle Memorial Institute Columbus, OH	• Multisolids Fluidized Bed • Catalytic • High Pressure • No Oxygen Required	2 ODT/D	Wood-whole tree-Chips and Residues	MBG (~350 BTU/scf) or Methane	Larger units, energy farms (300-1,500 ODT/D)	PDU designed startup mid 1980
Texas Tech University Lubbock, TX	• Counter Current Fluidized Bed (top feed) • Non-Catalytic (Steam-Air Gasification) • Low Pressure • No Oxygen Required	0.5 ODT/D	Manure, Wood Cotton Gin Thrash, Corn Stover, and Other Agricultural Stalks	MBG (270-360 BTU/scf as is basis) NH_3 synthesis gas	Larger units 300-1,500 ODT/D ammonia production from feedlot wastes, other industrial uses	Operational
University of Missouri Rolla, MO	• Fluidized Bed • With or Without Catalyst • Low Pressure • No Oxygen Required	2.4 to 24 ODT/D	Sawdust, Hogged Wood Chips and Others	Low BTU gas, MBG and synthesis gas	Larger units 300-1,500 ODT/D PDU will be used to verify Texas Tech projections and develop scale up data for commercial size units	Operational

*oven dried tons/day

is responsible for the technical management of this program. An organization chart for the direct liquefaction effort is shown in Figure 4. The main thrust of the effort is centered on the operation of a direct liquefaction PDU located at Albany, Oregon. Various subcontractors provide program support.

The Albany, Oregon PDU, designed to process three tons of wood per day, was constructed during 1975-1976 and commissioned by Bechtel National, Inc. The PDU is now being operated by the Rust Engineering Company division of Wheelabrator Cleanfuel Corporation.

The original process flowsheet for the Albany PDU was based on a series of batchwise bench scale biomass liquefaction experiments conducted by the Pittsburgh Energy Research Center (PERC) of the U.S. Bureau of Mines in the 1960s and early 1970s. In this flowsheet biomass flour (30 parts) is mixed with a vehicle oil (70 parts) and 20% sodium carbonate solution (7.5 parts) and injected into a high pressure vessel (3,000 psi) along with synthesis gas. The slurry is heated to about 700°F at a rate of about 12°F/min. The product stream is then cooled and flashed in a pressure let-down vessel. The bottoms are diverted into a three phase centrifuge to separate the solid residue (as a sludge) and the aqueous phase containing the sodium salts from the oil phase. Part of the oil (about 15 parts) is withdrawn as a product and most of it (70 parts) is recycled to serve as a vehicle oil.

The process development activities based on the original PERC flowsheet have been beset with many mechanical and operational difficulties and it has not yet been possible to obtain a pure wood derived oil which is free of the anthracene start up oil. Rust Engineering believes that the PDU needs modifications in order to develop the PERC process. However, a great deal of engineering design and materials compatability information has been accumulated which will be useful in designing future biomass liquefaction facilities.

Since October of 1978, LBL has been engaged in process research and development in support of PDU operations. LBL researchers now believe that the suitability of the oil produced from wood to serve as a vehicle oil is in question. Based on the results of bench scale experiments, they conceived a process in which wood chips (23 parts on dry basis) are prehydrolyzed in water (77 parts) containing 500 ppm sulfuric acid. The resultant slurry is pumpable and can be liquefied directly after the addition of sodium carbonate (1.15 parts) or other catalysts. The slurry, after being subjected to liquefaction, contains an aqueous phase and an oil phase containing small amounts of solid residue. The oil phase is separated as a product.

This optional process flowsheet was evaluated in a PDU trial run during the first week of May with moderate success. For the first time an oil entirely derived from wood was obtained. The oil has a heating value of 15,500 BTU/lb., contains about 82 percent carbon, 8 percent hydrogen, 10 percent oxygen, and less than 0.1 percent nitrogen. Additional test runs on this flowsheet are now being repeated to obtain a large batch of oil for characterization and upgrading purposes. Whether or not the Albany PDU is adequate to develop this process is not yet certain.

Supporting studies are being conducted by PNL, LBL, SRI, Catalytica, and the University of Arizona. The work area being investigated by each of these organizations is shown in Figure 4.

4. THERMOCHEMICAL CONVERSION BUDGET

A geographical distribution of current biomass thermochemical conversion projects sponsored by the Biomass Energy Systems Branch is shown in Figure 5.

