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1982 Annual Report: Biomass Thermochemical Conversion Program

January 1983

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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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1982 ANNUAL REPORT: BIOMASS THERMOCHEMICAL CONVERSION PROGRAM

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Pacific Northwest Laboratory
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EXECUTIVE SUMMARY

Biomass represents an important but under utilized 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.

The Thermochemical Conversion Program is part of DOE's Biomass Energy Technology Division, Office of Renewable Energy. Pacific Northwest Laboratory has been designated the lead laboratory for the Biomass Thermochemical Conversion Program with responsibility for overall field management of the program. This report provides a brief overview of the Thermochemical Conversion Program's activities and major accomplishments during fiscal year 1982.

Program Objectives and Strategy

The objective of the Biomass Thermochemical Conversion Program is to generate scientific data and fundamental biomass conversion process information that, in the long term, could lead to establishment of cost effective processes for conversion of biomass resources into clean fuels and petrochemical substitutes. The goal of the program is to improve the data base for biomass conversion by investigating the fundamental aspects of conversion technologies and exploring those parameters which are critical to these conversion processes.

To achieve this objective and goal, the Thermochemical Conversion Program is sponsoring high-risk, long-term research with high payoff potential which industry is not currently sponsoring, nor is likely to support.

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

- Combustion to produce heat, steam, electricity, direct mechanical power;
- Gasification to produce fuel gas or synthesis gases for the production of methanol and hydrocarbon fuels;
- Direct liquefaction to produce heavy oils or distillates;
- Pyrolysis to produce a mixture of oils, fuel gases, and char.

Biomass feedstocks have unique properties when compared to other solid fuels, such as coal, which offer great potential advantages for biomass thermochemical conversion processes. Biomass is highly reactive which means these feedstocks can be decomposed and converted at much lower temperatures than coals, making these processes more efficient and less costly. 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 natural advantages of biomass.

Program Organization

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

1. Gasification Technology
2. Pyrolysis Technology
3. Direct Liquefaction Technology
4. Direct Combustion Technology
5. Program Support Activities

The remainder of this paper briefly describes Program activities and major accomplishments in each of these areas for fiscal year 1982.

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 by either 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 nitrogen is eliminated from the product gas a medium Btu gas with a heating value ranging from 300 to 600 Btu 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. Specific research projects include:

- Research on indirect reactor heating methods at the University of Missouri-Rolla, Texas Tech University and Battelle-Columbus Laboratories,
- Research on high pressure (up to 500 psia) steam-oxygen gasification of biomass in a fluidized bed reactor at the Institute of Gas Technology, and
- Research on producing synthesis gas via catalytic gasification at Pacific Northwest Laboratory and via oxygen gasification at Texas Tech University.

Pyrolysis Technology

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. Recently, researchers have discovered that the yields of higher valued light liquid hydrocarbons and gases can be increased to as high as 95% if biomass is heated very rapidly. These high valued products contain up to 20% ethylene and BTX (benzene, toluene, and xylene) useful as fuels, octane enhancers, and petrochemical feedstocks.

During 1982, the Thermochemical Conversion Program sponsored research projects in the area of biomass pyrolysis including;

- Determination of individual sequential pyrolysis mechanisms at the Solar Energy Research Institute (SERI),
- Determination of the effects of pressure on biomass pyrolysis at the University of Hawaii,
- Research at the Solar Energy Research Institute on a unique entrained, ablative fast pyrolysis reactor for supplying the high heat fluxes required for fast pyrolysis,

- Work on rapid pyrolysis of biomass in atmospheres of hydrogen and methane to increase the yields of olefin and BTX products at Brookhaven National Laboratory,
- Research at the Georgia Institute of Technology on an entrained rapid pyrolysis reactor, and
- Determination of the technical feasibility of burning biomass derived pyrolytic oils in a direct fired gas turbine at Teledyne CAE.

Direct Liquefaction Technology

The Biomass Thermochemical Conversion Program is sponsoring research on the direct liquefaction of biomass. In this research, 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 research is to produce liquid products which could be used as substitutes fuel oils, and distillate fractions which could potentially be used for diesel fuels, octane enhancers, and other related uses.

During 1982, DOE sponsored research in direct liquefaction has focused on evaluating the technical feasibility of existing process concepts and conducting research on new concepts which could lead to major technical advances. Specific projects included:

- Completion of final report on the multi-year operation of the Albany, Oregon Direct Liquefaction Facility by Wheelabrator Clean Fuels Corporation,
- Research on an aqueous phase liquefaction process at Lawrence Berkeley Laboratory,
- Extensive characterization of biomass derived oils produced in the Albany, Oregon Direct Liquefaction Facility by Pacific Northwest Laboratory,
- Research on advanced high pressure slurry feeding systems and liquefaction reactor design at the University of Arizona, and
- Studies of potential new direct liquefaction catalysts at SRI International and Lawrence Berkeley Laboratory.

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, and
- Adaption of Stirling engine external combustion systems to biomass fuels at United Stirling, Incorporated. Figure 22 depicts the Stirling engine combustion chamber heat exchanger.

Program Support Activities

During 1982, the Thermochemical Conversion Program sponsored additional research activities with the goal of supporting major program elements. These activities included:

- Initiation of a wood supply infrastructure of sites capable of supplying wood to intermediate size (500-200 tons/day) biomass conversion facilities by Pyros, Incorporated,
- Completion of a "Solar Cost Data Bank" study by SRI International on biomass feedstock/conversion technology options,
- Compilation of a catalog of Biomass Thermochemical Conversion projects by EnergyTrack, Incorporated, and
- Completion of a technoeconomic study by Science Applications, Incorporated to assess the applicability of advanced biomass gasification concepts to the production of methanol.

Outstanding Accomplishments in 1982

Outstanding accomplishments of the Biomass Thermochemical Conversion Program during this fiscal year 1982 include:

- Achieved greatly increased carbon conversions and reactor throughput rates in an indirectly heated research gasifier at Battelle-Columbus Laboratories. The BCL entrained gasifier utilizes a recirculating sand system to provide heat to the gasification reactor. The hot sand is heated in an entrained bed combustor by burning biomass or char and fed to the gasifier to serve as a hot fluidizing medium. Reactor internals which create highly turbulent mixing zones were installed in the reactor in 1982. Carbon conversions in the modified reactor increased from 60 to 90% at reactor throughputs as high as 1860 lb/hr-sq ft, which is about six times greater than that achieved in conventional fluidized bed reactors.

- Showed that catalytic gasification of biomass was feasible at elevated pressures. The catalytic fluidized bed gasifier at Pacific Northwest Laboratory was modified and successfully operated at pressures up to 150 psia to determine the effects of pressure on catalyst performance. This fluidized bed research gasifier utilizes a Ni-Co-Mo/SiO_2-Al_2O_3 catalyst as a fluidizing medium to produce a synthesis gas containing the correct molecular ratio of hydrogen and carbon monoxide for methanol production directly within the reactor. Preliminary analysis of data obtained shows that catalytic gasification at elevated pressures is technically feasible. Further analysis will be performed to determine the effect of pressurized operation on process economics. The Pacific Northwest Laboratory catalytic gasification research unit is shown in Figure 9.

- Achieved increased efficiency in the entrained flow, ablative fast pyrolysis reactor at the Solar Energy Research Institute. SERI is conducting research to determine the feasibility of using this concept to supply the high heat fluxes needed for rapid pyrolysis. The unique reactor is capable of providing heatup as high as 500,000°C/second at the surface of a biomass particle. During 1982, SERI increased operating efficiencies by modifying the reactor to eliminate feedstock channeling. SERI also showed that low steam/biomass ratios could be used, lowering process steam requirements. The reactor is shown in Figure 13.

