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Biomass Thermochemical Conversion Program 1983 Annual Report

August 1984

G. F. Schiefelbein
D. J. Stevens
M. A. Gerber

Biomass Program Office

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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BIOMASS THERMOCHEMICAL CONVERSION PROGRAM 1983 ANNUAL REPORT

G. F. Schiefelbein
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Prepared for
the U.S. Department of Energy
under Contract DE-ACD6-76RLO 183D

Pacific Northwest Laboratory
Richland, Washington 99352

EXECUTIVE SUMMARY

Biomass represents an important but underutilized energy resource in the United States. The Congressional Office of Technology Assessment has estimated that, with proper resource management and the development of efficient conversion processes, the potential contribution of biomass to U.S. energy demand could range as high as 17 quadrillion Btu per year--almost 20% of current U.S. energy consumption. Similarly, the Energy Research Advisory Board (ERAB) has estimated a potential of approximately 10 quadrillion Btu per year.

Wood and crop residues constitute a vast majority of the biomass feedstocks available for conversion, and thermochemical processes are well suited for conversion of these materials. The U.S. Department of Energy (DOE) is sponsoring research on this conversion technology for renewable energy through its Biomass Thermochemical Conversion Program.

The program is part of DOE's Biomass Energy Technology Division, Office of Renewable Energy. Pacific Northwest Laboratory has been designated the Field Management Office for the Biomass Thermochemical Conversion Program with responsibility for overall management of the program. This report briefly describes the Thermochemical Conversion Program structure and summarizes the activities and major accomplishments during fiscal year 1983.

PROGRAM OBJECTIVE, GOAL, AND STRATEGY

The objective of the Biomass Thermochemical Conversion Program is to generate scientific data and conversion process information that will lead to establishment of cost-effective processes for converting biomass resources into clean fuels. The goal of the program is to develop the data base for biomass thermal conversion by investigating the fundamental aspects of conversion technologies and by exploring those parameters that are critical to the conversion processes.

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

- gasification to produce fuel gas or synthesis gases for the production of methanol and hydrocarbon fuels

- direct liquefaction and pyrolysis to produce heavy oils or a mixture of oils, fuel gases, and char
- combustion to produce heat, steam, electricity, and direct mechanical power.

Compared to other solid fuels such as coal, biomass feedstocks have unique properties that offer great potential advantages for thermochemical conversion processes. Biomass is highly reactive; thus, feedstocks can be decomposed and converted at much lower temperatures than coals, making these processes more efficient and competitive at smaller scale. Biomass feedstocks also have much lower ash and sulfur content than coals. The lower sulfur content greatly reduces gas cleanup costs and allows biomass to be reacted directly with catalysts without catalyst poisoning problems. The research activities sponsored by the Biomass Thermochemical Conversion Program are directed toward exploiting these properties of biomass.

PROGRAM RESEARCH AREAS

The research activities sponsored by the Thermochemical Conversion Program can be divided into four areas:

1. Gasification Technology
2. Liquid Fuels Technology
3. Direct Combustion Technology
4. Program Support Activities.

The following sections briefly describe program activities and major accomplishments in each of these areas for fiscal year 1983.

Gasification Technology

Gasification of biomass can be achieved by reacting biomass with steam, at moderately high temperatures, to produce a combustible gas mixture containing large quantities of hydrogen and carbon monoxide. Heat is provided to the gasification reactor either by combusting a portion of the biomass with air or oxygen, or by indirectly heating the reactor. When air is used to heat the gasifier, the nitrogen in the air significantly dilutes the product gas, and a low-Btu gas with a heating value of 90 to 200 Btu/scf is produced. Low-Btu fuel gas is limited by the restrictions that the gas must be used at or near the site of production in a close-coupled process. The high nitrogen content of low-Btu gas precludes its use for synthesis of liquid fuels.

If heat is supplied to the gasifier using oxygen or indirect methods instead of air, nitrogen is eliminated, and a medium-Btu gas product with a heating value ranging from 300 to 600 Btu/scf can be produced. Medium-Btu gas is suitable for substitution for fuel oil and natural gas in most applications and for the synthesis of liquid fuels.

The gasification research activities sponsored by the Biomass Thermochemical Conversion Program are directed toward exploiting the unique properties of biomass. Primary emphasis has been on production of a medium-Btu gas for either fuel or synthesis gas uses. In addition, research has also been conducted to improve the performance and reliability of low-Btu gasifiers. Specific research projects include:

- production of a medium-Btu gas without using purified oxygen at Battelle-Columbus Laboratories
- high pressure (up to 500 psia) steam-oxygen gasification of biomass in a fluidized bed reactor at the Institute of Gas Technology
- producing synthesis gas via catalytic gasification at Pacific Northwest Laboratory
- indirect reactor heating methods at the University of Missouri-Rolla and Texas Tech University
- improving the reliability, performance, and acceptability of small air-blown gasifiers at University of Florida-Gainesville, Rocky Creek Farm Gasogens, and Cal Recovery Systems.

Liquid Fuels Technology

The Biomass Thermochemical Conversion Program is sponsoring research on the production of hydrocarbon-compatible liquid fuels from biomass. Two approaches--fast pyrolysis and direct liquefaction--are currently being investigated.

Pyrolysis refers to the thermal decomposition of biomass in an oxygen-free environment. Conventional pyrolysis produces products consisting of about one-third each gases, pyrolysis oil, and char. Researchers have discovered that the yields of higher-valued light liquid hydrocarbons and gases can be increased to greater than 95% if biomass is heated very rapidly. These high-valued products contain up to 20% ethylene and BTX (benzene, toluene, and xylene), which are useful as fuels and octane enhancers.

Direct liquefaction refers to a specific process in which biomass is heated at moderate temperatures (350°C) and high pressures (3000 psi) with a catalyst in a reducing atmosphere of carbon monoxide and hydrogen. The goal of this research is to produce liquid products that can be used as substitute heavy fuel oils or, after upgrading, as distillate fractions, diesel fuels, octane enhancers, and in other related applications.

During 1983, the Thermochemical Conversion Program sponsored research in both liquid fuel technology areas. Research has focused on developing a better understanding of the basic reaction mechanisms governing these processes and on improving the competitiveness of these technology concepts. Specific projects include:

- determination of individual sequential pyrolysis mechanisms at the Solar Energy Research Institute (SERI)
- research at the Solar Energy Research Institute on a unique entrained, ablative fast pyrolysis reactor for supplying the heat fluxes required for fast pyrolysis
- work at Brookhaven National Laboratory on rapid pyrolysis of biomass in an atmosphere of methane to increase the yields of olefin and BTX products
- research at the Georgia Institute of Technology on an entrained rapid pyrolysis reactor to produce higher yields of pyrolysis oil
- research on an advanced concept to liquefy very concentrated biomass slurries in an integrated extruder/static mixer reactor at the University of Arizona
- research at Pacific Northwest Laboratory on the characterization and upgrading of direct liquefaction oils including research to lower oxygen content and viscosity of the product.

Direct Combustion Technology

Direct combustion of biomass feedstocks, particularly wood, is already widely practiced by the private sector. Direct combustion projects funded by the Biomass Thermochemical Conversion Program have focused on unique, innovative combustion systems. These include:

- research on a directly fired wood combustor/gas turbine system at Aerospace Research Corporation
- adaptation of Stirling engine external combustion systems to biomass fuels at United Stirling, Incorporated
- theoretical modeling and experimental verification of biomass combustion behavior at Jet Propulsion Laboratory to increase biomass combustion efficiency and examine the effects of additives on combustion rates.

Program Support Activities

During 1983, the Thermochemical Conversion Program sponsored additional research activities with the goal of supporting major program elements. These activities included:

- completion of a study by Pyros, Incorporated, on the wood supply infrastructure in the eastern U.S. for supplying wood to intermediate size (500 to 2000 tons/day) biomass conversion facilities
- continuing technoeconomic analysis by Science Applications, Incorporated, of advanced biomass thermochemical conversion processes for producing liquid fuels, with particular emphasis on advanced pyrolysis concepts
- research at Georgia Tech on methods to reduce aqueous effluents in biomass gasification systems
- research at Dynecology, Incorporated, to determine the feasibility of using biomass/coal/municipal solid waste (MSW) briquets in coal gasification systems.

OUTSTANDING ACCOMPLISHMENTS IN 1983

The Biomass Thermochemical Conversion Program made major progress in 1983 toward verifying the technical feasibility of several advanced technology concepts. These state-of-the-art research concepts offer the potential for significant advancement of biomass conversion technology. In addition, progress was made at the fundamental level in understanding the reaction behavior involved in upgrading biomass liquefaction products. Outstanding accomplishments of the Biomass Thermochemical Conversion Program during fiscal year 1983 include:

- Successful Extended Operation of Combustor/Gas Turbine System. Aerospace Research Corporation successfully showed that combustion gases from a pressurized wood combustor can be used to directly power a gas turbine for extended time periods. A 375-kW gas turbine was operated for approximately 500 hours without evidence of corrosion or erosion of turbine components. The experimental testing verified earlier sampling showing that particulate loading in the gas stream to the turbine was low and would meet operational requirements. The sampling indicated that 80 to 90% of the particulate was less than 0.5 micron. The results of this research have been used to design a larger 3000-kW system, which is currently nearing completion. Operation of the 3000-kW system is expected in 1984. This research is the first to successfully use biomass combustion gases to directly power a gas turbine.
- Successful Production of Medium-Btu Fuel Gas Using an Indirectly Heated, Dual Bed Gasifier. Battelle-Columbus Laboratories successfully produced a medium-Btu fuel gas in an indirectly heated dual bed gasifier. The entrained bed gasifier uses sand that has been heated in a separate combustor to provide heat for the biomass conversion reactions. The indirect heating eliminates the need for expensive oxygen purification equipment. Throughput in the reactor, based upon cross-sectional area, is about three times greater than in conventional fluidized beds, and about ten times greater than in fixed beds. During 1983, the gasifier diameter was increased from 6 inches to 10 inches ID. The modified

reactor operated successfully, obtaining even higher conversion efficiencies than previously obtained in the small unit. Feeding rates up to the gasifier design capacity of about 1100 pounds per hour were achieved.

- Successful Oxygen-Blown Biomass Gasification in a Pressurized Fluidized Bed Reactor. The Institute of Gas Technology verified that biomass could be gasified to a medium-Btu gas in an oxygen-blown, pressurized, fluidized bed gasifier. Initial tests showed that about 0.4 pound of oxygen per pound of dry wood were consumed during gasification. The gas produced during initial operation also had a H_2/CO ratio of about 2, which is ideal for synthesis.

- Successful Operation of Indirectly Heated Gasifier Using a Fire-Tube Heat Exchanger Concept. Research at the University of Missouri-Rolla successfully showed that biomass could be gasified in a fluidized bed reactor using a fire-tube heat exchanger. In this gasifier concept, heat for gasification reactions is provided by hot combustion gases passing through a fire-tube heat exchanger inside the gasifier. The concept eliminates the need for oxygen and would be particularly useful for catalytic gasification systems where oxygen addition would destroy the catalysts. The concept was successfully tested during 1983 in a 20-inch gasifier. Heat exchange rates were approximately as predicted, and the mixing in the fluidizing section appeared to be excellent. Wood feed rates of up to 400 pounds per hour (10% moisture) were achieved. These results are the first verification of the technical feasibility of this type of concept.

- Produced High Yields of Liquid Oil Products Using an Entrained Pyrolysis Reactor. Georgia Tech successfully operated a newly constructed pyrolysis reactor for generating liquid products. The reactor is an entrained flow pyrolysis unit in which both feedstock heat-up rates and product quench rates are rapid. During 1983, yields of pyrolytic oils exceeding 40% by weight (moisture-free basis) were obtained. This represents nearly a twofold increase in yield over conventional pyrolysis processes, which produce only 20 to 25% moisture-free liquid products.

Further research is expected to result in even higher liquid yields as process conditions are optimized.

- Showed That Biomass Derived Crude Oils Could Successfully be Hydrotreated to Obtain Synthetic Gasoline. Pacific Northwest Laboratory successfully conducted upgrading studies of biomass direct liquefaction oils. The purpose of the work is to produce a high octane gasoline blending stock that retains the aromatic components of the biomass feedstock. Unlike conventional exhaustive hydrotreating, which would reduce the biomass oils to low octane, straight-chain hydrocarbons, this approach uses less hydrogen and retains higher-valued aromatic components. Biocrude oils previously produced at the DOE biomass liquefaction facility in Albany, Oregon, were treated using a sulfided colbalt-molybdenum catalyst. Distillate fractions were successfully converted to high octane gasoline components. Research on upgrading the biomass whole oils is continuing.

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INTRODUCTION

Biomass represents an important but underutilized energy resource in the United States. Wood and forest product residues, grasses, agricultural crops and their residues, animal wastes, and other biomass resources currently supply nearly 3% of total U.S. energy consumption. As an abundant, renewable, domestic energy resource, biomass can help the United States reduce its dependence on imported oil and natural gas.

The Office of Technology Assessment has estimated that, with proper resource management and the development of efficient conversion processes, the potential contribution of biomass to the U.S. energy demand could range as high as 17 quadrillion Btu per year[a]. This amounts to almost 20% of current U.S. energy consumption. Similarly, the Energy Research Advisory Board (ERAB) has estimated that biomass could potentially supply the nation with about 10 quadrillion Btu by the year 2000[b]. Thermochemical conversion processes are expected to contribute significantly to this total.

The U.S. Department of Energy (DOE) is actively encouraging increased utilization of biomass resources through research projects sponsored by its Biomass Energy Technology Division, Office of Renewable Energy. Pacific Northwest Laboratory (PNL)[c] has been designated the Field Management Office for the Biomass Thermochemical Conversion Program. As such, PNL has responsibility for overall management of the program.

This report first describes the Biomass Thermochemical Conversion Program: its organization, underlying objective, and goal, rationale, and

(a) Office of Technology Assessment. 1980. Energy from Biological Processes, Volume I - Biomass Resource Base. U.S. Goverment Printing Office, Washington, D.C.

(b) Solar Energy Research and Development: Federal and Private Sector Roles, Draft Report to the Solar R&D Panel of the Energy Research Advisory Board, September 2, 1982.

(c) Operated for the U.S. Department of Energy by Battelle Memorial Institute.

approach. Then, the program subcontracted research activities during fiscal year 1983 are documented. Program publications issued in FY83 are listed in the Appendix.

PROGRAM DESCRIPTION

The Biomass Thermochemical Conversion Program began in 1977 as one aspect of DOE's overall effort to develop renewable energy resources in the U.S. The recognized potential of biomass as a significant contributor to meet the nation's energy demand suggested the need for research into more efficient processes for converting the resource into usable energy. This section describes the Thermochemical Conversion Program's role in meeting that need.

ORGANIZATION

The relationship of the Biomass Thermochemical Conversion Program to other programs within DOE's Biomass Energy Technology Division is shown in Figure 1.

OBJECTIVE AND GOAL

The objective of the Biomass Thermochemical Conversion Program is to generate scientific data and biomass conversion process information that will lead to establishment of cost-effective processes for conversion of biomass resources into clean fuels. Areas of research included in the program are gasification, liquid fuels production, and combustion of biomass. The goal of the program is to improve the data base for biomass conversion by investigating those parameters that are critical to thermal conversion processes.