The Fiscal Year 1979 budget for those thermochemical conversion activities managed by Lawrence Berkeley and Pacific Northwest Laboratory was $12.5 million. The distribution of funding by major activity element is shown in Figure 6. This does not represent the total thermochemical conversion budget for the Biomass Energy Systems Program. A few additional thermochemical conversion activities, which are not technically managed by PNL and LBL, are funded by the Biomass Energy Systems Program.

5. SOURCES OF ADDITIONAL INFORMATION

The purpose of this paper is to provide a brief overview of the biomass thermochemical conversion activities of the Biomass Energy Systems Branch. Detailed papers on each of the projects mentioned in this overview were presented at the 3rd Annual Biomass Energy Systems Conference held in Golden, Colorado, June 4-7, 1979. Copies of the proceedings of this conference will be available from the National Technical Information Service (NTIS) as SERI/TP-33-285, beginning approximately December 1, 1979.

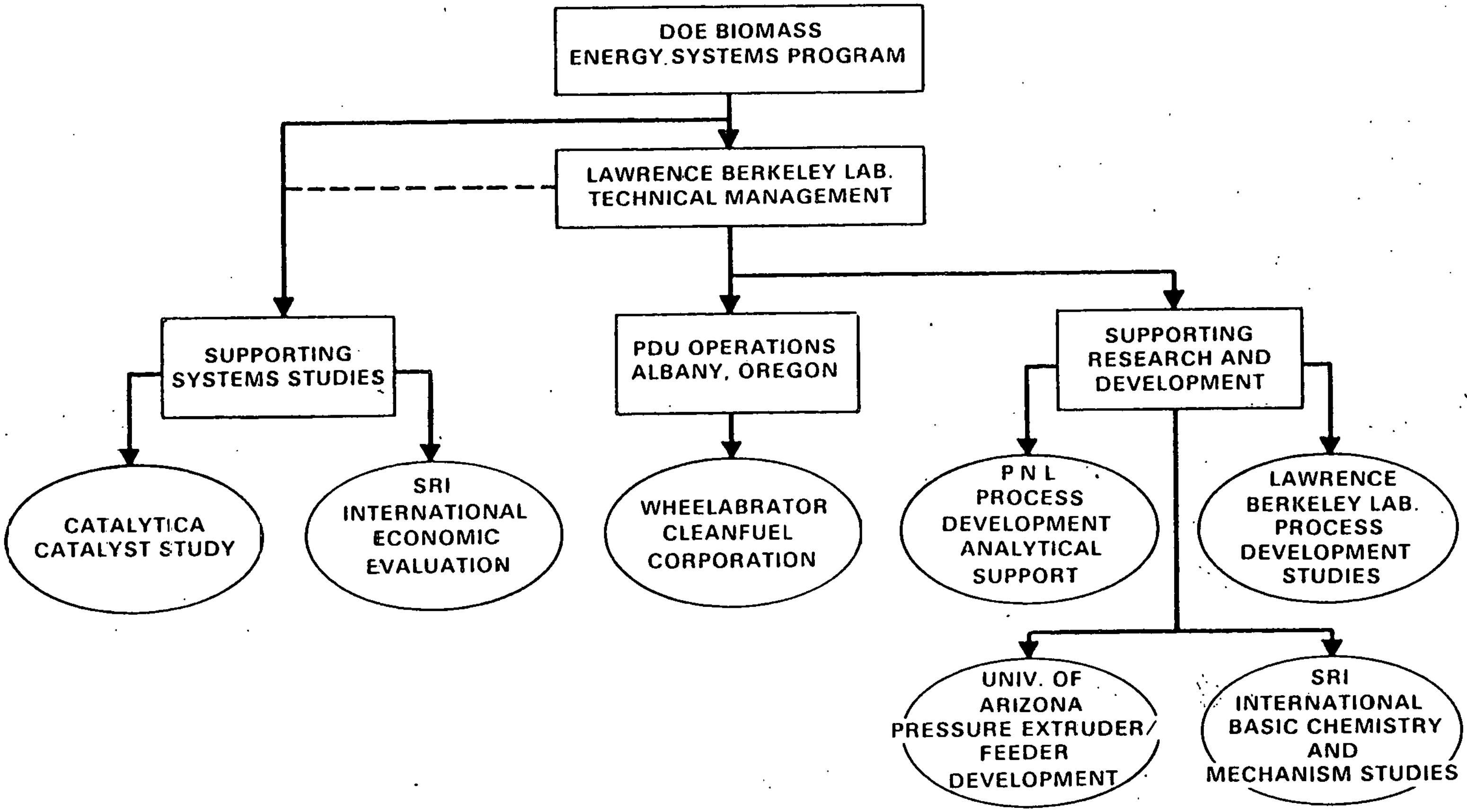

FIGURE 4. Direct Liquefaction Systems

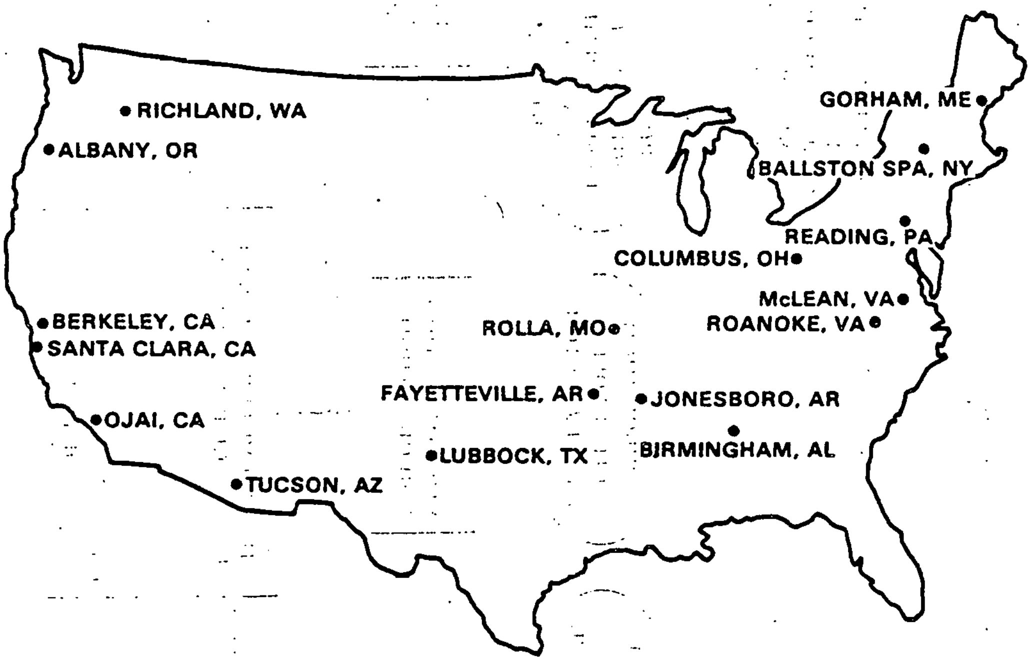

FIGURE 5. Geographic Distribution of Thermochemical Conversion Projects

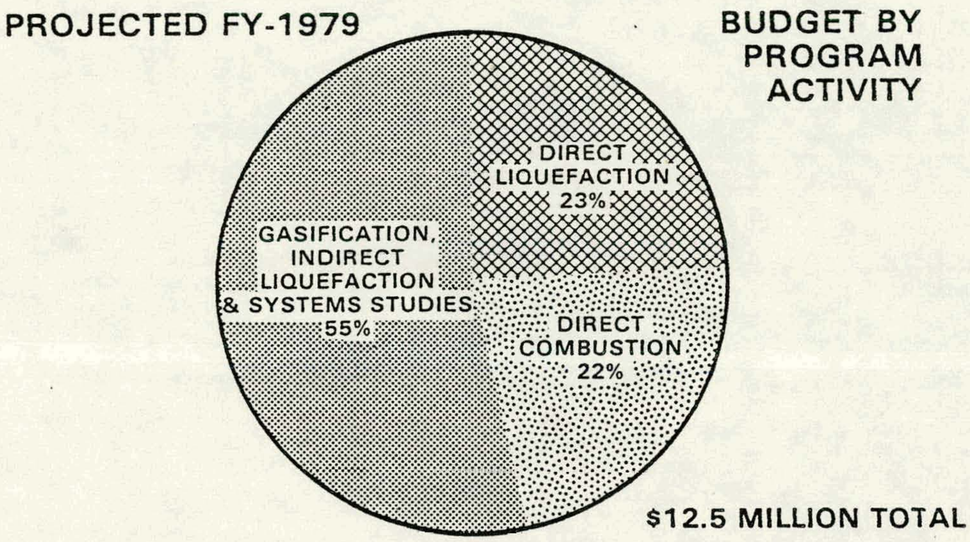

FIGURE 6. Projected Fiscal Year 1979 Budget
Thermochemical Conversion