- Determined that the combustion gases from a pressurized wood combustor can be used to directly power a gas turbine after cleanup in a series of cyclones. Aerospace Research Corporation accumulated 200 hours of test operation of a 375 KW wood fired combustor/gas turbine system without evidence of corrosion or erosion of turbine components. Data obtained on the combustion gases entering the turbine indicated that 80 to 90 percent of the particles present were less than 0.5 m in diameter, which strongly suggests that turbine erosion will not be a problem. The Aerospace Research combustor/gas turbine unit is shown in Figure 23.

INTRODUCTION

Biomass represents an important but under utilized 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 three percent 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 Congressional Office of Technology Assessment (OTA) 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.(1) The Office of Technology Assessment has also indicated that biomass resources and conversion processes, if managed properly, are potentially more environmentally acceptable than many other synfuels. If this valuable resource is to be fully utilized for reducing U.S. dependence on imported oil, additional research is needed on converting biomass into more useful energy forms.

Thermochemical conversion processes offer great potential for effectively utilizing biomass resources in terms of both gross energy use and displacement of conventional petroleum fuels.

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(1) Energy from Biological Processes, Volumes I and II, Office of Technology Assessment, Congress of the United States, Washington, D.C. 20510.

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

- Combustion to produce heat, steam, electricity, direct mechanical power and combinations of these;
- Gasification to produce low or medium Btu fuel gas;
- Gasification to produce synthesis gas for the production of methanol or mixed alcohol fuels, Fischer-Tropsch hydrocarbon liquids and gasoline, ammonia, or synthetic natural gas (SNG);
- Direct liquefaction to produce heavy oils or, with upgrading, lighter boiling liquid products such as distillates, light fuel oils, gasoline and chemicals;
- Pyrolysis to produce a mixture of pyrolytic oils, fuel gases, char and chemical feedstocks.

Biomass feedstocks have unique properties when compared to other solid fuels, such as coal, which greatly enhance the advantages of biomass thermochemical conversion processes. Biomass feedstocks have a very high content of volatile matter; typically 70-90% on a dry weight basis versus 30-40% for typical coals. The high volatile matter content allows biomass feedstocks to be decomposed very rapidly and at relatively low temperatures. Biomass chars are much more reactive than coal chars. The high reactivity of biomass means these feedstocks can be decomposed and gasified at much lower temperatures than coals, making these processes more efficient and less costly. Biomass feedstocks generally have much lower ash contents than coal, greatly reducing handling and ash disposal problems. In addition, the low sulfur content of biomass feedstocks greatly reduces gas cleanup costs and allows biomass to react directly in the presence of catalysts without catalyst poisoning problems. Therefore, it is clear that dramatic improvements in biomass thermochemical conversion processes are possible by addressing and exploiting the unique features of biomass.(1)

The U.S. Department of Energy is actively encouraging increased utilization of biomass resources through research projects sponsored by the Biomass Thermochemical Conversion Program. This research is directed toward exploiting the natural advantages of biomass. The Thermochemical Conversion Program is part of DOE's Biomass Energy Technology Division, Office of Renewable Energy. Pacific Northwest Laboratory* has been designated the Lead Laboratory for the Biomass Thermochemical Conversion Program with responsibility for overall field management of the Program. The organization of this program is shown in Figure 1. This report provides a summary of the Thermochemical Conversion Program research activities during fiscal year 1982.

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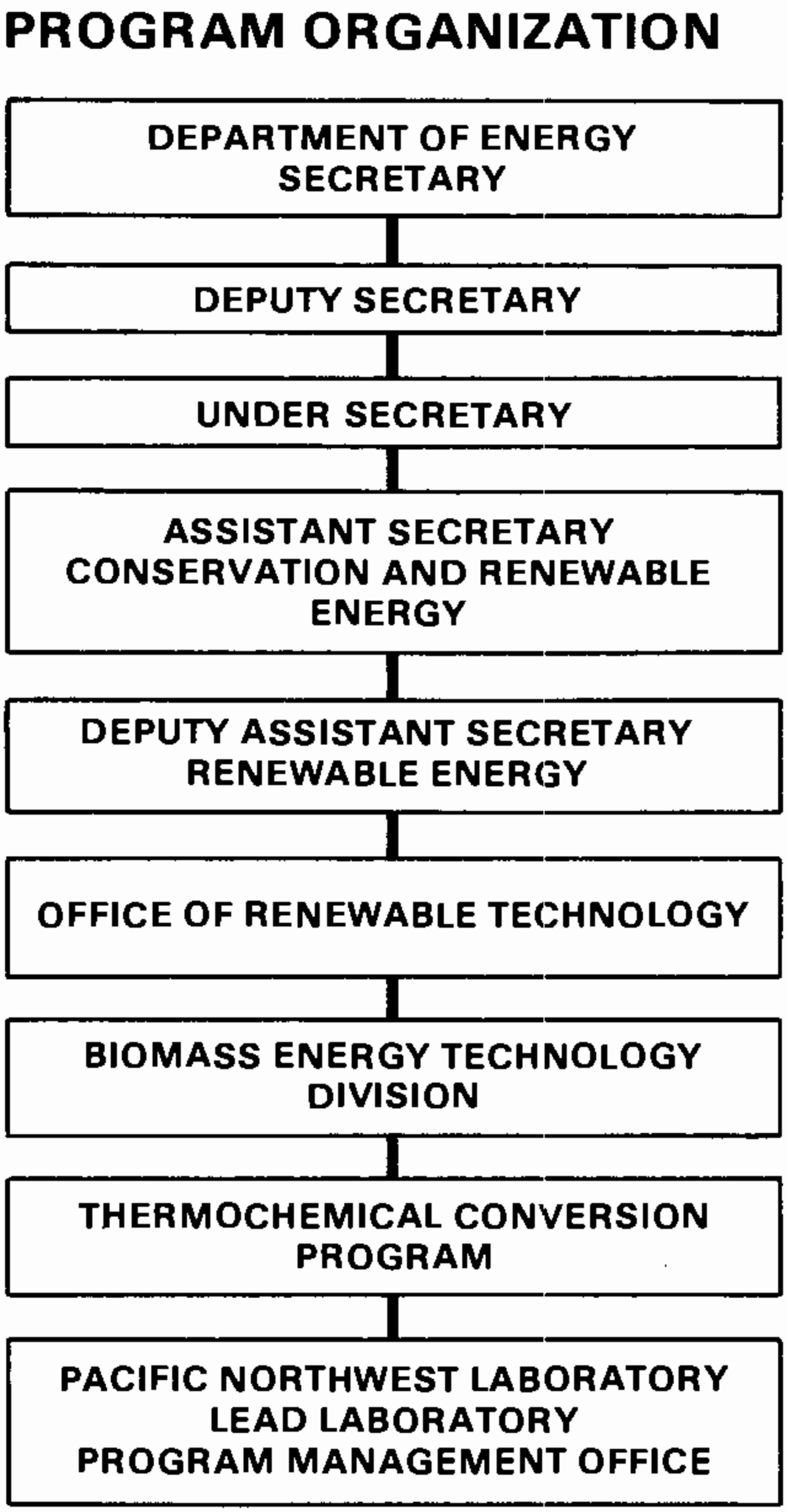


Figure 1. Organization of the Biomass Thermochemical Conversion Program

PROGRAM OBJECTIVES AND STRATEGY

The objective of the Biomass Thermochemical Conversion Program is to generate scientific data and fundamental biomass conversion process information that, in the long term, could lead to establishment of cost effective processes for conversion of biomass resources into clean fuels and petrochemical substitutes. Areas of research included in the program are pyrolysis, gasification, direct liquefaction and combustion of biomass. The goal of the program is to improve the data base for biomass conversion by investigating the fundamental aspects of conversion technologies and exploring those parameters which are critical to these conversion processes.