RATIONALE

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

- combustion to produce heat, steam, electricity, direct mechanical power, and combinations of these
- gasification to produce low- or intermediate-energy fuel gas
- gasification to produce synthesis gas for the production of alcohol fuels, hydrocarbon liquids, or synthetic natural gas (SNG) via catalytic

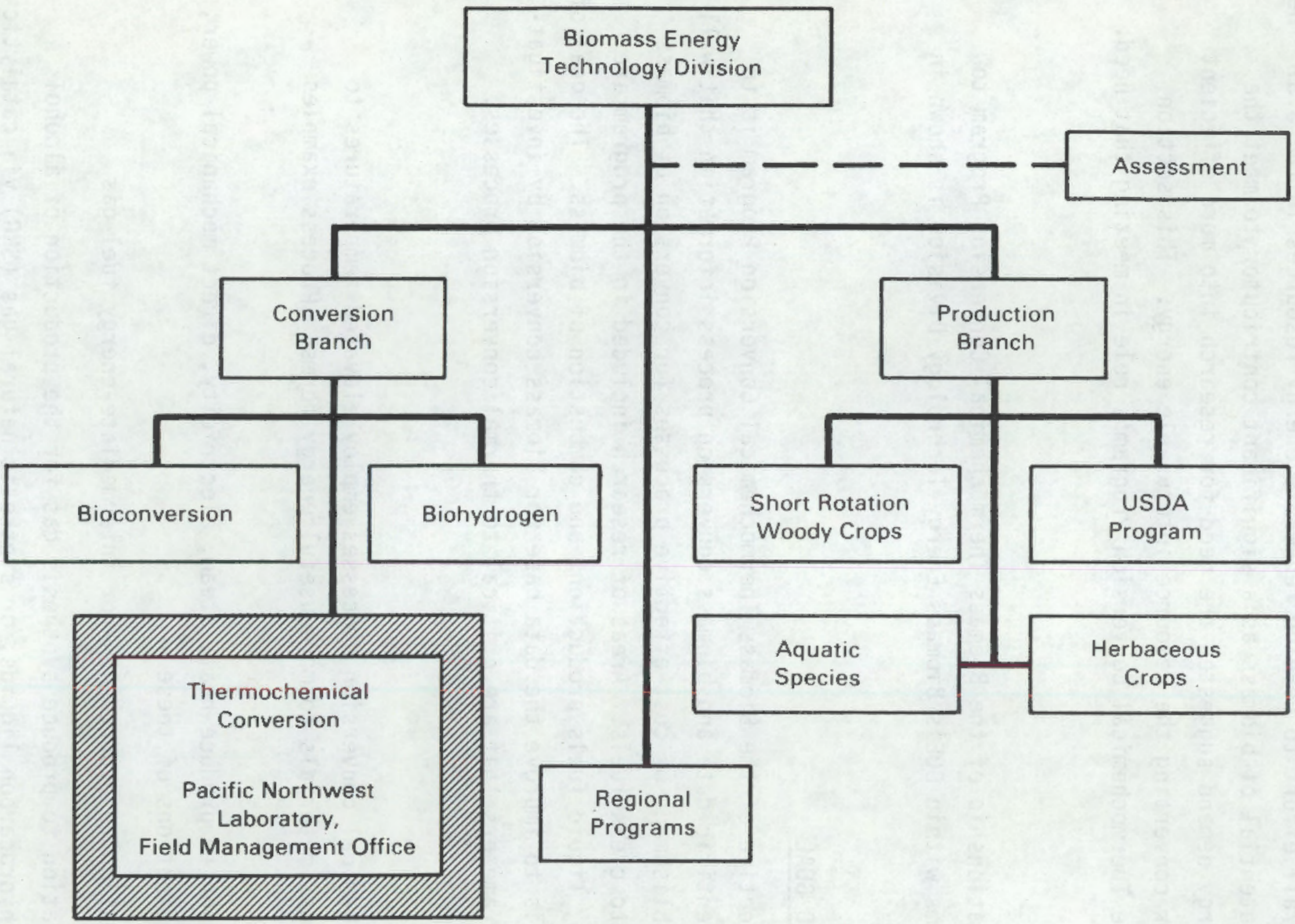

FIGURE 1. Relationship of Biomass Thermochemical Conversion Program to Biomass Energy Technology Division Organization

processes

- direct liquefaction to produce heavy oils or, with upgrading, lighter boiling liquid products
- pyrolysis to produce a mixture of pyrolysis oils, fuel gases, and char.

Wood and crop residues comprise 96% of biomass feedstocks available for conversion to liquid and gaseous fuels. Thermochemical processes are well suited for conversion of these materials. These processes can convert 85 to 95% of the organic material in such feedstocks with high efficiency and relatively little sensitivity to variations in the feed material. As illustrated in Figure 2, thermochemical conversion processes can provide a wide spectrum of versatile products congruent with U.S. energy use patterns.

Compared to other solid fuels such as coal, biomass feedstocks have unique properties that offer great potential advantages for thermochemical conversion processes. These properties include:

- high volatility - Biomass feedstocks contain a high proportion of volatile material, 70 to 90% for wood compared to 30 to 45% for typical coals. This means that a large fraction of most biomass feedstocks can be pyrolyzed (devolatilized) rapidly at relatively low temperatures. Figure 3 presents a comparison of wood and one typical coal in terms of weight loss due to devolatilization at various temperatures.
- high char reactivity - Biomass chars gasify rapidly in the presence of steam at relatively low temperatures. This property is illustrated in Figure 4, which compares the char reactivity of some biomass feedstocks with peat and coal at 800°C and 300 psi in the presence of steam.
- low sulfur content - Typical wood feedstocks contain less than 0.2% sulfur, which greatly reduces gas cleanup costs and allows biomass to be reacted in the presence of catalysts without sulfur poisoning problems.
- low ash content - Wood and most other biomass feedstocks contain less than 3.0% ash. Ash removal systems are simplified and ash disposal costs are reduced.

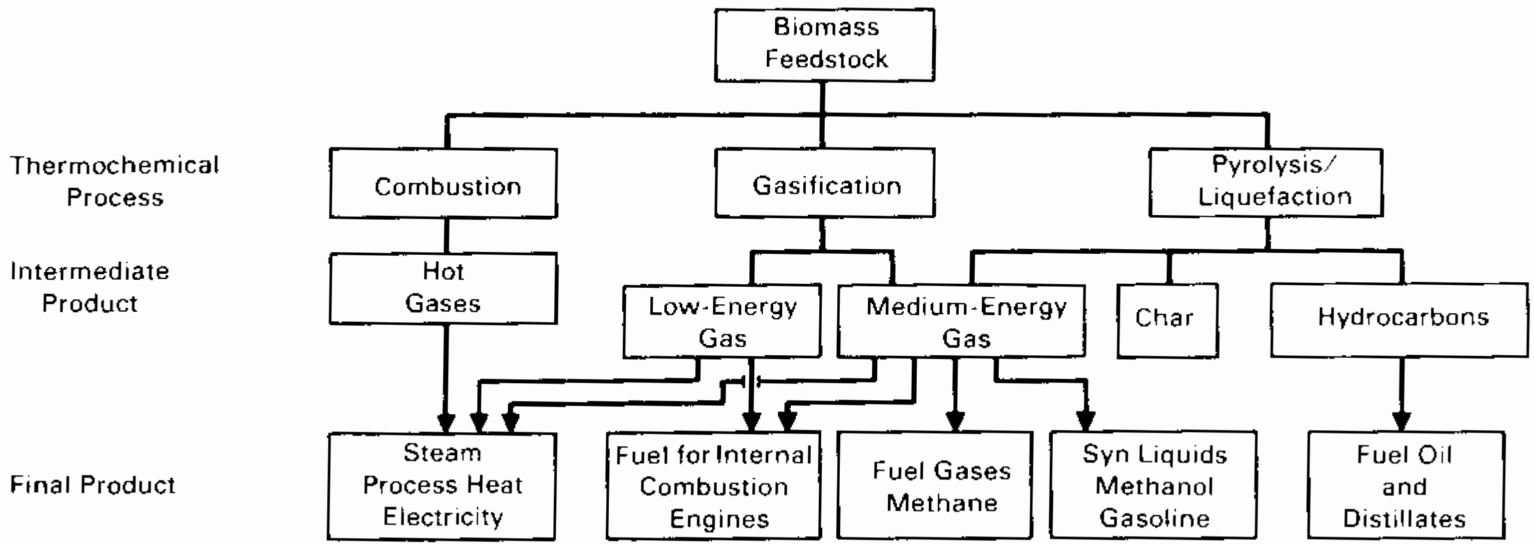

FIGURE 2. Biomass Thermochemical Conversion Processes Produce Versatile Fuels

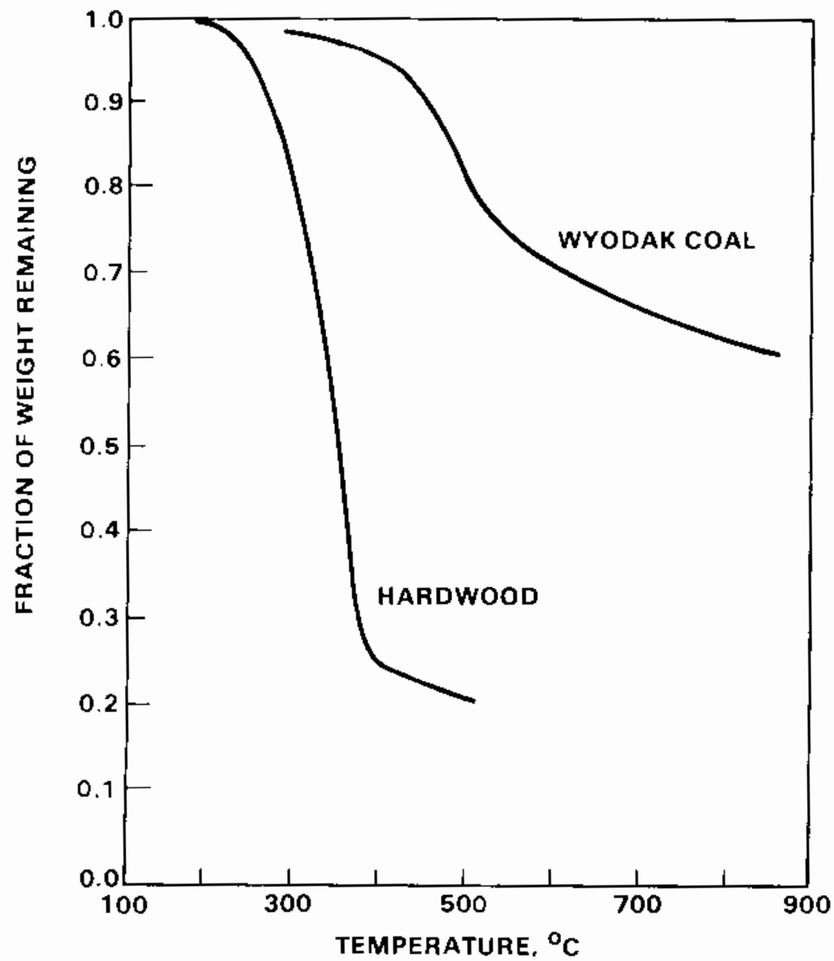

FIGURE 3. Pyrolytic Weight Loss Comparison: Wood Versus Coal

Source: Antal, M. J. 1978. Biomass Energy Enhancement - A Report to the President's Council on Environmental Quality. Princeton University, Princeton, New Jersey.

The combination of these four properties makes it possible to convert biomass feedstocks into gaseous and liquid fuels at faster rates and lower temperatures, and with fewer waste disposal problems, than most coals.

Thus, biomass feedstocks have some potential advantages when compared to fossil feedstocks. However, biomass is a widely distributed resource with a relatively high moisture content. This disadvantage limits the distance over which it can be shipped economically. Developing conversion processes that exploit the unique properties of biomass feedstocks will result in higher conversion rates and lower costs. This will allow biomass-derived gaseous and liquid fuels to be produced competitively in smaller-scale facilities.

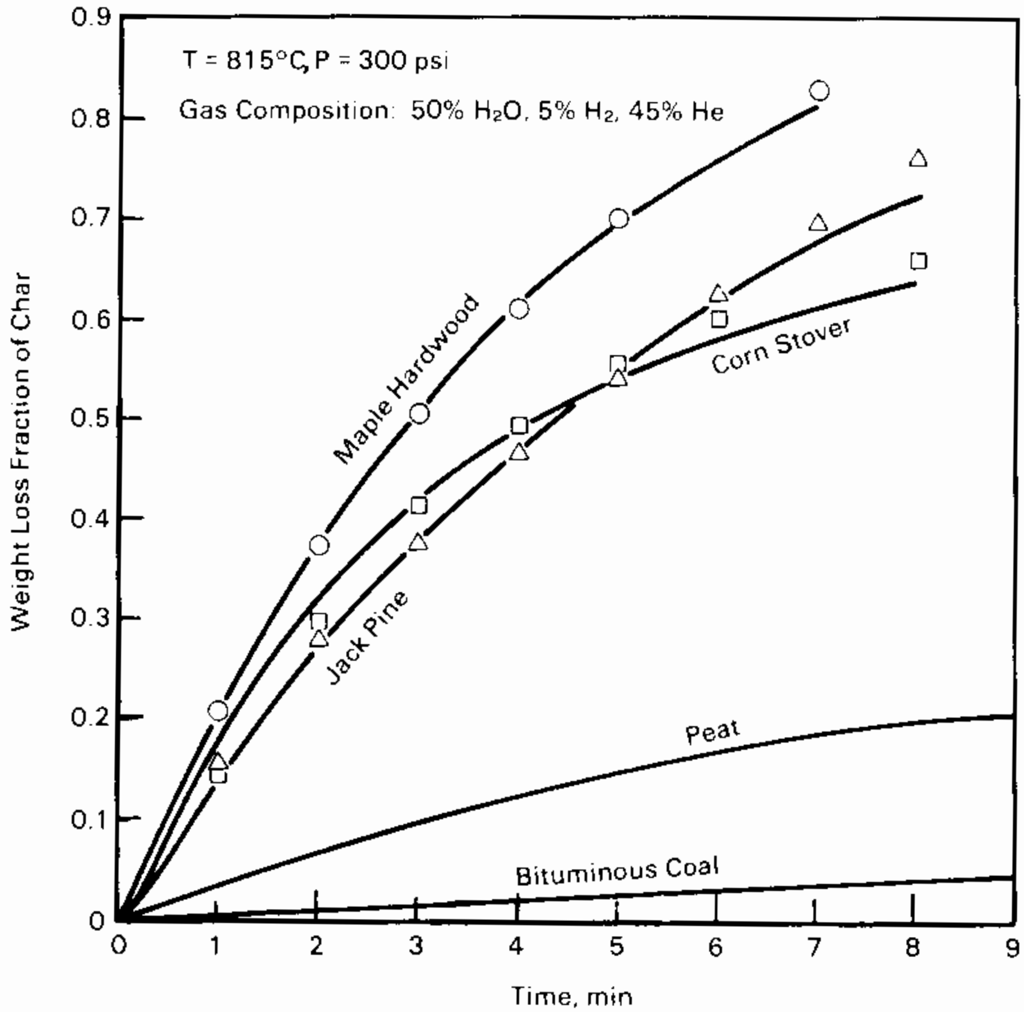

FIGURE 4. Char Reactivity Comparisons: Biomass Feedstocks Versus Peat and Coal

APPROACH

To achieve its objective and goal, the Thermochemical Conversion Program sponsors research and development activities with high payoff potential. Innovative basic research concepts are initially selected on the basis of program research needs, the concepts' potential contribution to advancing the state of the art of biomass conversion, and the availability of research funds.

Initial research usually consists of determining the technical feasibility of individual concepts in bench-scale experiments. Concepts passing the preliminary technical feasibility test are studied in continuous process research units. These small-scale research units permit further investigation of the concept under realistic conditions in a continuous, dynamic, interactive mode. This research stage allows the evaluation of variations in operating parameters in a continuous process environment and the determination of material and energy balances critical to determining the potential of the process. Individual concepts are then combined into an integrated process. The integrated process is evaluated to estimate process economics at commercial scale. This research approach is shown conceptually in Figure 5.

The interaction between the federal government and private industry in funding research on evolving technologies is shown in Figure 6. To assure the maximum opportunity for technology transfer to the private sector, industrial interest and involvement is sought at all stages of research. The government role is primarily to explore basic research concepts and establish the technical feasibility of promising technologies. These early stages of research involve risks that are too great and lead times that are too long to be supported by industry. As the data base for evolving technologies becomes better defined, cost-sharing by both the government and private industry becomes more practical.