To achieve this objective and goal, the Thermochemical Conversion Program is sponsoring high-risk, long-term research with high payoff potential which industry is not currently sponsoring, nor is likely to support. 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 scientific verification of the technical feasibility (proof of principle) of the individual research concept. Concepts passing the preliminary technical feasibility test are frequently studied further in continuous process research units. These small-scale research units allow the concept to be further investigated under realistic conditions in a continuous, dynamic, interactive mode. This stage of research allows the evaluation of variations in operating parameters in a continuous process environment and the determination of material and energy balances which are 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. Integrated processes exhibiting favorable economic projections are then made available for transfer to the private sector.

To ensure the maximum opportunity for technology transfer to the private sector, industrial interest and involvement is sought at all stages of research. However, industrial interest and involvement is expressed most strongly in determining scale-up factors and commercial economics after the technical feasibility of a concept has been fully evaluated in continuous research units. The evolution and transfer of basic research concepts into integrated processes useful to industry is shown in Figure 2.

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

1. Gasification Technology
2. Pyrolysis Technology
3. Direct Liquefaction Technology
4. Direct Combustion Technology
5. Program Support Activities

Research in each of these program areas for fiscal year 1982 is discussed in the following sections of this report.

PROGRAM APPROACH

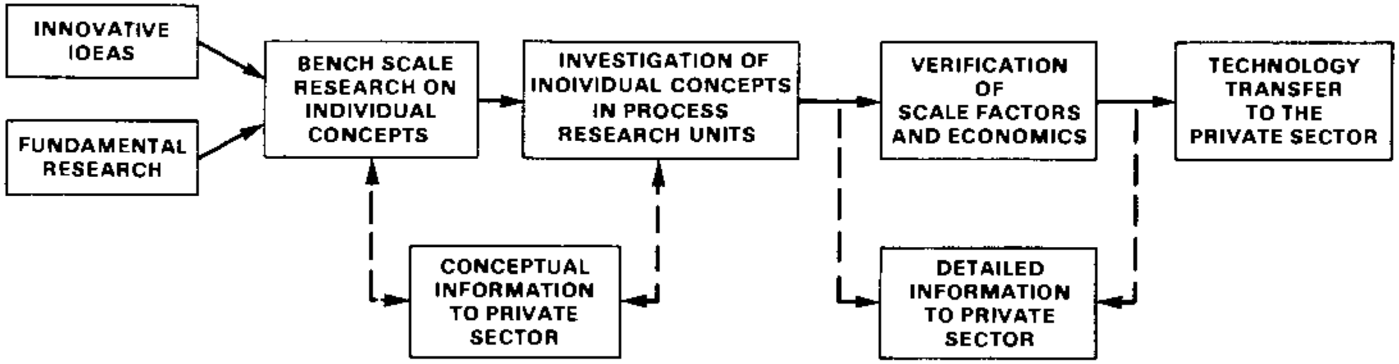


Figure 2. Evolution and Transfer of Basic Thermochemical Conversion Research to the Private Sector

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. As shown in Figure 3, heat is provided to the reactor by either 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. 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 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 will frequently result in boiler derating unless expensive modifications are made to the boiler.

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

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. Medium Btu gas has a heating value typically ranging from 300 to 600 Btu/SCF, and is much more versatile than low Btu gas.

PRINCIPLES OF GASIFICATION

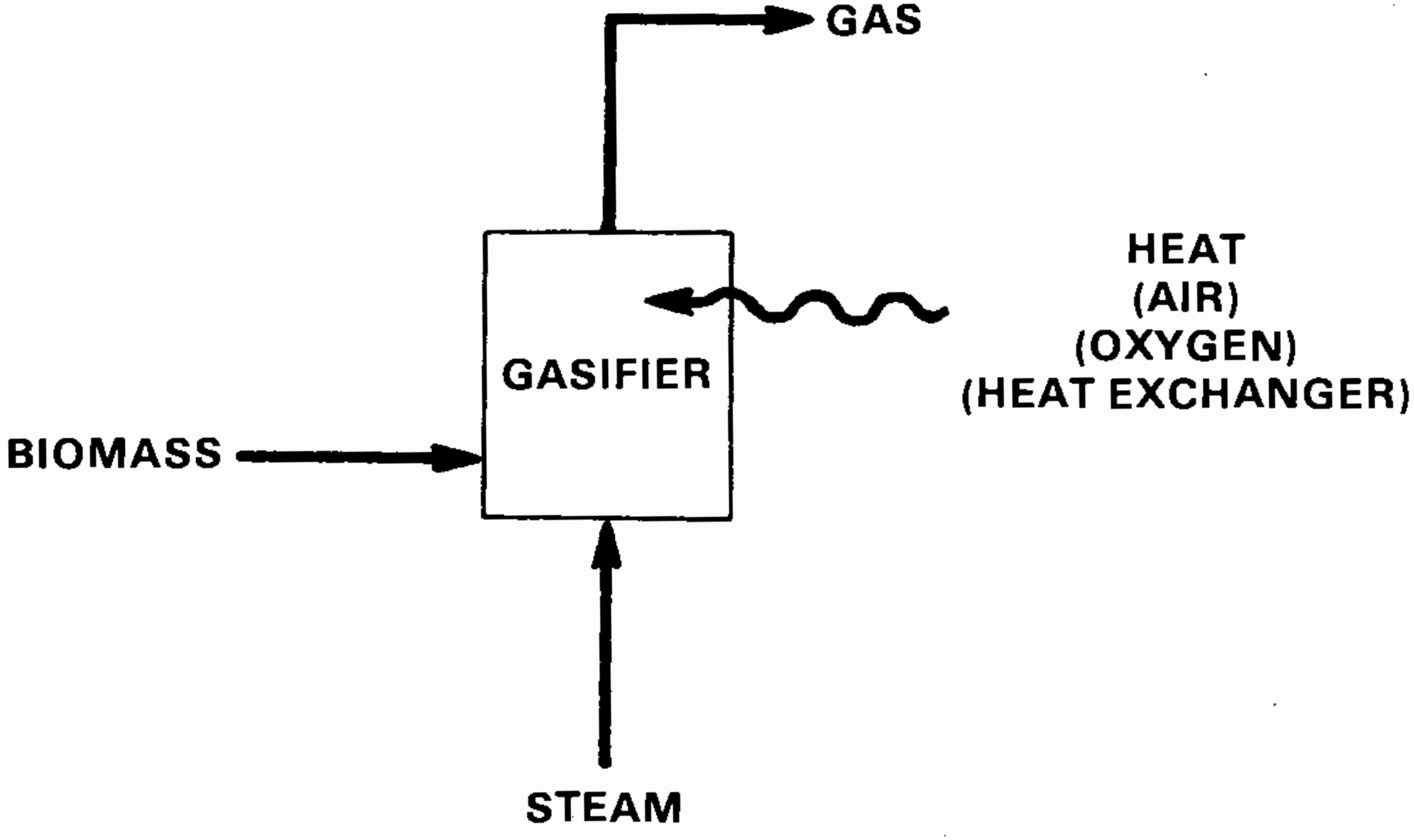


Figure 3. Schematic Diagram of a Typical Biomass Gasifier

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 critical processes such as lime recovery kilns in the pulp and paper industry which currently use fuel oil or natural gas. These applications require high flame temperatures but limited volumetric flow rates of combustion gases.
- 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.
- Since there is no nitrogen diluting the gas, medium Btu gas can be used for the synthesis of derived liquid fuels.

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 in order to be competitive.