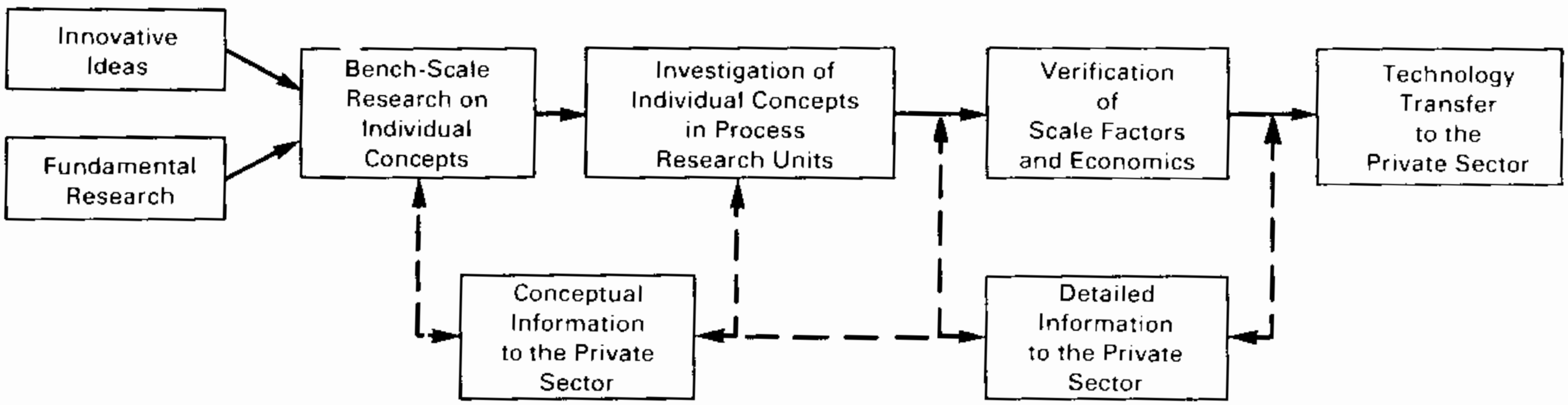

FIGURE 5. Conceptual Approach to Biomass Thermochemical Conversion Research

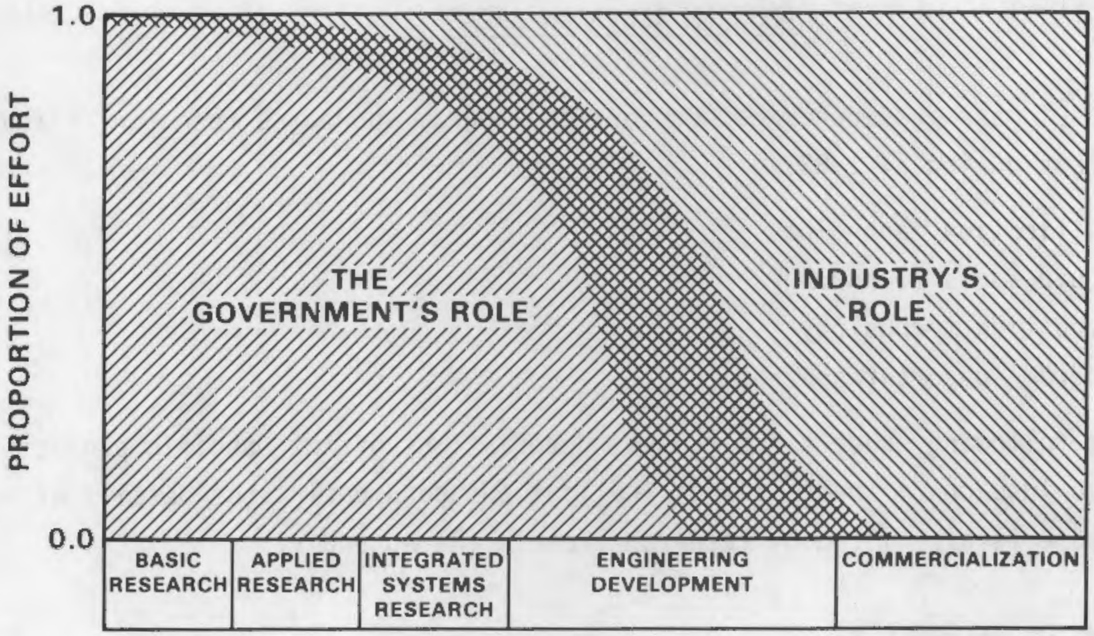

FIGURE 6. Government and Private Industry Interaction in Biomass Thermochemical Conversion Research

PROGRAM RESEARCH AREAS

The Biomass Thermochemical Conversion Program sponsored research in four major areas during FY 1983:

1. gasification technology
2. liquid fuels technology
3. combustion technology
4. program support research.

The following subsections present descriptions of the specific projects conducted in each of these areas. Publications documenting the details of these projects are listed by research area in the Appendix.

GASIFICATION TECHNOLOGY

Gasification of biomass can be achieved by reacting biomass with steam, at moderately high temperatures, to produce a combustible gas containing large quantities of hydrogen and carbon monoxide. Heat is provided to the reactor either by combusting a portion of the biomass with air or oxygen, or by indirectly heating the reactor.

If air is used to heat the gasifier, the nitrogen in the air significantly dilutes the product gas, and a low-Btu gas is produced, as shown in Figure 7. Low-Btu gas typically has a heating value ranging from 90 to 200 Btu/scf. Today, low-Btu gasification of biomass is considered to be a commercial or near-commercial technology. Low-Btu gas can substitute for natural gas and oil to fire boilers, subject to the following limitations:

- Low-Btu gasifiers must be close-coupled to boilers to take advantage of the high temperature of the gas leaving the gasifier.
- Burning low-Btu gas in a boiler designed for oil or natural gas will frequently result in boiler derating unless expensive modifications are made to the boiler.

Low-Btu gas can also be used instead of gasoline and diesel fuel to fuel internal combustion engines, provided that the gas is sufficiently cleaned and cooled. However, the efficiency of the engine will be reduced by about 20%.

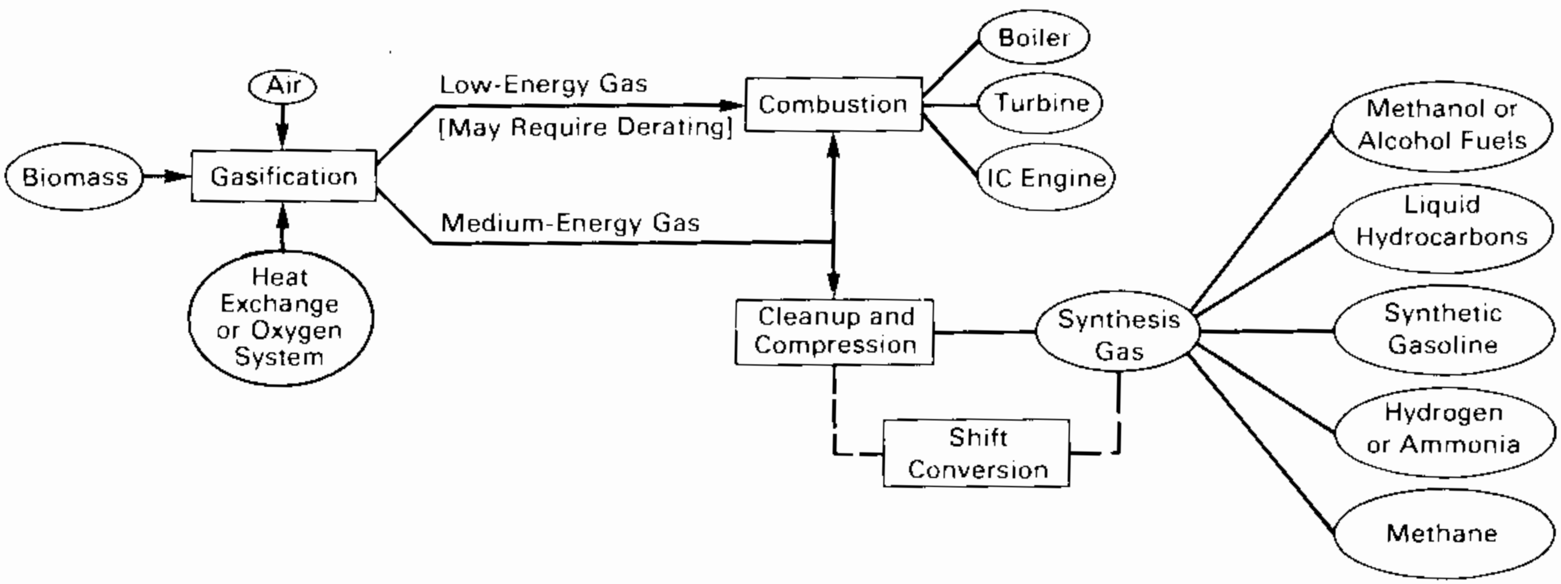

FIGURE 7. Thermochemical Gasification of Biomass

Although low-Btu gasifiers are commercially available, questions about overall reliability remain.

If nitrogen is eliminated from the product gas of a biomass gasifier by heating it indirectly or with oxygen, a medium-Btu gas can be produced as shown in Figure 7. Medium-Btu gas has a heating value typically ranging from 300 to 600 Btu/scf, and is much more versatile than low-Btu gas.

Because of its higher heating value, it possesses the following advantages over low-Btu gas:

- Medium-Btu gas can be used in nearly all boiler retrofit applications without any boiler derating problems.
- Medium-Btu gas produces a higher flame temperature than low-Btu gas, making it suitable for retrofitting processes where this is a critical factor.
- Medium-Btu gas has two to five times the energy density of low-Btu gas, allowing it to be transported moderate distances by pipeline at a reasonable cost.
- Medium-Btu gas can be used for the synthesis of derived liquid fuels such as methanol, fuel oils, and gasoline.

Medium-Btu fuel gas can also be produced from coal. The major disadvantage of coal gasification is that coal is not very reactive. Large quantities of oxygen are required to achieve sufficiently high reactor temperatures and reasonable reaction rates. Oxygen plants, however, are very expensive to build and operate. This dictates that medium-Btu coal gasification plants be constructed with very large capacities to take advantage of economies of scale to be competitive.

Because biomass is a distributed resource, transportation costs limit the amount of biomass that can be delivered to a central facility. Consequently, biomass gasifiers are limited to a maximum capacity of about 2,000 dry tons of wood per day. Therefore, it is necessary to reduce or eliminate the requirement for oxygen to achieve a cost-effective process at a smaller scale. Fortunately, biomass is much more reactive than coal and can be gasified at lower temperatures. Less heat is required for reaction due to the higher volatile content, and the remaining chars are also more reactive, as shown in Figures 3 and 4. This reduces the oxygen requirement for medium-Btu gasifiers that are directly heated with oxygen. Furthermore, the lower reactor temperatures and heating requirements make it possible to indirectly heat the biomass in the reactor without using expensive, exotic heat exchanger materials, thereby eliminating the requirement for oxygen. This approach offers the opportunity for significantly reducing gasification costs. In addition, the low sulfur content of most biomass feedstocks makes it possible to gasify biomass in the presence of catalysts without catalyst poisoning problems. The use of catalysts allows for even lower reaction temperatures and makes it possible to adjust the composition of the product gas directly within the reactor to produce synthesis gases for methane and liquid fuels. The lower sulfur content also eliminates the need for a costly gas cleanup system to remove sulfur from the product gas.

The gasification research projects sponsored by the Biomass Thermochemical Conversion Program are directed primarily toward exploiting the natural advantages of biomass to produce medium-Btu gas. The medium-Btu gas, depending on process concept, can be utilized either as a fuel gas or as a synthesis gas for production of methane or liquid fuels. Research in medium-Btu gasification has focused on using the high reactivity of biomass to reduce or eliminate the requirement for oxygen in the gasifier. Research has also centered on determining the technical feasibility of producing synthesis gas for production of high-value liquid and gaseous fuels. In addition to the primary emphasis on medium-Btu gasification research, the Biomass Thermochemical Conversion Program also sponsors a small amount of research on low-Btu gasifiers to improve overall reliability and acceptability of such systems. This research is aimed at methods of increasing gasifier performance and improving product gas cleanup.

The gasification research projects sponsored by the Biomass Thermochemical Conversion Program are shown in Figure 8. A brief description of each project and a discussion of progress during FY 1983 are given below.

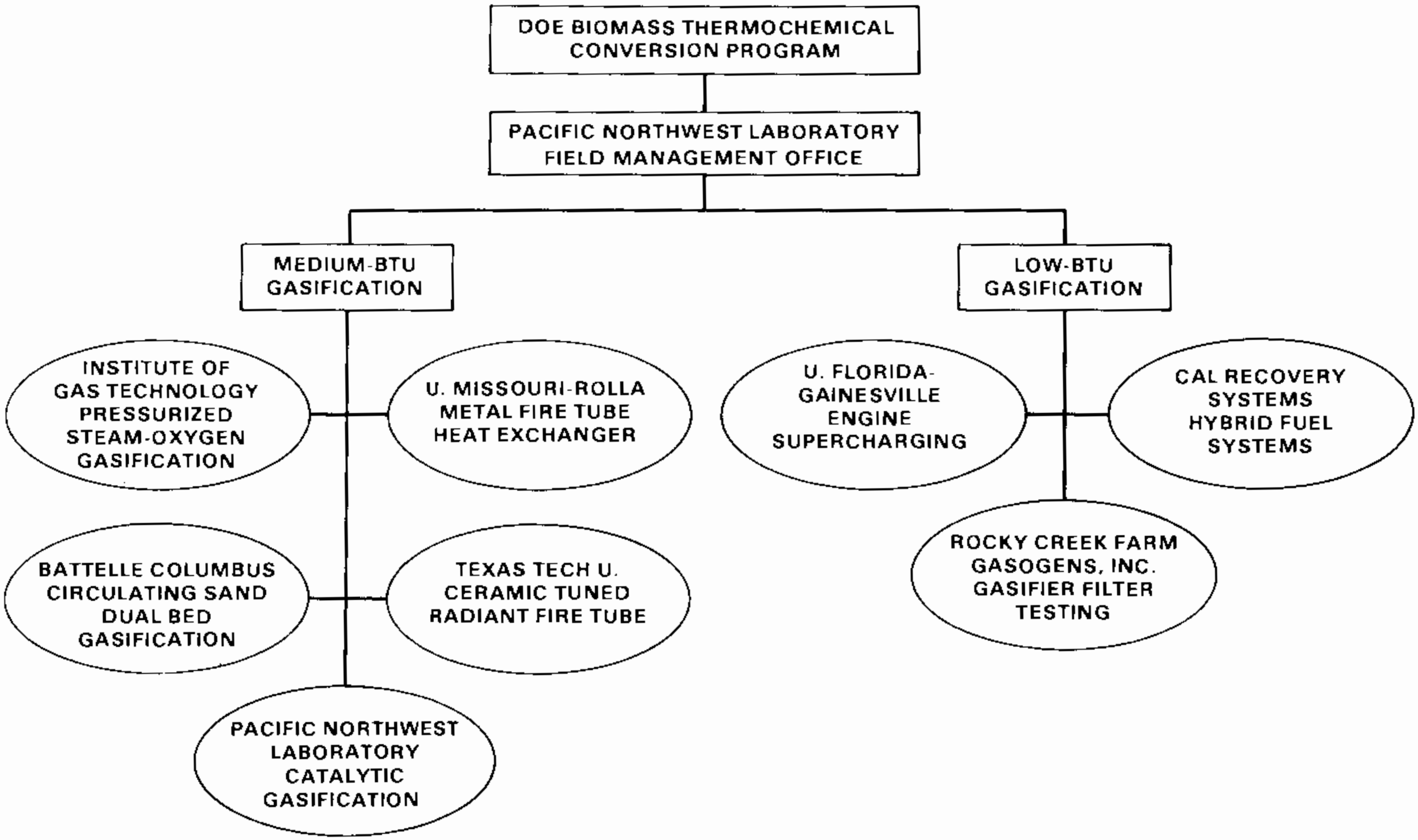

FIGURE 8. Gasification Research Projects

Medium-Btu Gasification Research

BATTELLE-COLUMBUS LABORATORIES (BCL), Columbus, Ohio, is conducting research to determine the feasibility of using a dual bed, entrained gasifier to produce a medium-Btu fuel gas. The concept provides for indirect heating of the gasifier by circulating a low density, hot incandescent sand from a combustor to the gasifier, eliminating the need for using purified oxygen. As shown in Figure 9, the entrained sand and any char leaving the gasifier is separated from the product gas in a cyclone. Both the sand and char are transferred to an entrained bed combustor where the char is burned with air. The sand is heated to a high temperature and recirculated back to the gasifier. The apparatus is shown photographically in Figure 10; the feeder is in the foreground with the insulated gasifier behind it.

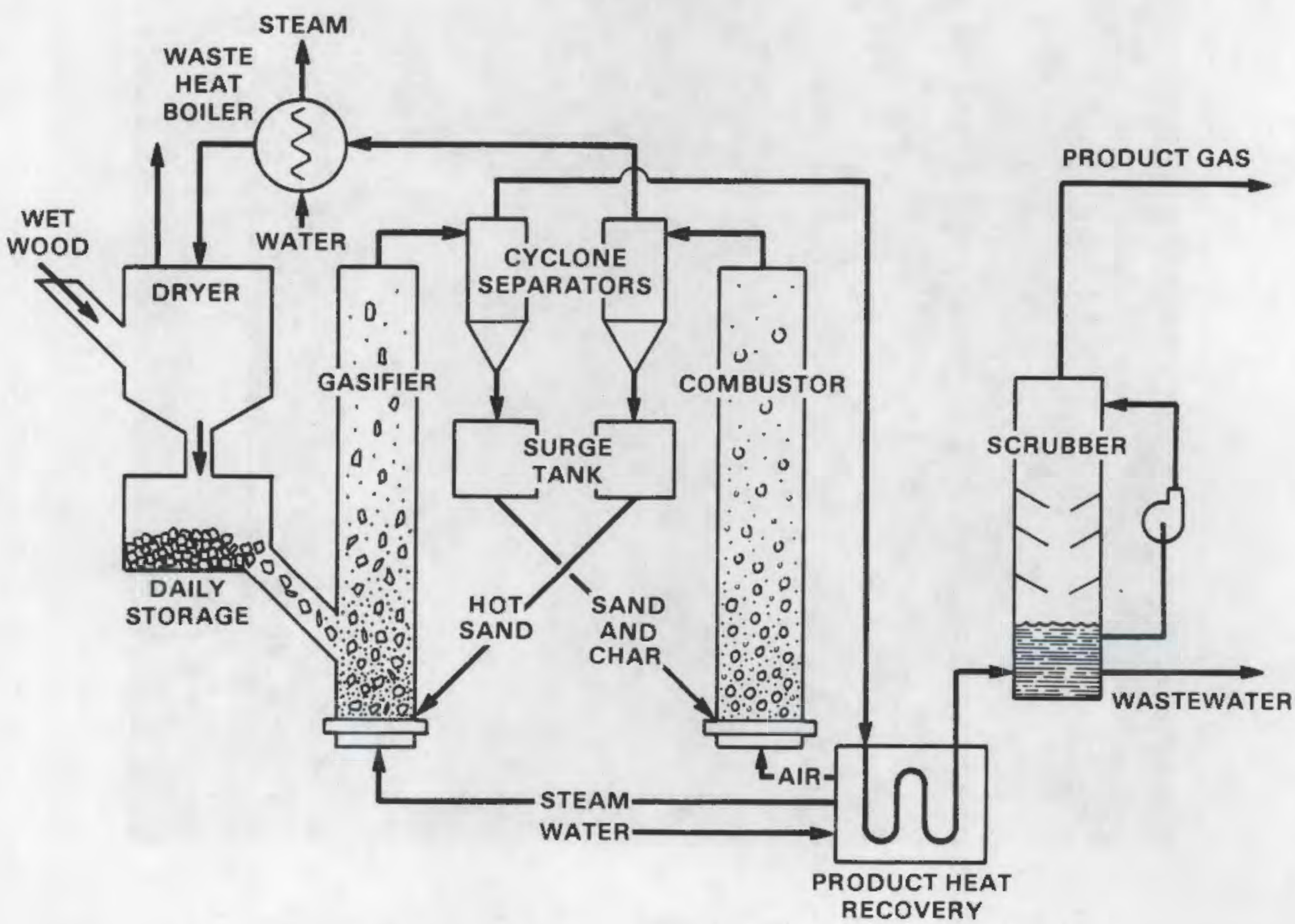

FIGURE 9. Battelle-Columbus Dual Bed, Entrained Gasifier Process

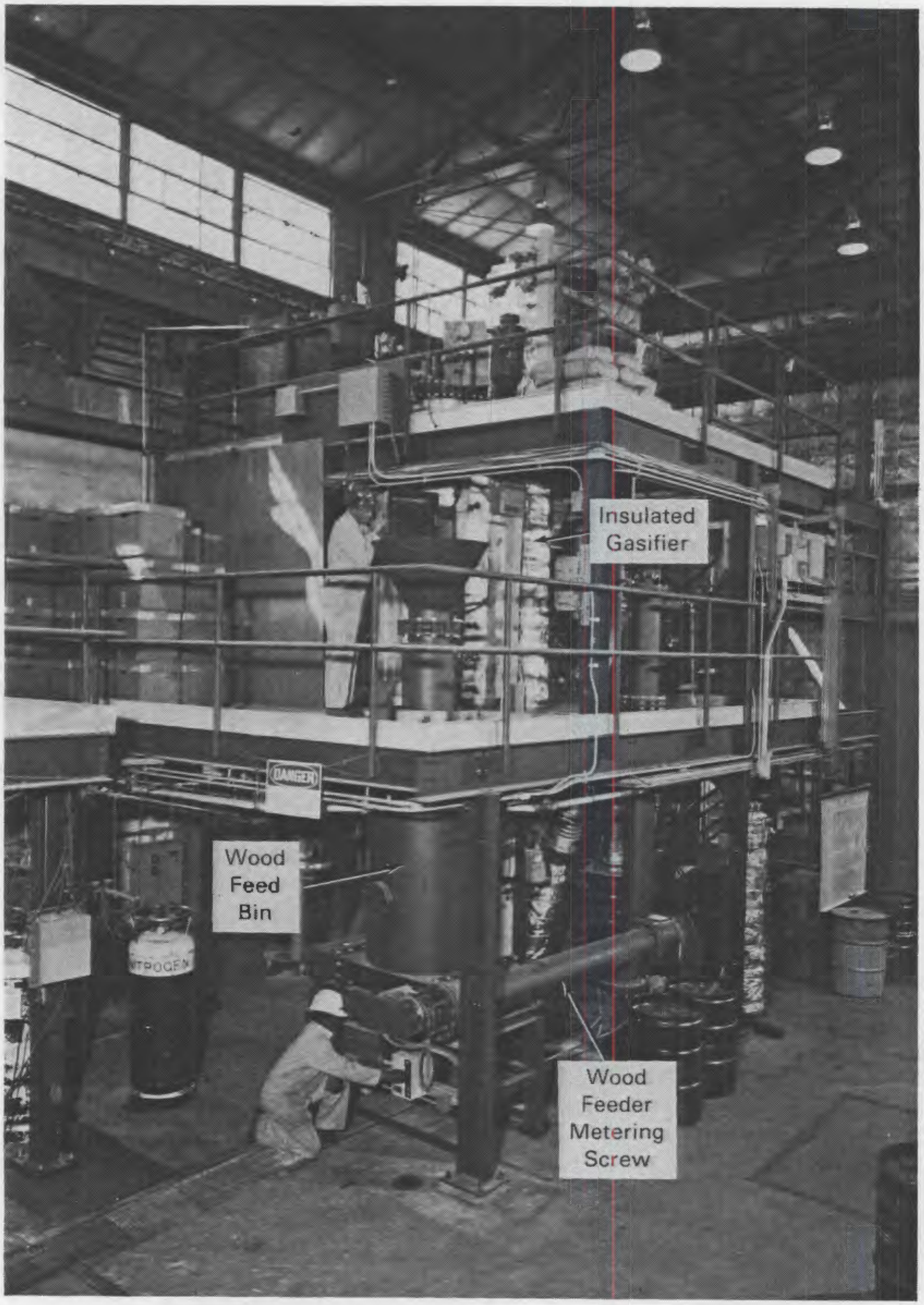

FIGURE 10. Battelle-Columbus Dual Bed, Entrained Gasifier

In the previous research using a 6-in. diameter gasifier, BCL successfully produced a medium-Btu fuel gas with a heating value of about 475 Btu/scf using both wood chips and coarsely shredded bark. As shown in Figure 11, this heating value did not vary significantly for feedstocks containing from 8% to 40% moisture on a wet basis. Gasifier throughputs of up to 1800 $lb/hr/ft^2$ were achieved.

In 1983, the gasifier was modified from 6 in. to 10 in. in diameter to more fully examine the critical operating parameters. The modified reactor was operated successfully, obtaining even higher carbon conversions under similar operating conditions than were obtained in the smaller unit. Feed rates of about 1100 lb/hr (2000 $lb/hr/ft^2$) were also achieved.

THE INSTITUTE OF GAS TECHNOLOGY (IGT), Chicago, Illinois, is conducting research to determine the actual oxygen requirements for gasifying biomass to produce a medium-Btu gas. A 12-in. diameter fluidized bed research gasifier

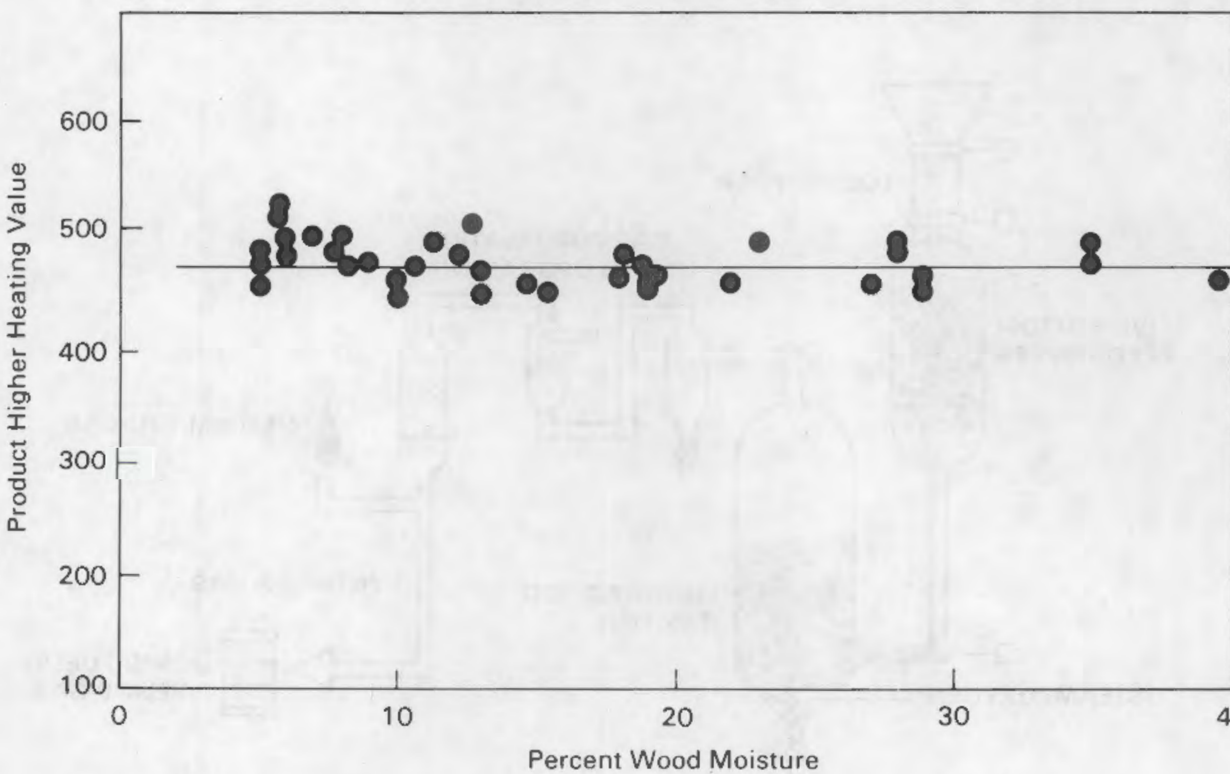

FIGURE 11. Product Gas Heating Value Versus Feedstock Moisture

was designed to explore the effects of pressure (up to 500 psia), reactor bed height, feed positions, feedstock type, and temperature on product gas yield and composition. The gasifier is shown schematically in Figure 12.

During 1983, construction of the fluidized bed gasifier was completed and system shakedown operations began. Initial results showed that the system can gasify wood at feed rates up to 270 lb/hr and pressures up to 270 psia. This system will ultimately be tested at feed rates up to 1000 lb/hr at pressures exceeding 300 psia. Research using this reactor system will be performed to determine the optimal oxygen and steam requirements for producing synthesis gases.

THE UNIVERSITY OF MISSOURI, Rolla, Missouri, is investigating the technical feasibility of using metal fire-tubes to provide heat indirectly to a fluidized bed gasifier. In the conceptual design, a portion of the feedstock or product gas would be burned to provide heat for the fire-tube heat exchanger. The concept eliminates the need for pure oxygen in the gasifier. As a result,

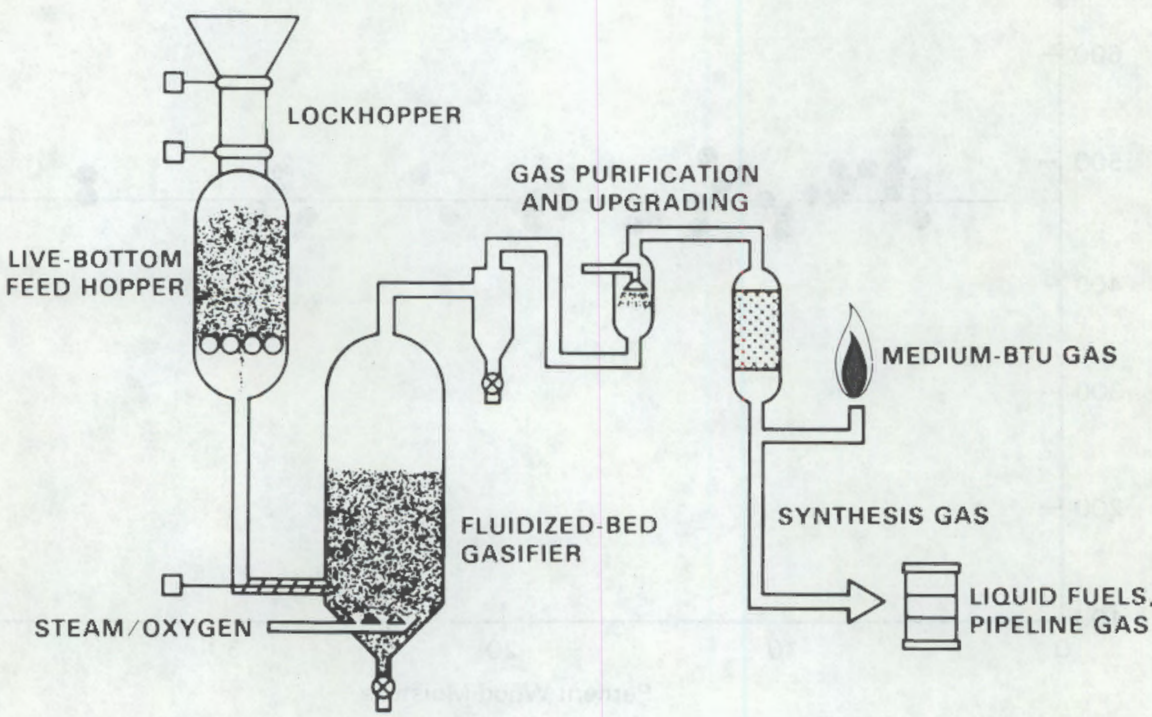

FIGURE 12. Institute of Gas Technology Fluidized Bed Gasifier

catalysts could potentially be used in the fluidized bed without harmful oxidation.