Because biomass is a distributed resource, transportation costs limit the amount of biomass which 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 drastically reduce or eliminate the requirement for oxygen in order to achieve a cost effective process at the smaller scale. Fortunately, biomass is much more reactive than coal and can be gasified at lower temperatures. Less heat is also required for reaction due to the higher volatile content. 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 costly and exotic heat exchanger materials, thereby eliminating oxygen requirements altogether. This offers an 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 derived liquid fuels. The lower sulfur content also eliminates the need for a costly gas cleanup system to remove sulfur from the product gas.

The goals of the gasification research sponsored by the Biomass Thermochemical Conversion Program are directed toward: 1) developing reactor heating methods to eliminate or reduce the requirement for oxygen in medium Btu biomass gasifiers by exoloiting the high reactivity of biomass; and 2) to determine the technical feasibility of employing medium Btu gasifiers to produce synthesis gas for derived liquid fuels. In accordance with these goals, medium Btu gasification technology has been divided into two project areas: Reactor Heating Methods and Synthesis Gas Production, as shown in Figure 4.

The Biomass Thermochemical Conversion Program is currently sponsoring four projects which are investigating reactor heating methods. The Institute of Gas Technology (IGT) is conducting research

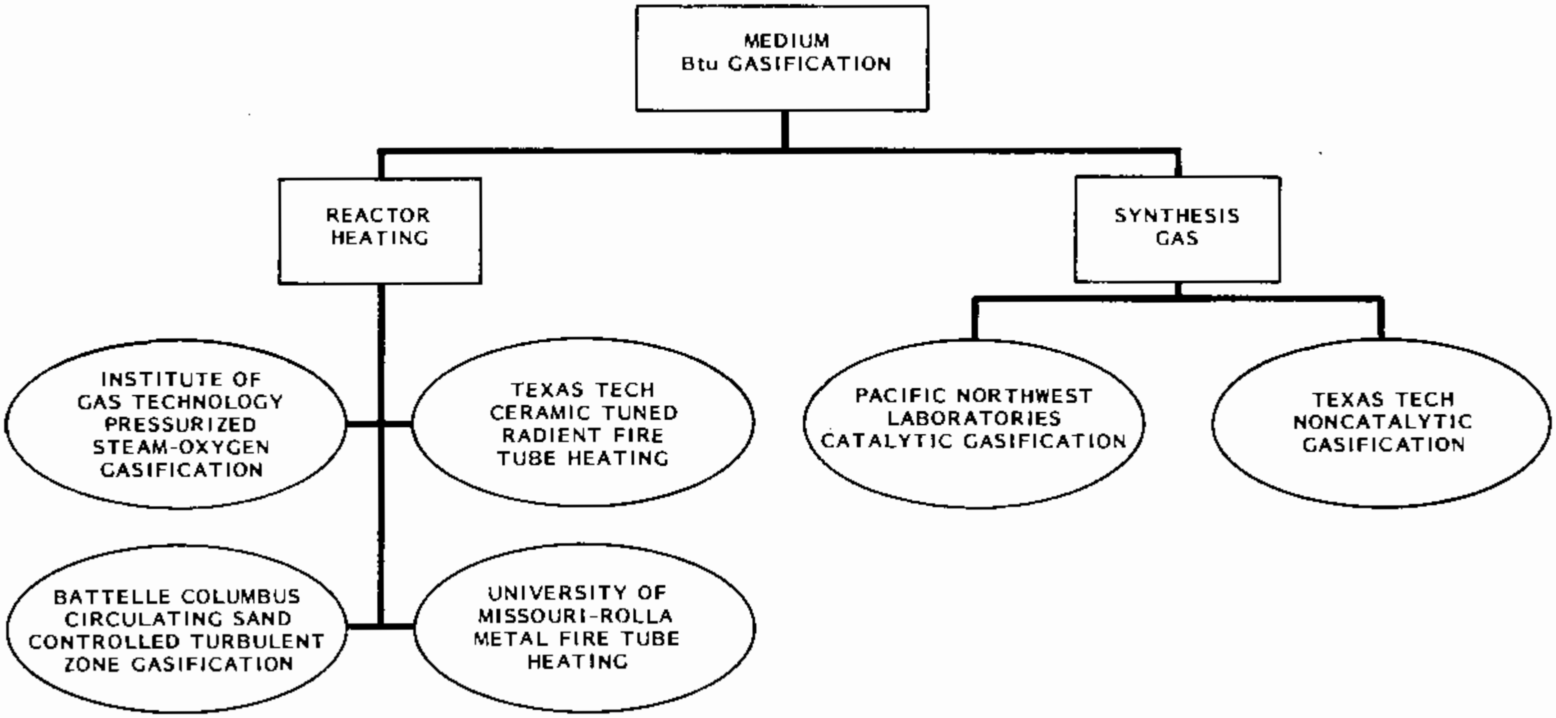


Figure 4. Medium Btu Gasification Research Projects

to determine the actual oxygen requirements for gasifying biomass to produce a medium Btu gas. IGT has been constructing a fluidized bed research gasifier which is 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.

IGT has also conducted bench scale research to examine the physical and chemical characteristics of candidate feedstocks including Douglas fir, maple, pine and corn stover. Experiments with these species have been performed to evaluate their devolatilization and char gasification characteristics. Preliminary results show that the devolatilization of biomass into gases and liquids typically increases only slightly, from 93 percent to 95 percent, for increasing temperatures between 1300°F and 1600°F. The gas yield, however, increases from approximately 65 percent to 85 percent of dry feed over the same temperature range due to increased conversion of liquids to gases. These results show the impact of reactor temperature, during devolatilization, on the production of a medium Btu gas.

Char gasification results, shown in Figure 5, indicate that the gasification rates for the different biomass species were comparable to one another but were nearly 20 times greater than the gasification rates for coal chars. Final analysis of the bench scale data will be used to select operating conditions for the fluidized bed research gasifier.

The University of Missouri - Rolla is conducting a research program to investigate 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 tubes.

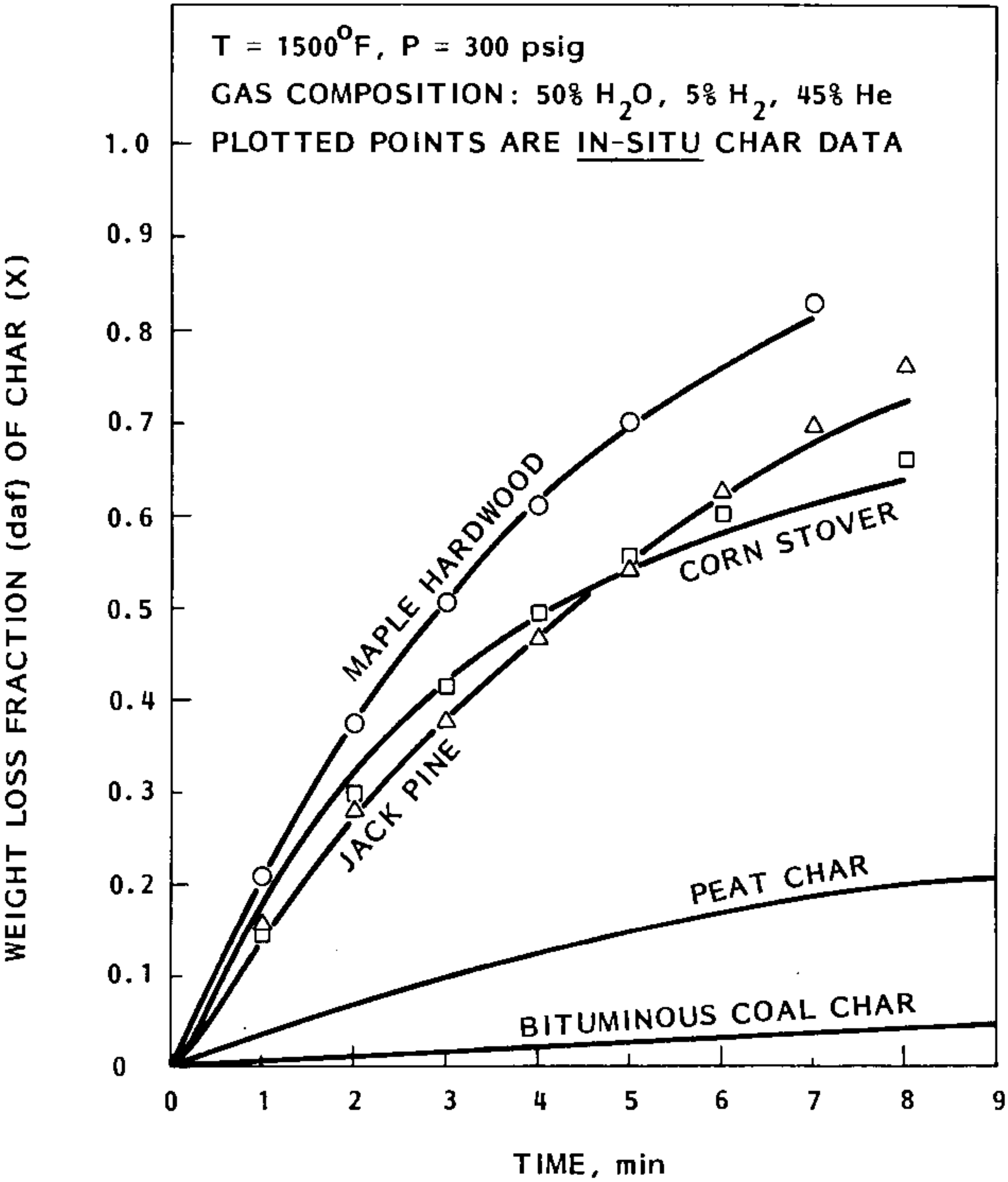


Figure 5. Comparison of Gasification Rates of Various Biomass *In-Situ* Chars With Those of Peat and Bituminus Coal Chars

Research at the University has centered on selecting an optimum fire tube configuration which will allow maximum reactor throughput in a fluidized bed research gasifier that will be used to test the concept. Several alternative design configurations were evaluated. The configuration selected for actual testing has 30 one-inch diameter U-tubes spaced using a 2 inch pitch. The design is expected to produce a reactor throughput of 230 lb/hr-sq ft at a bed temperature of 1400°F. Operation of the indirectly heated gasifier is expected in late 1982.

Texas Tech University is investigating the technical feasibility of enhancing the radiant heat transfer capabilities of indirectly heated fluidized bed gasifiers. The concept uses doped ceramic fire tubes which match the wave length of the heat radiated by the tubes to the absorption wave lengths of the biomass. Figure 6 shows absorption spectra for cellulose, a major component of biomass. By doping the ceramic tubes to emit radiant heat at selected wave lengths, 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 mathematical model for radiant heat transfer in an absorbing fluidized bed of biomass particles and the development of a kinetic model for biomass pyrolysis in a radiant heating environment. The results of this fundamental research are being used to design a small multiple fire tube reactor for testing the concept under continuous reaction conditions.

Battelle-Columbus Laboratories (BCL) is conducting research to determine the technical feasibility of indirectly heating an entrained bed gasifier by circulating a low density, hot, incandescent sand to the gasifier. As shown in Figure 7, the entrained sand and any unreacted

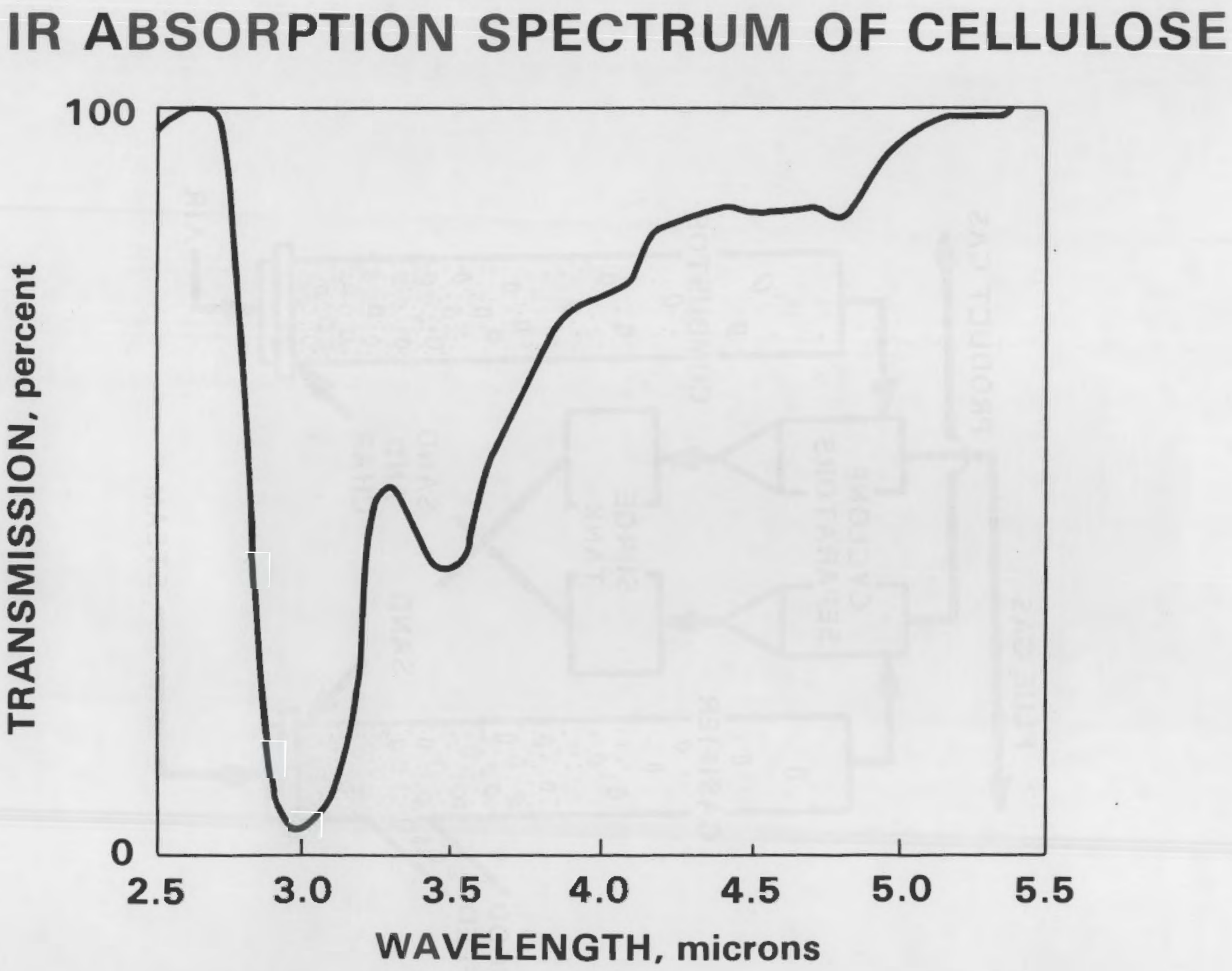


Figure 6. Infrared Absorption Spectrum of Cellulose Fibers [M. Tsuboi, J. Polymer Sci., 25(2), 159-171 (1957)]