During 1983, the university completed construction of a 20-in. gasifier and began shakedown operation. The configuration selected for actual testing uses thirty 1-in. diameter U-tubes spaced on a 2-in. pitch. One view of the reactor is shown in Figure 13. The system has been operated at feed rates up to 400 lb/hr (10% moisture wood) and temperatures up to 1365°F. Future research will determine the optimal process conditions for producing medium-Btu gas and will determine critical design parameters for the heat exchanger.

TEXAS TECH UNIVERSITY, Lubbock, Texas, is investigating the technical feasibility of enhancing the radiant heat transfer capabilities of indirectly heated fluidized bed gasifiers. The concept uses ceramic heat exchanger fire-tubes doped with rare-earth metals to match the wavelength of the heat radiated by the tubes to the absorption wavelengths of the biomass. By doping the ceramic tubes to emit radiant heat at selected wavelengths, a large portion of the radiant energy will be absorbed by the biomass, increasing the rate of devolatilization and gasification. Fundamental research at Texas Tech University has been directed toward developing a predictive mathematical model for radiant heat transfer in an absorbing fluidized bed of biomass particles. A small single-tube reactor was completed during 1983, and heat transfer measurements were made for correlation with the theoretical model. Results will be used to design a small multitube reactor for additional research.

PACIFIC NORTHWEST LABORATORY (PNL), Richland, Washington, is studying the technical feasibility of producing tailored synthesis gas in a medium-Btu gasifier. Synthesis gases for the production of liquid fuels such as methanol require relatively pure mixtures of hydrogen and carbon monoxide with a molecular ratio of 2.0 to 2.5 moles of hydrogen per mole of carbon monoxide. Research at PNL is examining the feasibility of producing synthesis gases tailored to specific needs directly in the gasifier. This concept uses a catalyst in a fluidized bed gasifier to produce hydrogen and carbon monoxide products in ratios of 2.0 or greater and is shown schematically in Figure 14.

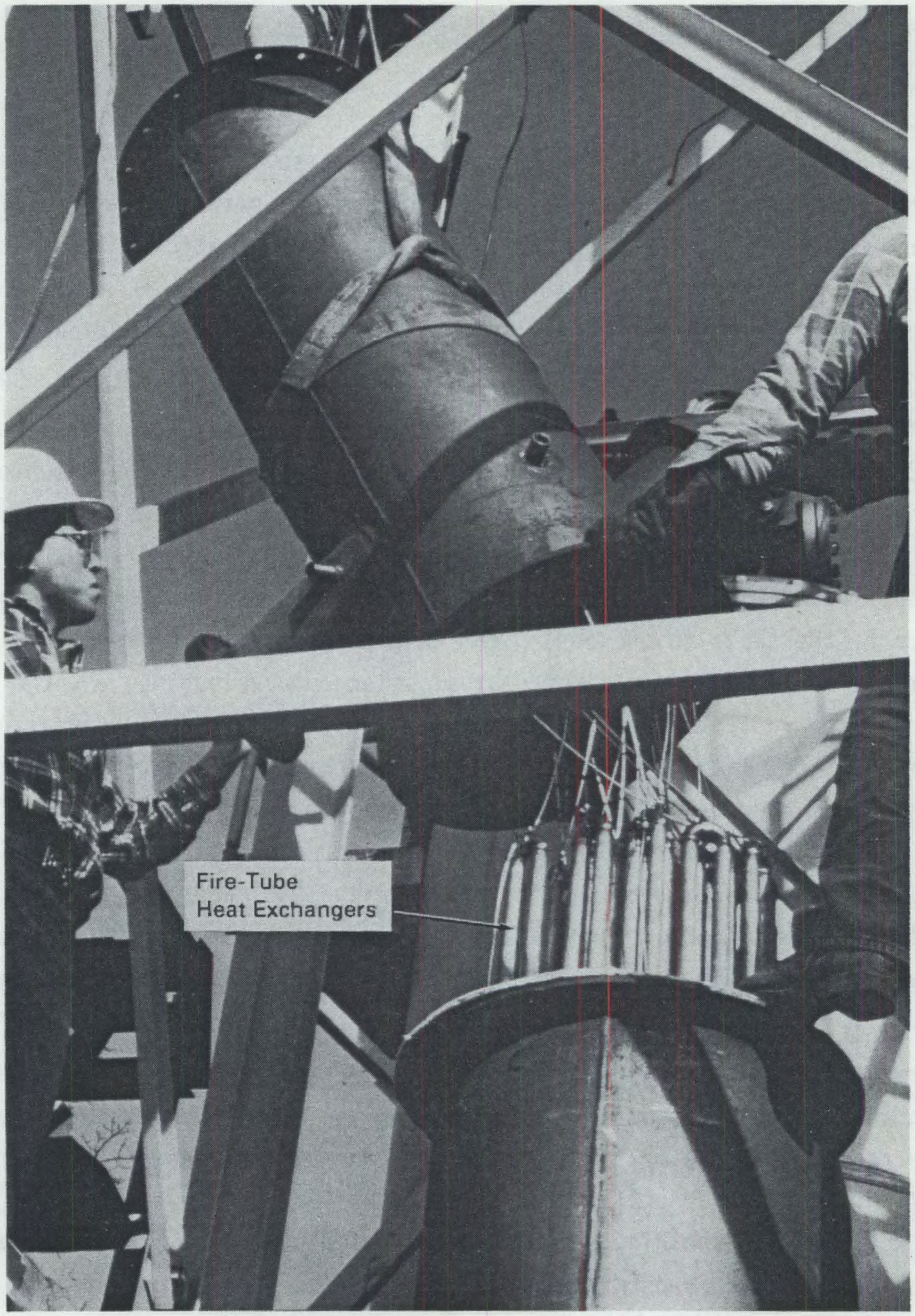

FIGURE 13. Metal Fire-Tube Heat Exchangers Inside Fluidized Bed Gasifier at University of Missouri-Rolla

During 1983, laboratory studies were conducted to determine the roles of primary and secondary catalysts in the gasification process. Alkali carbonate catalysts (primary catalysts) increased both the production of char during devolatilization and the rates of the subsequent steam gasification of that char. The primary catalysts also significantly reduced the production of tars and condensible organics at 750°C. Studies of supported reforming catalysts (secondary catalysts) with model compounds showed that catalyst deactiviation due to carbon deposition was more pronounced with heavier hydrocarbons. These data will be used in fluidized bed gasification experiments to determine optimal reactor conditions for catalytically producing synthesis gas.

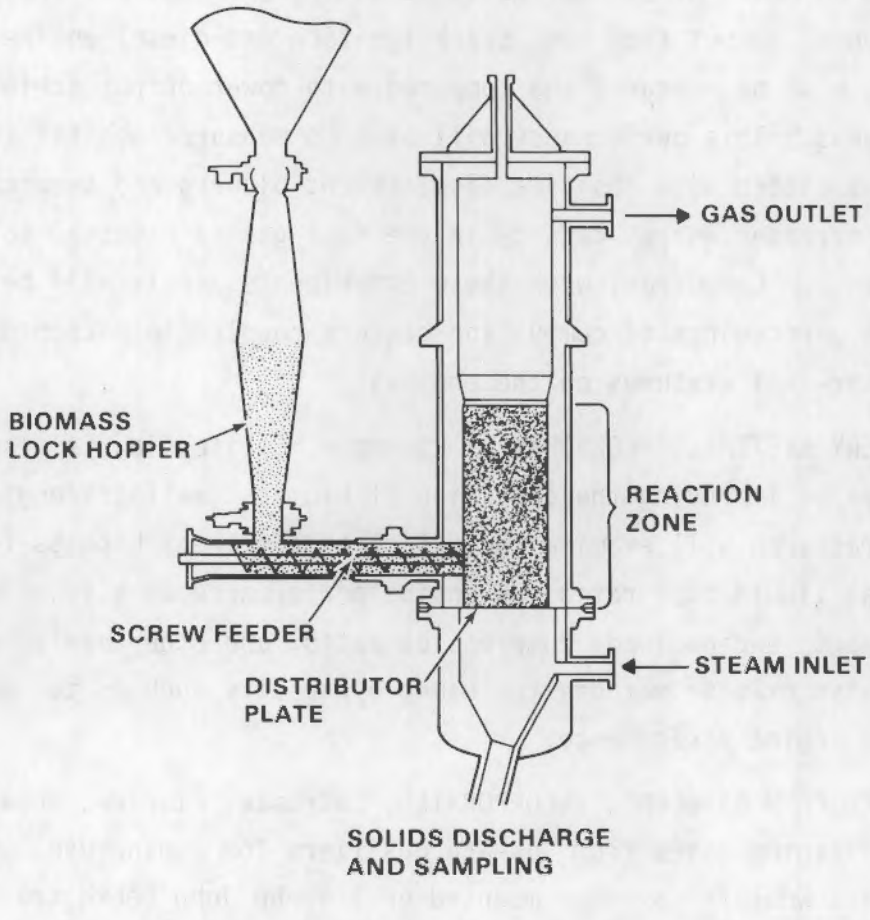

FIGURE 14. Pacific Northwest Laboratory Catalytic, Fluidized Bed Gasifier

Low-Btu Gasification Research

In addition to the primary goal of producing a technology data base for medium-Btu gasification, the Biomass Thermochemical Conversion Program conducted research on low-Btu gasification in fiscal year 1983. The main goal of this research has been to improve the overall reliability of this technology option.

THE UNIVERSITY OF FLORIDA, Gainesville, Florida, began research to enhance the performance of engines fueled with producer gas. Project goals are to evaluate the use of positive displacement and turbine superchargers for increasing the power output of engines operated on low-Btu gas and to evaluate microprocessors as means of automatically adjusting air-fuel mixtures in such engines. The power output from both spark ignition and diesel engines operated on producer gas will be measured and compared with power output achieved using conventional fuels. This performance will also be measured against that of the same engines fitted with positive displacement blowers and turbocharging systems. The increased energy density in the fuel gas is expected to enhance engine performance. Concurrent with these experiments, tests will be conducted to evaluate the performance of combustion sensors coupled to microprocessors for adjusting air-fuel mixtures on the engines.

CAL RECOVERY SYSTEMS, INCORPORATED, Richmond, California, is also working to identify ways of improving the operation of biomass gasifiers/engine systems. The research will examine the effect of different biomass fuel gas/conventional liquid fuel ratios on engine performance as a function of total energy input, engine load, compression ratio, and other variables. The research will also examine methods for using byproducts such as tar and waste heat to improve engine performance.

ROCKY CREEK FARM GASOGENS, INCORPORATED, LaCrosse, Florida, began research on methods of cleaning gases from low-Btu gasifiers for engine use. This research uses a downdraft gasifier mounted on a 40-hp John Deere tractor for a combination of laboratory research and field testing. Laboratory research will include particulate measurements as a function of gas cleanup method, fuel characteristics, and other factors. Field testing of the unit will also be performed to provide operational data on the acceptability of the producer gas-fueled tractor, including identification of best cleanup methods, operator-associated problems, and related factors.

LIQUID FUELS TECHNOLOGY

The Biomass Thermochemical Conversion Program is also conducting research on the production of liquid fuels from biomass. Liquid fuels have several advantages over the biomass resource itself. Perhaps most important, liquid fuels have a higher energy density. This allows the liquid product to be transported more economically and to be more easily stored. Liquid fuels also match existing end-use patterns, particularly by the transportation sector. The goal of the liquid fuels research sponsored by the Biomass Thermochemical Conversion Program is to provide the technology base for producing economical liquids that are compatible with existing hydrocarbon fuels. To meet this goal, the program is conducting research directed at:

- identifying reaction pathways and methods for producing high value liquid fuels
- improving yields and quality of liquid fuels
- producing economically competitive fuels.

As shown in Figure 15, the research is divided into two primary areas including pyrolysis and direct liquefaction. The differences in these approaches make it possible to generate a variety of fuels ranging from fuel oil substitutes to olefinic/aromatic hydrocarbons. The ability to produce a variety of fuels is important in meeting the wide range of demands from the liquid fuel market. These two research areas and the specific projects in each are described in detail below.

Pyrolysis

Pyrolysis refers to the heating of biomass in the absence of air. Traditionally, pyrolysis has been used to produce charcoal. Conventional pyrolysis typically produces about one-third each gases, pyrolysis oils, and char. The process is inefficient because large quantities of low value

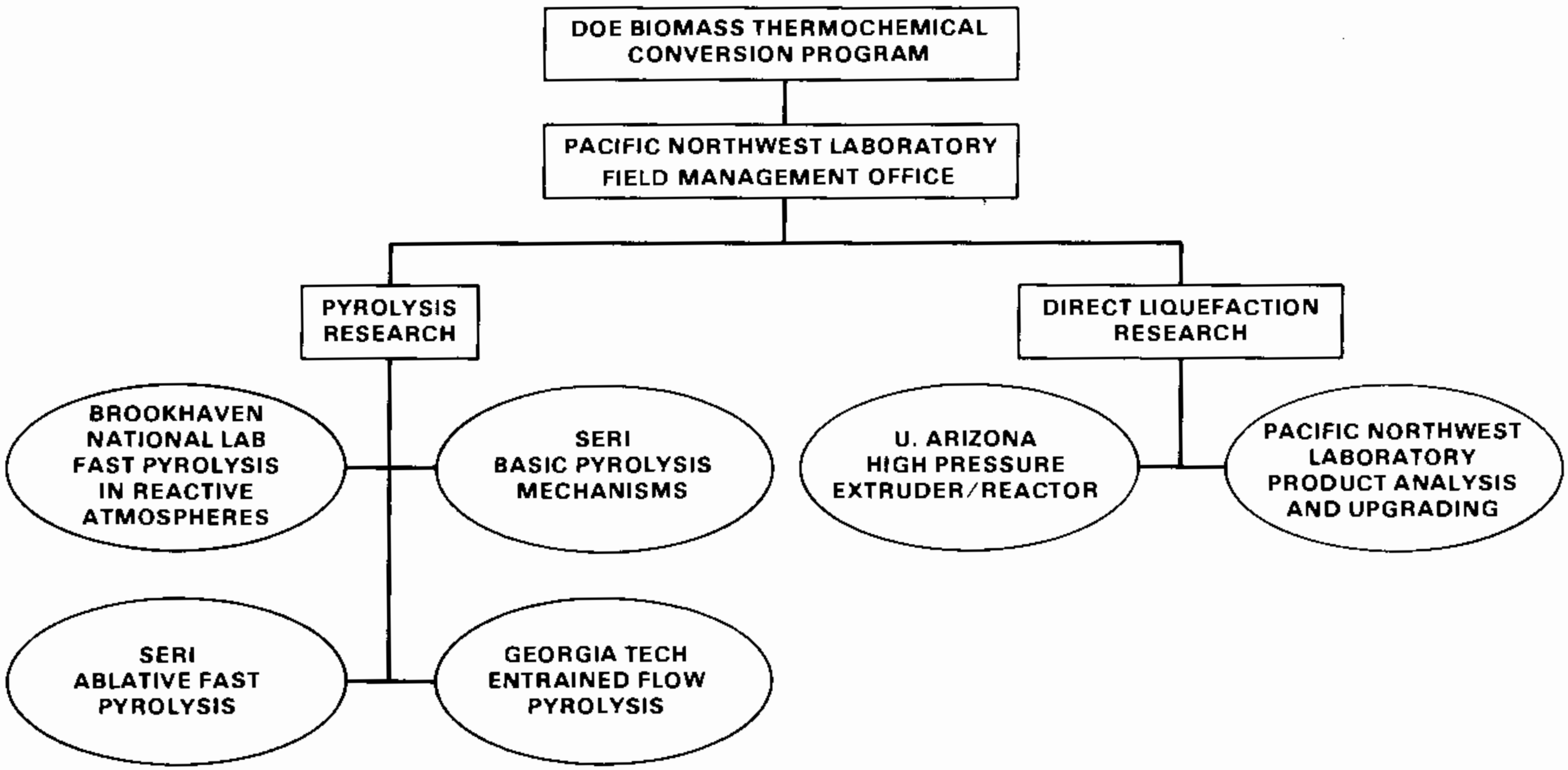

FIGURE 15. Liquid Fuels Research Projects

liquids and gases are formed in addition to desired solid products. Batchwise, often primitive, conversion units have also added to the inefficiency of conventional pyrolysis processes.