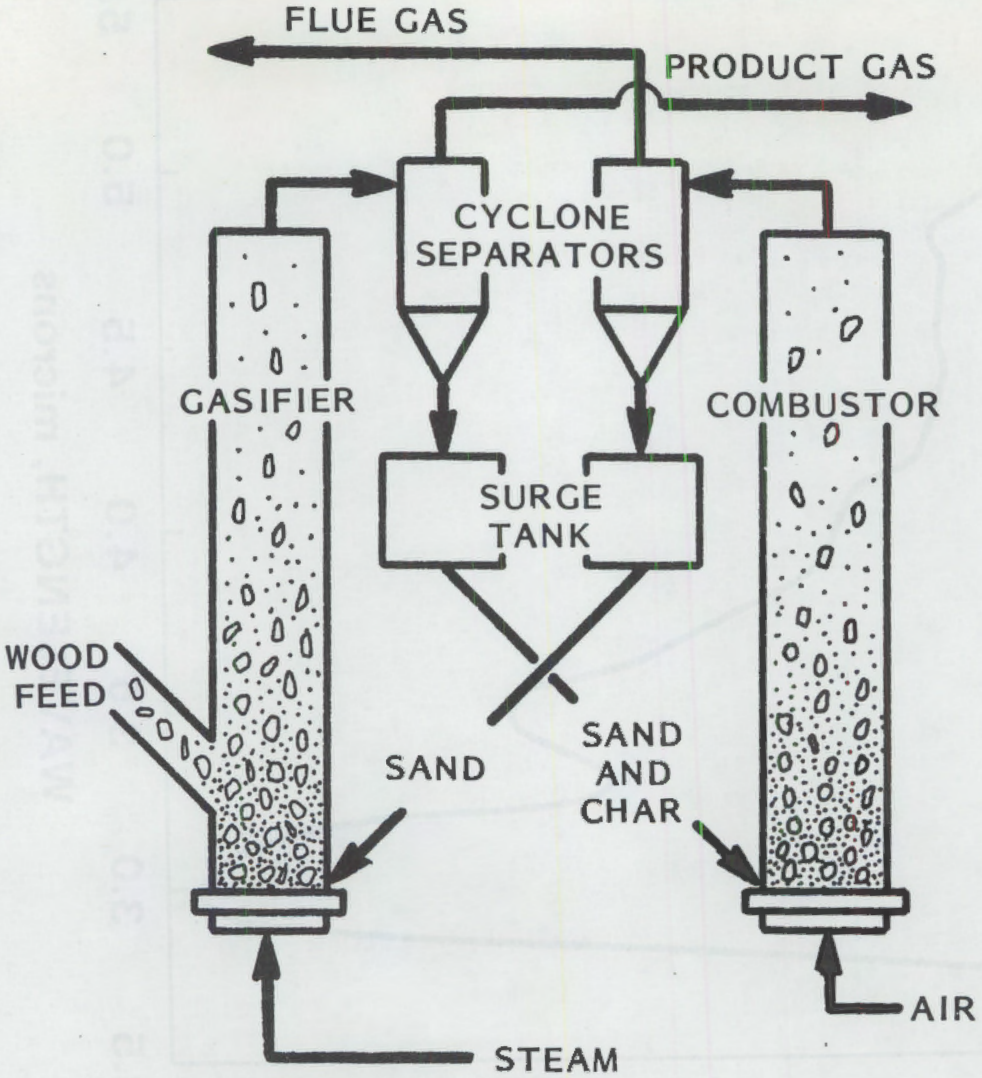


Figure 7. Simplified Process Flow Sheet For Heating Biomass Via Circulating Sand

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.

In previous research sponsored by the Biomass Thermochemical Conversion Program, the BCL gasifier also employed a dense phase of sand in a fluidized bed reactor to aid heat transfer and to help retain the char in the bed at the high steam velocities employed. Recent research during 1982 has shown that reactor internals can be used in place of the dense phase. The reactor internals serve as transport wake inducers, resulting in highly turbulent mixing zones in the reactor. The use of these internals allowed higher reactor temperatures and resulted in drastically improved gas yields, carbon conversions, and throughput for the reactor. Figure 8 compares carbon conversion for the original and modified reactor designs. It can be seen that carbon conversion at the higher temperatures is nearly 90 percent for the modified reactor compared to about 65 percent for the original reactor design. Throughput for the modified reactor has reached as high as 1860 lb/hr-sq ft which is about six times greater than that achieved in conventional fluidized beds and about 80 percent higher than that achieved in the original BCL reactor design. Research is continuing in order to more fully understand the role of the wake inducers in the gasifier and to more fully explore the operating parameters for the gasifier.

The Biomass Thermochemical Conversion Program is also sponsoring two research projects which are investigating the technical feasibility of producing synthesis gas in a medium Btu gasifier. Synthesis gases for the production methanol and liquid hydrocarbon fuels require

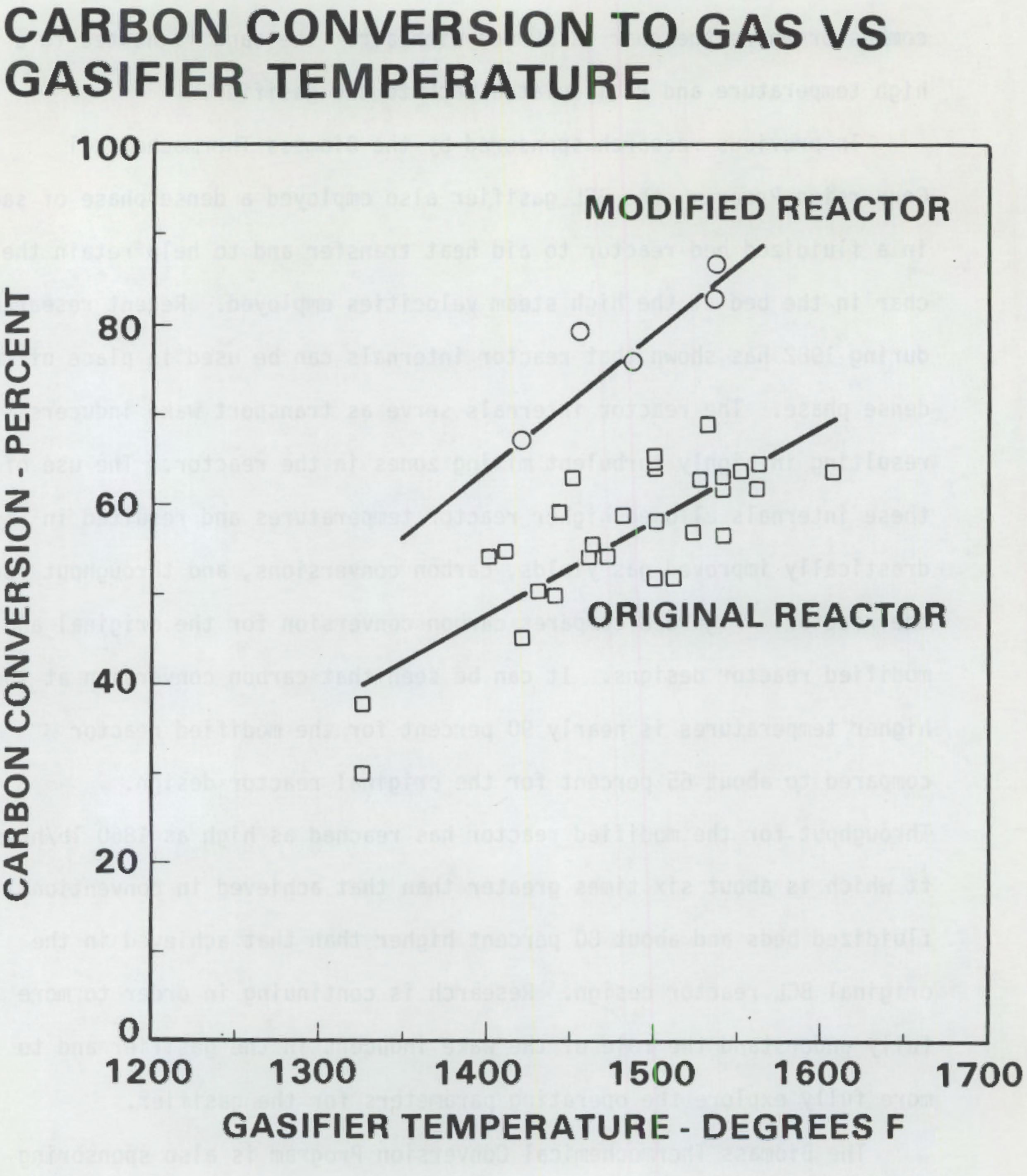


Figure 8. Carbon Conversion Using Circulating Sand to Heat a Biomass Entrained Bed Gasifier