In recent years, the concept of rapid pyrolysis has emerged as a promising alternative for producing liquid fuels. Using rapid heating rates, yields of gases and liquids as high as 95% can be produced. These products contain up to about 20% high value olefinic products such as ethylene and BTX (benzene, toluene, and xylene), and are potentially useful as fuels and octane enhancers.

The pyrolysis research sponsored by the Thermochemical Conversion Program is directed toward capitalizing on these results by:

- using extremely fast pyrolysis to maximize yields of high value olefins and aromatics
- improving the yields of fast pyrolysis reactions by using reactive atmospheres
- using fast pyrolysis to produce high yields of low-cost fuel oil substitutes.

Four research projects are currently being conducted in fast pyrolysis.

THE SOLAR ENERGY RESEARCH INSTITUTE (SERI), Golden, Colorado, is conducting two projects to investigate the fast pyrolysis of biomass. In the first project, basic research examining the mechanisms occurring in fast pyrolysis is underway. Using a molecular beam mass spectrometer, a detailed picture of the individual, sequential reaction steps occurring during fast pyrolysis is being developed by measuring the change in product spectrum occurring during millisecond intervals. Although there are many possible mechanisms for producing low value char and tars, the production of high-value products appears to be limited to conditions of high heating rates and relatively high temperatures (500 to 700°C). Representative competing pyrolysis reaction pathways are shown in Figure 16.

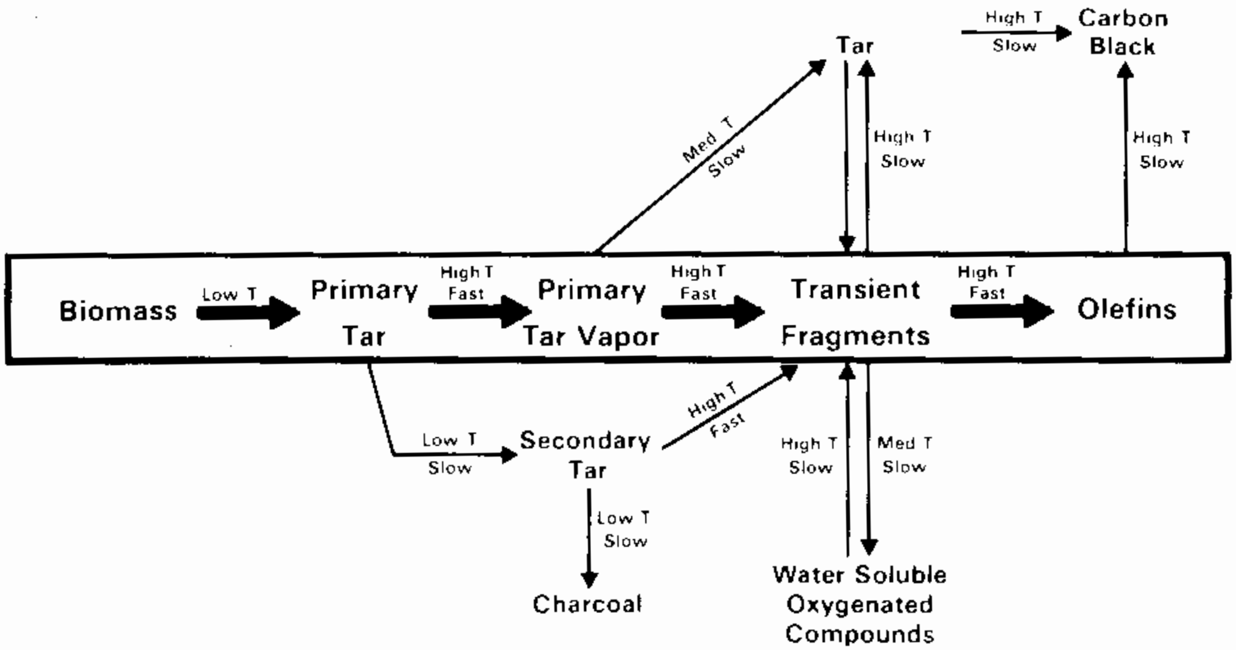

FIGURE 16. Competing Reactions During Biomass Pyrolysis

During 1983, SERI examined both the primary and secondary cracking patterns for cellulose and lignins and correlated the results with whole wood products. The researchers have also developed a method for quickly comparing biomass liquids and tars by establishing a mass spectrometric "fingerprint" of primary pyrolysis products. The technique serves as a useful qualitative method for comparing products from various types of processes.

The second project at SERI is investigating the use of a unique ablative reactor for fast pyrolysis. The objective of this work is to maximize yields of high-value olefins and other products such as benzene, toluene, and xylene, which are formed under conditions of very rapid pyrolysis. The goal of this research is to determine how to obtain the high heat fluxes needed for rapid pyrolysis and to investigate fundamental reaction mechanisms. In ablative pyrolysis of biomass, particles are heated by being forced against a hot reactor wall. Contact of the biomass with the reactor surface converts the biomass into a liquid layer, which is subsequently vaporized. Heatup rates as high as 500,000°C/sec can be obtained at the sample surface. A schematic of the reactor system is shown in Figure 17. In addition to the olefins, carbon monoxide and hydrogen are also produced and could be used for methanol synthesis.

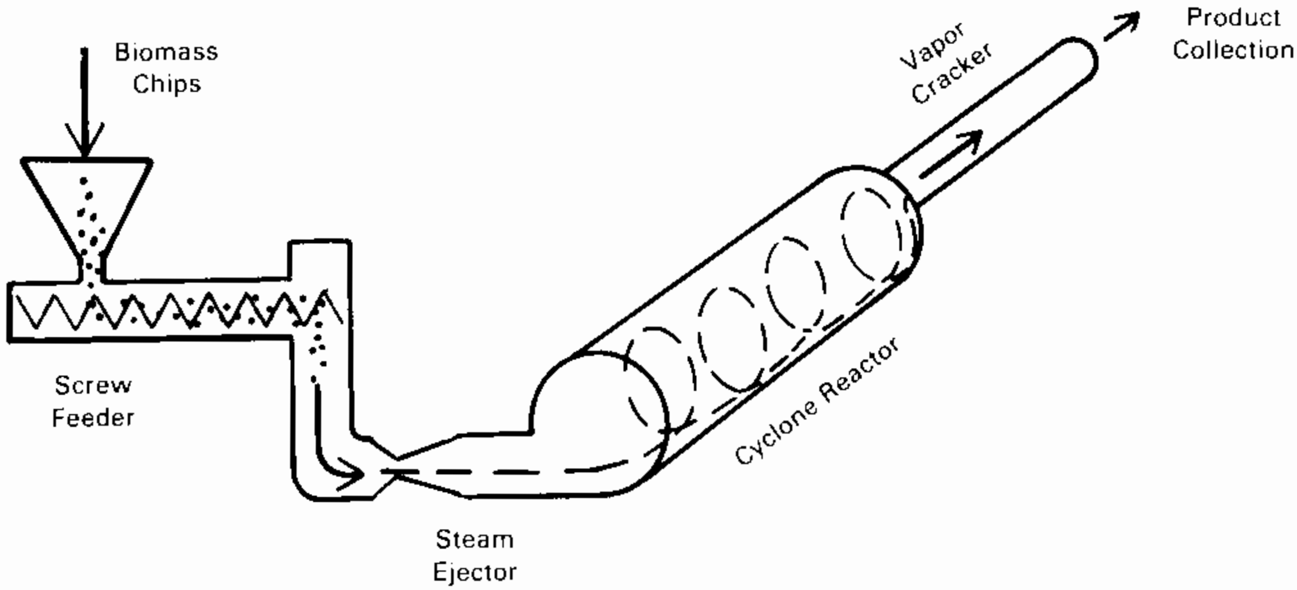

FIGURE 17. Rapid Pyrolysis Research Reactor at Solar Energy Research Institute

During 1983, SERI developed a theoretical model to predict reaction behavior under these conditions. The model uses Arrhenius rate parameters for approximately 10 reactions to predict global behavior. The model predicts that pyrolysis begins at about 350°C and that vapor cracking begins at about 625°C. However, at higher temperatures around 750°C, the rates begin to favor char formation. Thus, a temperature window may exist for maximum production of high-value products. Correlation of these theoretical results with experimental results is proceeding.

Research at BROOKHAVEN NATIONAL LABORATORY, Upton, New York, is investigating the effect of conducting rapid pyrolysis in the presence of reactive atmospheres. Using a bench-scale, entrained downflow reactor, biomass is pyrolyzed at pressures of 50 to 500 psi and temperatures of 800 to 1000°C. During 1983, research focused on reaction of biomass in a methane atmosphere (methanopyrolysis). Although the product spectra of wood pyrolyzed in either methane or helium are similar at moderate temperatures (800°C), significant differences occur at higher temperatures, as seen in Figure 18. At 1000°C, the yields of ethylene and olefins from the methane system increase

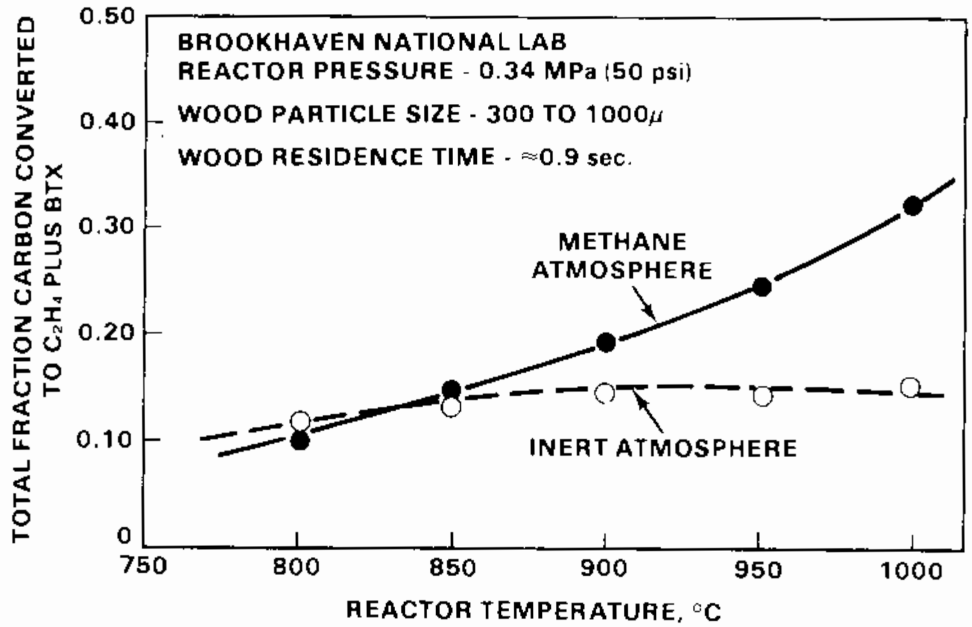

FIGURE 18. Comparison of Biomass Pyrolysis Products in Inert and Methane Atmospheres

rapidly to more than double those in the inert atmosphere. Extensive investigation during 1983 has shown that the methane is not reactive under identical conditions when biomass is absent. These results suggest that it may be possible to produce high yields of valuable olefinic products under much less rapid heating rates when reaction conditions are carefully selected. Further studies on these types of systems are continuing.

Under less rapid heating rates, biomass pyrolysis produces high yields of liquid products that could potentially be used as fuel oil substitutes. GEORGIA TECH, Atlanta, Georgia, is conducting research with an entrained flow pyrolysis unit with the goal of generating high yields of liquids at low cost. During 1983, Georgia Tech finished construction of an entrained flow pyrolysis reactor, shown schematically in Figure 19. The system consists of an upflow, entrained pyrolysis reactor and an oil recovery system that allows partial on-stream fractionation of the product. Initial experimental operation of the unit, shown in Figure 20, began recently. Reaction temperatures of 450 to 550°C have been examined and wood feed rates up to 85 lb/hr have been obtained. Preliminary results indicate that greater than 41% oils by weight (moisture-

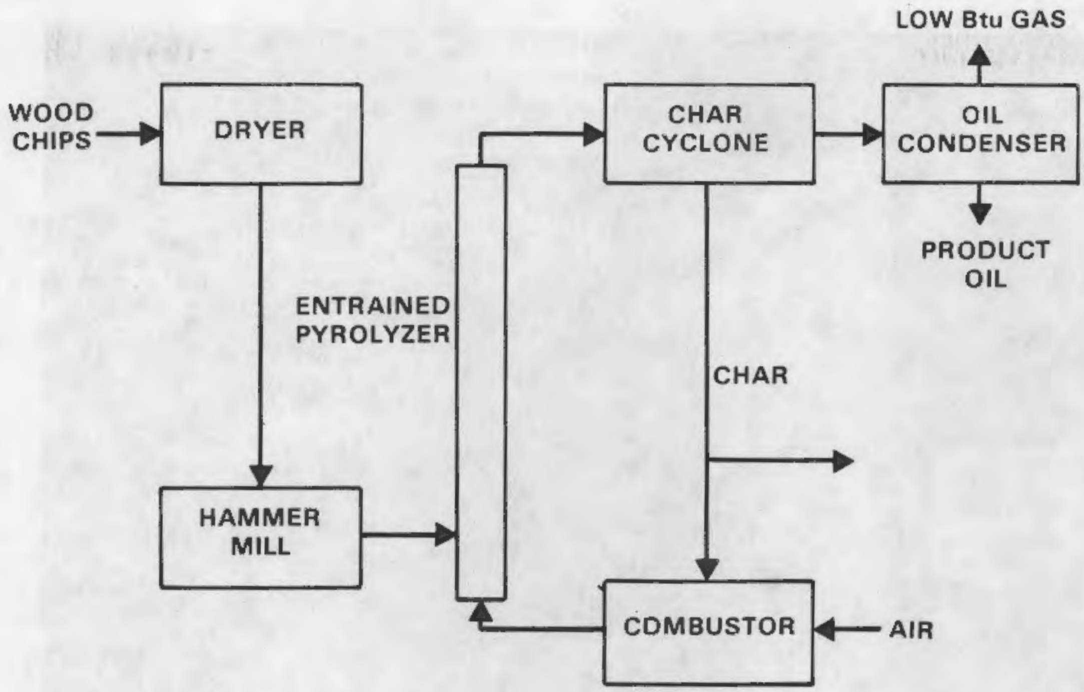

FIGURE 19. Entrained-Flow Pyrolysis Process at Georgia Tech

free basis) can be obtained. This represents nearly double the yields from conventional pyrolysis systems. Results from related research indicate that yields as high as 60% by weight may be obtained as operating parameters are optimized.

Direct Liquefaction

In addition to research on advanced pyrolysis concepts, the Thermochemical Conversion Program is sponsoring research on biomass direct liquefaction. Direct liquefaction is defined in the broadest sense as any thermochemical conversion process that produces liquid products from biomass feedstock without going through a separate intermediate gas phase. Over the past few years, however, this terminology has become more narrowly defined to describe a particular type of reductive liquefaction. Specifically, biomass slurries are heated to moderate temperatures at high pressures with a catalyst in a reducing atmosphere of carbon monoxide and hydrogen. The goal of this direct liquefaction research is to produce liquid products that can be used as substitutes for Nos. 2 and 6 fuel oils, and distillate fractions that can be

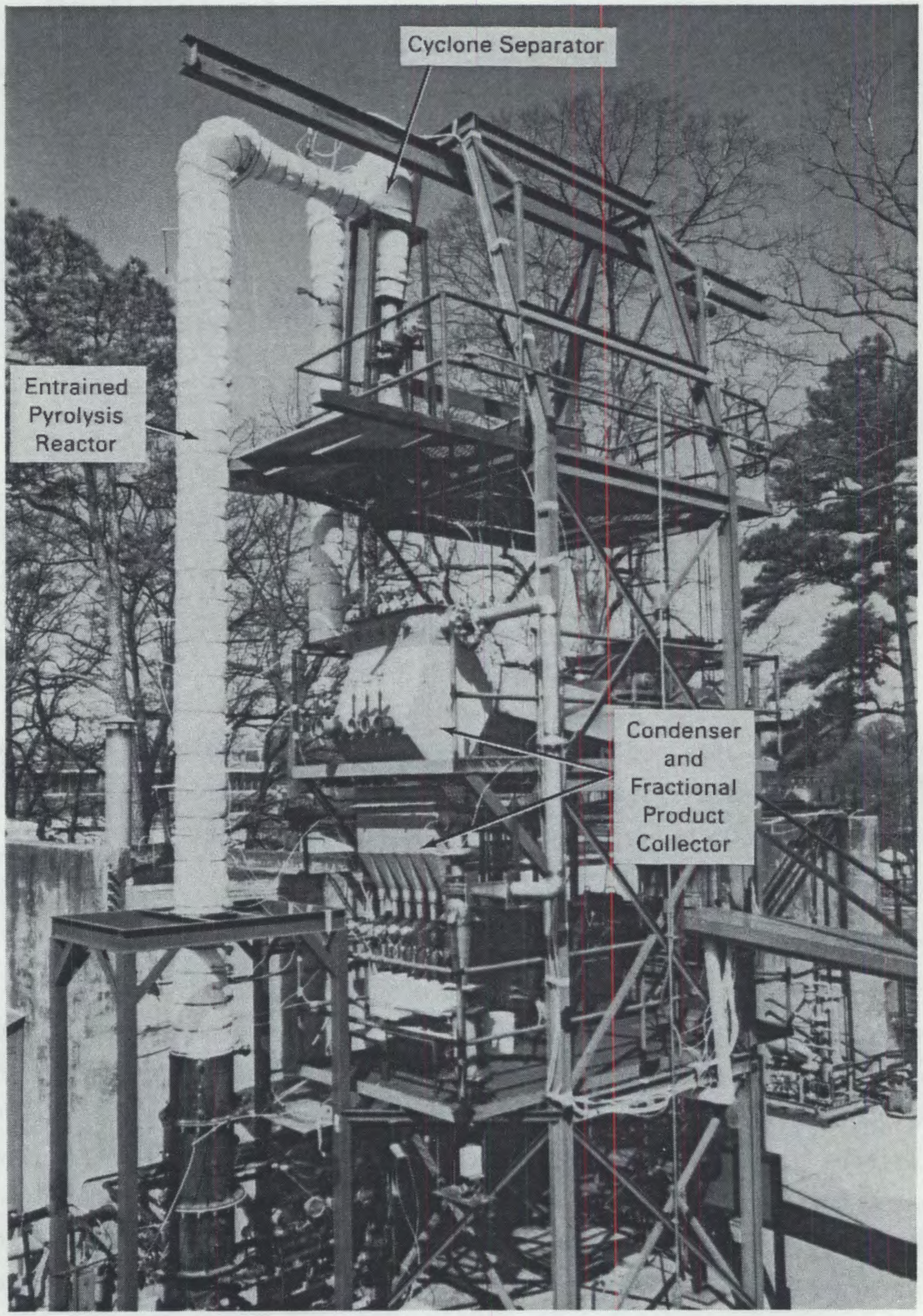

FIGURE 20. Georgia Tech Pyrolysis Unit

used for diesel fuels, octane enhancers, and other related applications.

Direct liquefaction research at this time is based primarily on a concept first proposed by the Pittsburgh Energy Research Center (PERC). In this concept, biomass is mixed with recycle wood oil and sodium carbonate catalyst along with a H_2/CO reducing gas of mixture. The mixture is injected into a high-pressure vessel (3000 psi) and heated to about 350°C. The product stream is cooled and flashed into a pressure let-down vessel. The oil phase product is withdrawn and part of it is recycled for use as slurry medium.

During 1981, the PERC process was tested in a DOE research facility located at Albany, Oregon. These tests confirmed the technical feasibility of this approach. Over 11,000 pounds of oil resembling No. 6 fuel oil were produced in one run alone. However, the results indicated that the process is not now economically competitive, partly because of the large recycle oil requirement. The Thermochemical Conversion Program is attempting to improve the competitiveness of direct liquefaction by:

- improving the economics of direct liquefaction through the use of increased feedstock slurry concentrations
- improving product quality by reducing oxygen content and molecular weight.

THE UNIVERSITY OF ARIZONA, Tucson, Arizona, is conducting research on an advanced concept for direct liquefaction that would use very concentrated biomass slurries. The goal of this work has been to use a polymer extruder as a slurry feeding/pumping device. The modified extruder/feeder system is capable of handling slurries as concentrated as 60% wood solids in biomass oil. Conventional systems, by comparison, typically cannot handle slurries containing over about 20% wood. Currently a static mixer reactor is being added to the feeder to create an integrated reactor system. The static mixer, similar to those used for mixing viscous polymer solutions, is expected to allow adequate mixing and agitation of the viscous slurries. A schematic diagram of the extruder/reactor is shown in Figure 21. Startup operation of the integrated extruder/static mixer reactor is expected in 1984.

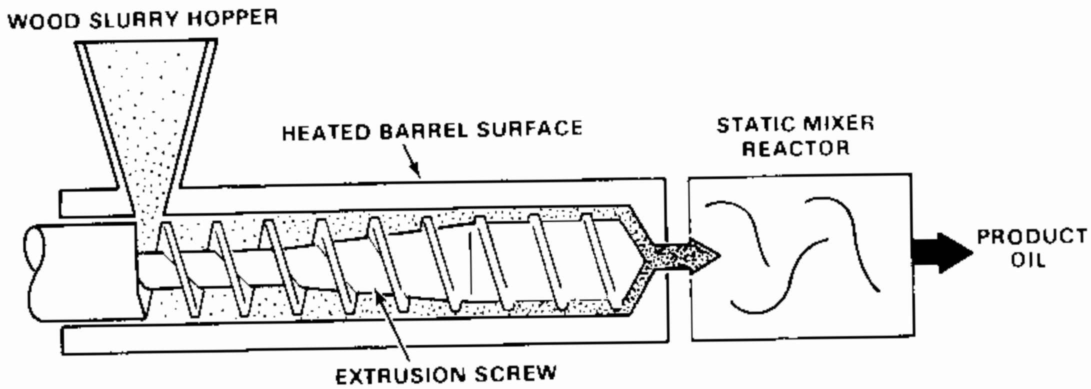

FIGURE 21. University of Arizona Extruder/Static Mixer Direct Liquefaction Reactor

PACIFIC NORTHWEST LABORATORY, Richland, Washington, is conducting research on the characterization and upgrading of direct liquefaction oils. Characterization studies show that there are significant differences between the pyrolysis and the direct liquefaction oils. As shown in Table 1, pyrolysis oils contain more oxygen and are less viscous than the liquefaction products. The liquefaction products contain large quantities of phenolic compounds while the pyrolysis oils have large concentrations of organic acids. These differences directly impact the methods for upgrading these products. During 1983, the direct liquefaction oils were successfully hydrotreated to form gasoline substitutes. Distillate fractions comprising the lighter half of the whole oil were successfully hydrotreated using cobalt-molybdenum catalysts. The hydrogenation is performed selectively to retain much of the aromatic nature of the biomass feedstock while simultaneously eliminating oxygen. The selective hydrogenation not only retains these high-value octane enhancing components but also uses less hydrogen than conventional, exhaustive hydrotreating concepts.

DIRECT COMBUSTION TECHNOLOGY

Direct combustion of biomass feedstocks, particularly wood, is already widely practiced by the private sector, especially in the forest products

TABLE 1. Biomass Liquefaction Products Comparative Analytical Data

Elemental Analysis (MAF)	Direct Liquefaction Oil (PERC-Albany TR12)	Fast Pyrolysis Oil (Georgia Tech #11)
Carbon	81.0%	59.2%
Hydrogen	10.2%	7.0%
Oxygen	8.8%	33.8%
Nitrogen	0.1%	0.1%
Sulfur	1.50	1.41
Moisture and Heating Value		
% H_2O	7.3	19.7
raw HHV	14,200 Btu/lb	7,950 Btu/lb
MAF HHV	15,300 Btu/lb	9,800 Btu/lb
Other Properties		
viscosity cps @ 40°C	400,000	62
density g/ml @ 23°C	1.14	1.24
pourpoint	27°C	-15°C

industry. Prior to the introduction of extensive natural gas distribution systems and cheap imported crude oil following World War II, many forest products companies utilized wood wastes from their operations to supply a large portion of their energy needs. In the current era of uncertain energy costs, there is widespread interest in returning to self-sufficiency in fuel supplies. Many types of direct combustion equipment, such as wood-fired boilers and various types of burners, are commercially available for this purpose.

Therefore, direct combustion projects funded by the Biomass Thermochemical Conversion Program have focused on unique, innovative combustion systems or special issues involved in combusting biomass fuels.

The Biomass Thermochemical Conversion Program is currently sponsoring direct combustion research that is focused on determining the technical feasibility of converting the heat released from direct combustion directly into mechanical power. By directly producing mechanical power without the use of an intermediate working fluid such as steam in a boiler/steam turbine system, high conversion efficiencies can be realized. In addition, costs associated with the working fluid, such as boilers and condensers, are eliminated, allowing small engines to operate economically. The Biomass Thermochemical Conversion Program is also sponsoring research on the fundamental aspects of biomass combustion. This research is aimed at increasing our understanding of basic combustion rates and mechanisms, to both improve combustion efficiencies and lower undesired combustion emissions. As shown in Figure 22, the Program sponsored three biomass direct combustion projects during 1983.

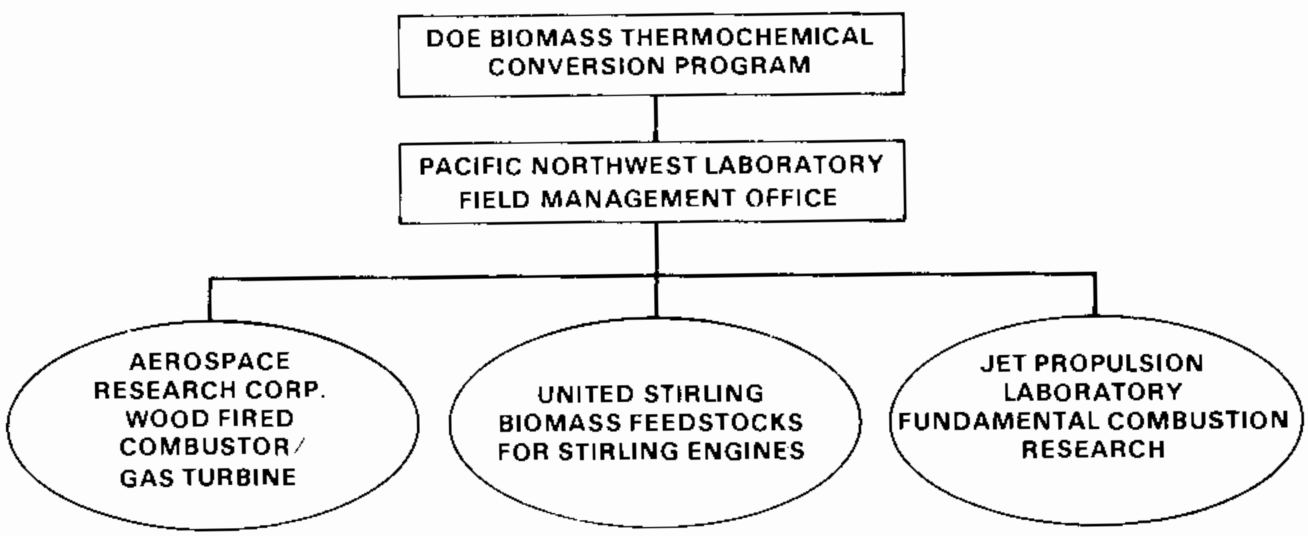

FIGURE 22. Direct Combustion Research Projects

AEROSPACE RESEARCH CORPORATION, Roanoke, Virginia, is conducting research on a directly-fired gas turbine generating system using wood feedstock. The objective of this project is to determine whether combustion gases from wood can be sufficiently cleaned using a series of cyclones to power gas turbines dependably and economically. Hot combustion gases from a pressurized wood-fired suspension burner are passed through a series of cyclones to remove particulate matter and are injected directly into a gas turbine. A schematic diagram of this concept is shown in Figure 23. During 1983, trials using a 375-kW combustor/gas turbine were completed. After over 500 hours of operation, no significant signs of erosion or corrosion were evident. Tests showed that 80% to 90% of the particulates entering the gas turbine were less then 0.5 micron in diameter. Total particulate loading entering the turbine ranged from 0.0038 to 0.0056 grains per dry standard cubic foot of combustion gas. These results strongly suggest that turbine erosion will not be a problem.

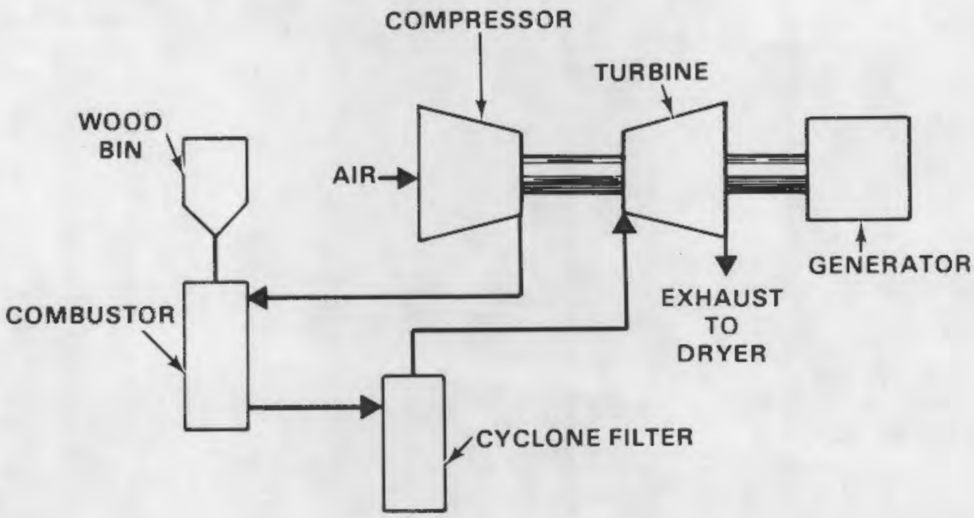

FIGURE 23. Combustor/Gas Turbine System at Aerospace Research Corporation

A 3000-kW combustor/gas turbine electrical generating system is currently under construction. After initial shakedown, the unit will be transported to Red Boiling Springs, Tennessee, where it will undergo long-term testing while generating electrical power to be sold to the Tennessee Valley Authority. Over 80% of the funds for the 3000-kW unit are being provided by the private sector. The Allison Division of General Motors is donating the gas turbine for the project. The newly constructed cyclones for the 3000-kW system are shown in Figure 24, and the turbine/generator set is shown in Figure 25.