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. Texas Tech University has conducted research to determine the technical feasibility of producing a methanol synthesis gas in a gasifier heated with oxygen. Research was conducted in a six inch diameter fluidized bed reactor. The experimental program explored the effects of oxygen feed rate, steam feed rate and solids residence time on the product gas yield and the hydrogen to carbon monoxide ratio in the product gas. A correlation was developed based on the experimental results and was used to estimate the optimum operating conditions for producing a methanol synthesis gas. Texas Tech concluded that an oxygen to dry feed ratio of 0.35 Kg/Kg feed, and a steam to dry feed ratio of 0.9 Kg/Kg feed would produce an acceptable hydrogen to carbon monoxide mole ratio of 2.0.

Pacific Northwest Laboratory has been conducting research to produce a methanol synthesis gas in a fluidized bed gasifier, utilizing various catalysts as the fluidizing medium. Bench scale studies have identified a $Ni-Co-Mo/SiO_2-Al_2O_3$ catalyst for the generation of methanol synthesis gas that has proven to be resistant to deactivation. Research using a six inch diameter fluidized bed gasifier, shown in Figure 9, demonstrated the technical feasibility of producing a synthesis gas with a hydrogen to carbon monoxide mole ratio exceeding 2.0. The fluidized bed gasifier has recently been modified to explore the effect of pressures up to 150 psia on the gasifier performance. Experiments are being conducted using the pressurized gasifier to determine whether the overall biomass to methanol process can be made more efficient by eliminating a portion of the compression requirements for the methanol synthesis reaction without adversely affecting the gasification process.

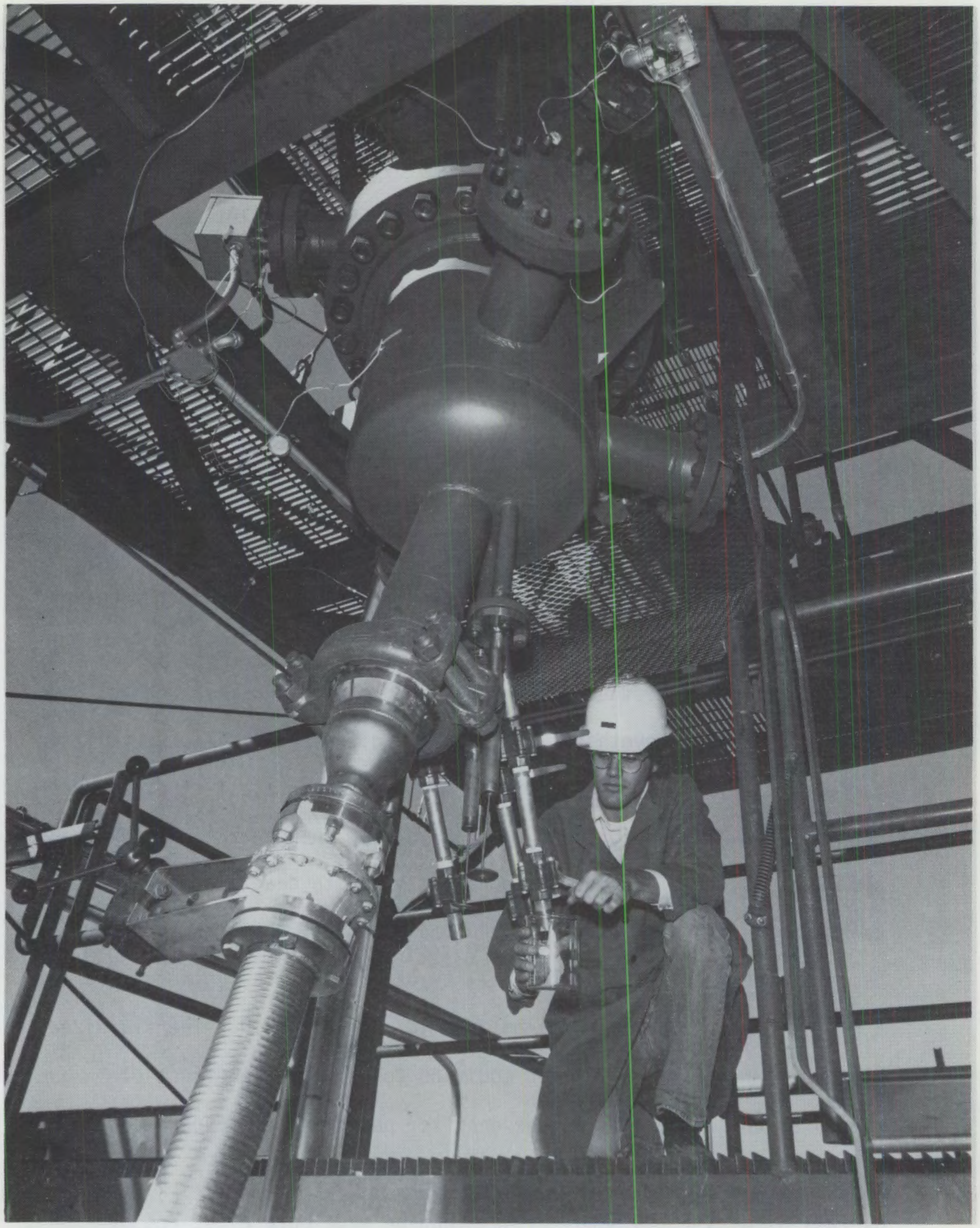


Figure 9. Bottom View of 6-Inch Diameter Fluidized Bed Gasifier at Pacific Northwest Laboratory

PYROLYSIS TECHNOLOGY

The term pyrolysis refers to the thermal decomposition of biomass in an oxygen-free environment. Traditionally, pyrolysis has been used as an age old process to produce charcoal. Conventional pyrolysis typically produces products consisting of about one third each gases, pyrolysis oil, and solid char. The process is inefficient since large quantities of low value 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. Although research such as that on the nearly commercial Tech Air process has been done to improve efficiencies, pyrolysis processes were limited to conventional products until about 10 years ago.

In recent years, the Biomass Thermochemical Conversion Program has played a major role in advancing the concept of rapid pyrolysis into a promising, state-of-the-art research area. Of major significance was research on the rates of heating during biomass pyrolysis. 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). These high value products are potentially useful as fuels, octane enhancers, and petrochemical feedstocks.