UNITED STIRLING INCORPORATED, Alexandria, Virginia, completed research on the feasibility of using biomass to fuel Stirling engines. The external combustion feature and high efficiency make the Stirling engine an attractive candidate for the direct production of shaft horsepower from solid fuels such as biomass. Other DOE programs have already committed extensive resources to

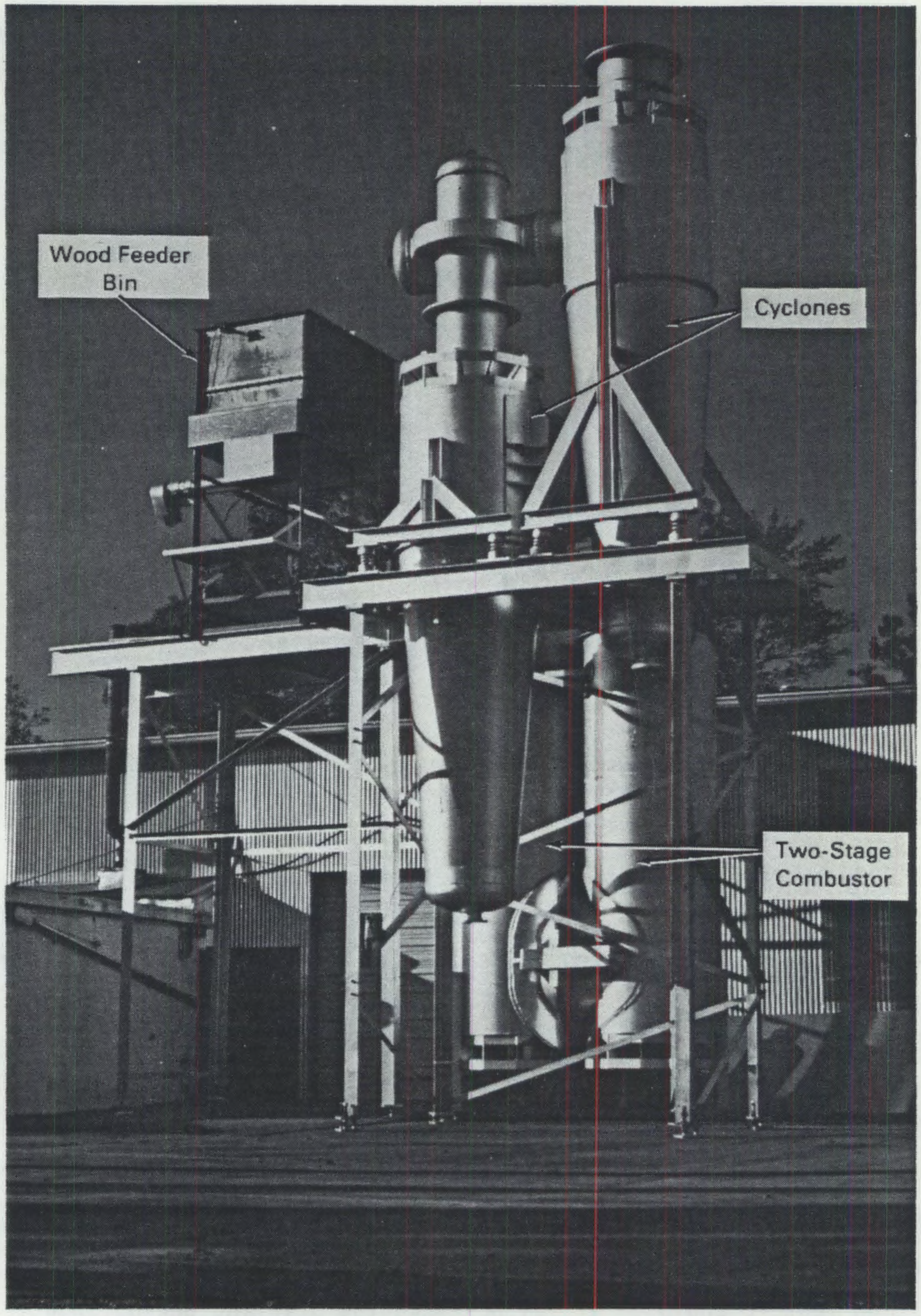

FIGURE 24. Two-Stage Combustor and Cyclones for 3-MW Combustor/Gas Turbine System at Aerospace Research Corporation

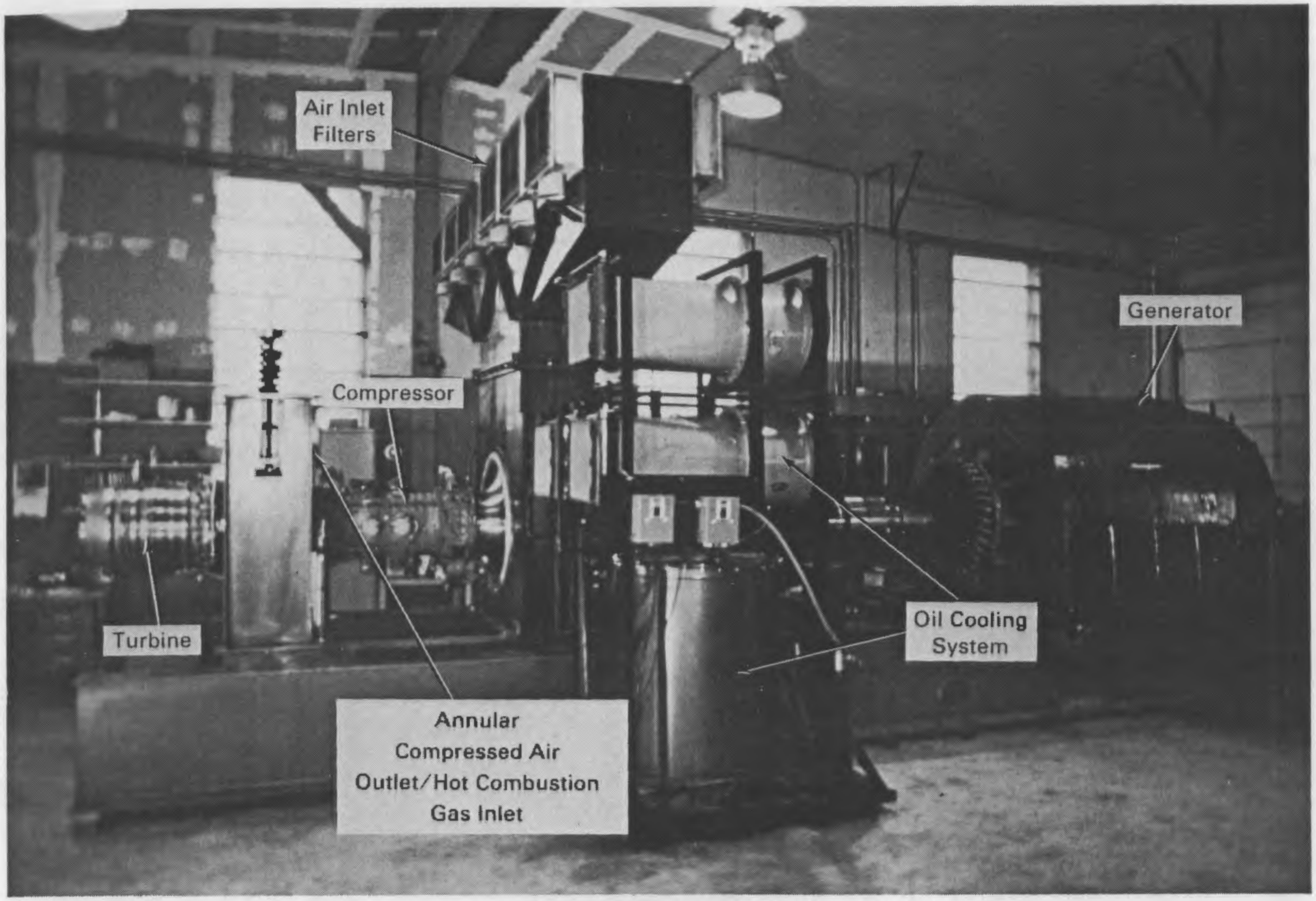

FIGURE 25. 3-MW Gas Turbine and Generator Set at Aerospace Research Corporation

the development of improved Stirling engines. The scope of this project was limited to the adaptation of Stirling engines to biomass fuels.

The main emphasis of this research has been to provide heat to the heat exchanger of the Stirling engine. Based on experimental data obtained in 1982, a two-stage cyclonic combustor was chosen as the most feasible method for providing the heat input. The first stage acts as an airblown gasifier in which hot combustible gases are generated and separated from the bulk of the ash. Combustion is completed in the second stage and the hot combustion gases are passed through the elaborate Stirling engine heat exchanger. The two-stage combustion approach minimizes ash fouling of the Stirling engine heat exchanger. The two-stage combustor was coupled with a United Stirling engine and extended tests were performed. The testing was successfully completed after 100 hours of operation, which showed the technical feasibility of this approach.

JET PROPULSION LABORATORY, Pasadena, California, began basic research on biomass combustion reactions. This work will develop a predictive model that correlates combustion behavior with wood particle size, type, moisture content, and heating value. Experimental verification of the predictive model will also be performed. In addition, the research will explore the effect of additives such as alkali salts on combustion behavior. The results of this research will be used to develop a more complete fundamental understanding of combustion reactions. By applying this knowledge, combustion processes that are both more complete and more environmentally acceptable should be possible.

PROGRAM SUPPORT ACTIVITIES

During 1983, the Biomass Thermochemical Conversion Program sponsored additional research activities with the goal of supporting major program elements. This research includes technoeconomic evaluation of candidate processes, evaluation of feedstock availability, examination of methods for reducing aqueous effluents in biomass gasification systems, and studies of using biomass/coal/MSW briquets in conversion systems. Program support research is shown in Figure 26.

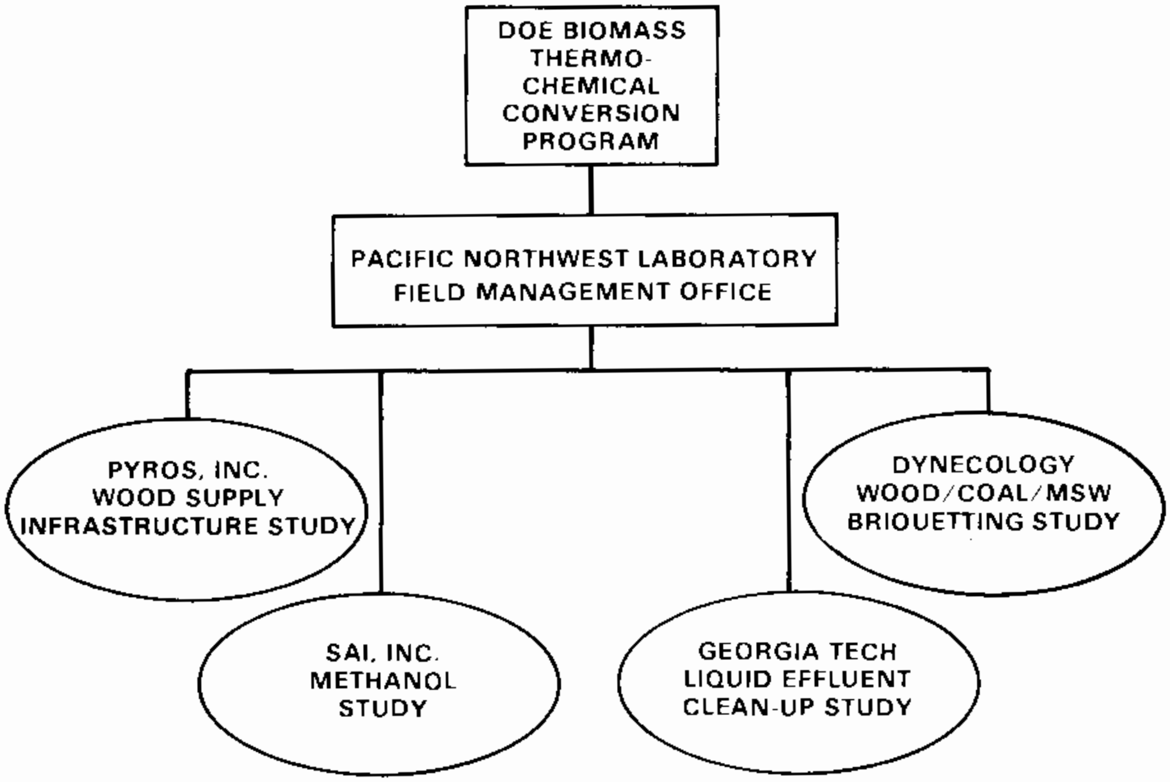

FIGURE 26. Program Support Research Projects

SCIENCE APPLICATIONS, INCORPORATED (SAI), Arlington, Virginia, conducted engineering and economic studies to assess advanced biomass conversion concepts. During 1983 SAI completed a biomass-to-methanol process sensitivity analysis to identify controllable process parameters that would affect overall methanol process efficiency. The analysis examined the effects of feedstock composition, gasification temperature, steam rate, optimal H_2/CO ratio, pressure, and other factors. Overall efficiency was found to correlate directly with the carbon content, steam to wood ratios, and heating value of the feedstock. Lower steam rates and higher temperatures increase overall efficiency. At low steam rates, thermal efficiencies increase from 53% to 57% as temperature increases from 700 to 900°C. Maximum thermal efficiencies were reached with H_2/CO ratios of 2.0 to 2.6, depending on gasifier pressure. These results suggest that emerging gasification concepts can be improved by optimizing these and other parameters. SAI, Inc., also completed a preliminary analysis of an advanced flash pyrolysis process based on the research at Brookhaven National Laboratory. Although flash pyrolysis is still at an early research stage and major uncertainties exist, the analysis indicates that there may be considerable potential for the advanced pyrolysis concept.

PYROS, INCORPORATED, Gaithersburg, Maryland, completed a study to determine the potential for supplying wood feedstocks to intermediate-size (500 to 2000 tons/day of wood) conversion facilities in the northeastern and southeastern United States. This study is based in part upon the experiences gained by the Burlington Electric Department in setting up a wood supply infrastructure for a 50-MW electric power plant in Vermont. The study concluded that there are substantial quantities of forest biomass in both the northeastern and southeastern U.S. However, some major differences in these potential supplies exist. In the Northeast, for example, the resource base is divided into many small parcels with many owners. The small parcels many be more difficult to economically harvest than the larger units in the southeastern U.S. These issues are not expected to be serious barriers to biomass utilization but should be considered in planning for adequate resources.

GEORGIA TECH, Atlanta, Georgia, is conducting research to reduce tar and aqueous effluents in biomass gasification systems. The concept uses an external combustor to burn tars produced in an updraft gasifier. The hot combustion products will then be used to vaporize a portion of the aqueous effluent. The resulting mixture is used as a moderator gas in the gasifier, thus eliminating the need for a separate steam boiler. The concept also provides for destruction of the difficult-to-handle tars that otherwise would present disposal problems. During 1983, Georgia Tech designed and began construction of a system coupled to their gasifier that will simulate the injection of the tar combustion products and steam into an updraft gasifier. A predictive model has also been developed; that will be used to estimate the effects of displacing part of the air flow through the gasifier with the moderator gas produced in the combustor. The results are expected to provide important information for designing the tar combustor/waste water vaporizer system to be tested later in the program.

OYNECOLOGY INCORPORATEO, New York, New York, is conducting research to determine the feasibility of using biomass/coal/sewage sludge briquets in gasification systems. The addition of biomass to the briquets reduces the caking tendencies of certain agglomerating coals. The effects of composition and compaction pressure on briquet strength are being measured. Compaction pressures of 10,000 psi resulted in briquets that were 38% stronger than those produced at 5,000 psi. However, those produced at 15,000 psi were only 42% stronger than the 5,000-psi briquets. This indicates that additional compaction beyond 10,000 psi is unnecessary. Results to date also indicate that the sewage sludge in the composite briquets is quite stable to biological growth and that lime stabilizer can be minimized. The data will be used to form optimal briquets for extended gasification tests.

Additional Information

Detailed descriptions of all the research and development projects funded by the Biomass Thermochemical Conversion Program are given in the Proceedings of the 15th Biomass Thermochemical Conversion Contractors' Meeting, June 1983. This document, CONF-830323, is available from the National Technical Information Service, United States Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. Additional information is also available from the publications listed in the Appendix.

APPENDIX

BIOMASS THERMOCHEMICAL CONVERSION PROGRAM

PROGRAM MANAGEMENT

Project Title: Biomass Thermochemical Conversion Program Management - Lead Laboratory - Pacific Northwest Laboratory

Proceedings of the 15th Biomass Thermochemical Conversion Contractors' Meeting, March 16-17, 1983. Atlanta, Georgia. CONF-830323, National Technical Information Service, Springfield, Virginia.

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