During 1982, the Thermochemical Conversion Program sponsored six basic research projects in the area of biomass pyrolysis, as shown in Figure 10. The objective of this work is to investigate the phenomenon of rapid pyrolysis in order to develop a fundamental data base for this

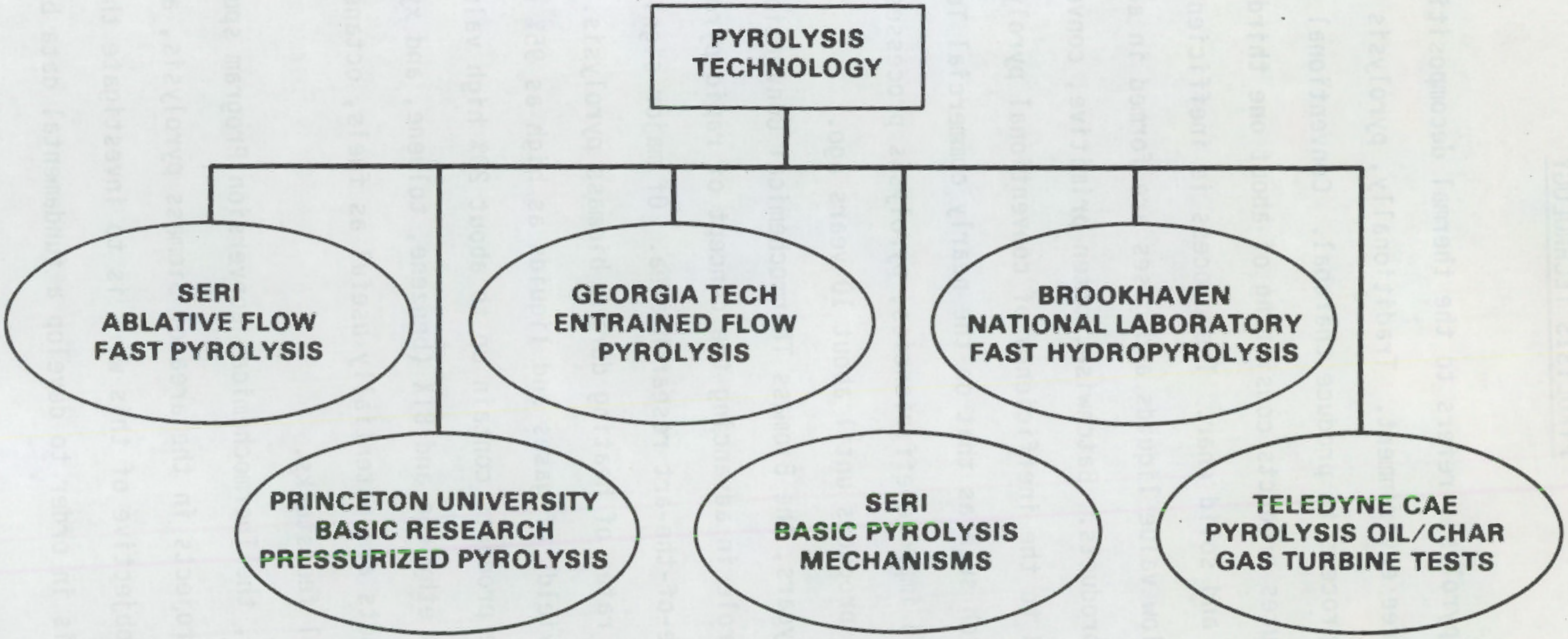


Figure 10. Pyrolysis Research Projects

promising research area. Specific goals include:

- Elucidation of reaction pathways during rapid pyrolysis
- Examination of methods for achieving high heat fluxes in rapid pyrolysis systems
- Examination of liquids production via rapid pyrolysis
- Determination of the effects of pressure on biomass pyrolysis
- Determination of the effects of reactive atmospheres on rapid pyrolysis products and yields, and
- Determination of pyrolysis oil combustion characteristics.

The Solar Energy Research Institute (SERI) is conducting two projects investigating the fast pyrolysis of biomass. In the first project, basic research on the mechanisms involved in fast pyrolysis is being conducted. 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. A schematic of the mass spectrometer is shown in Figure 11. During 1982, the primary pyrolysis products from a number of celluloses were surveyed. Major findings include the observation that the higher mass components appear to evolve nearly simultaneously during decomposition. This may reflect the fact that the cellulose "unzips" and dehydrates on a very short time scale compared to the total time of the rapid pyrolysis. Such evidence is important to understanding fundamental reaction mechanisms in fast pyrolysis.

The second project at SERI is investigating the use of an 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

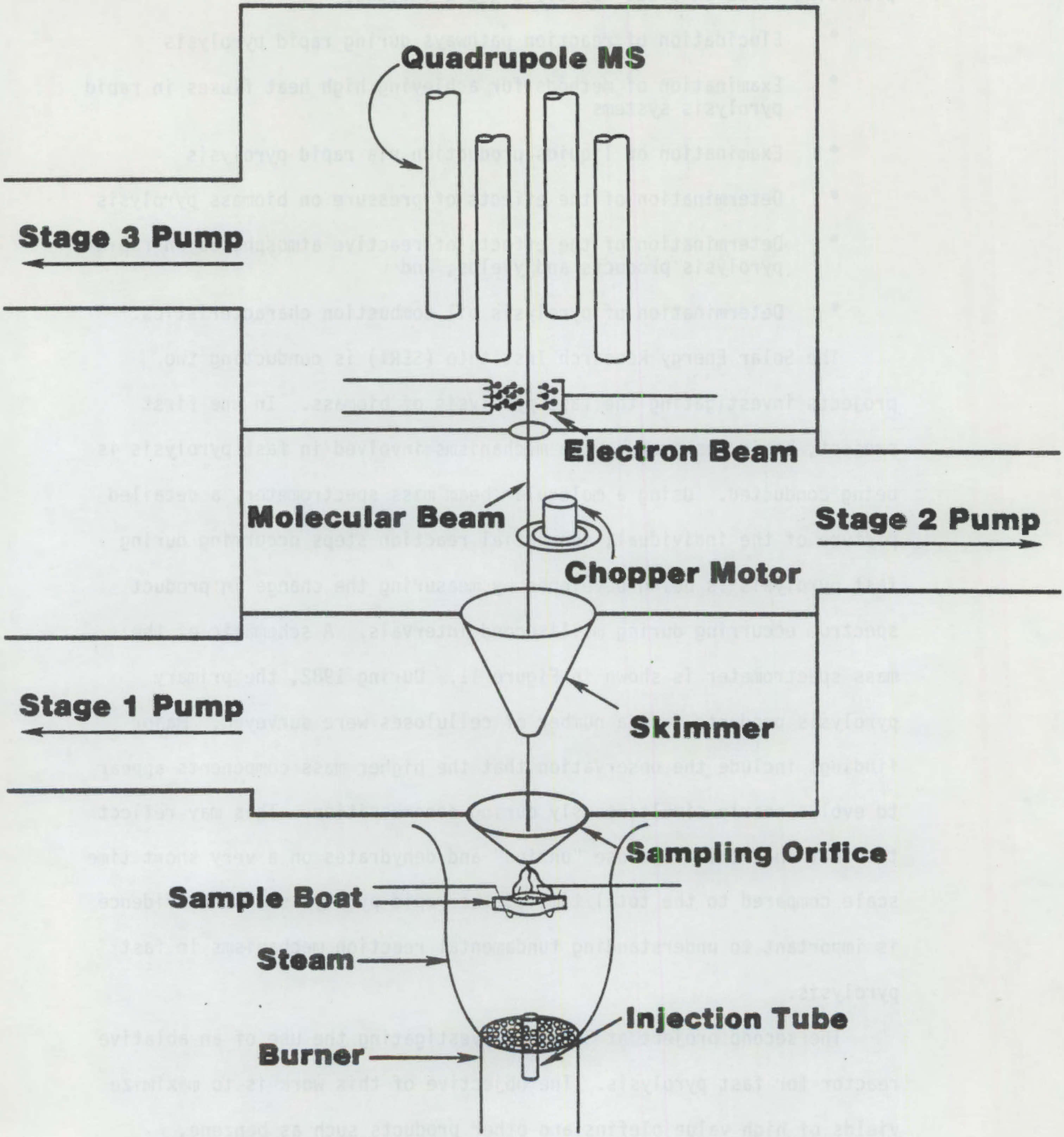
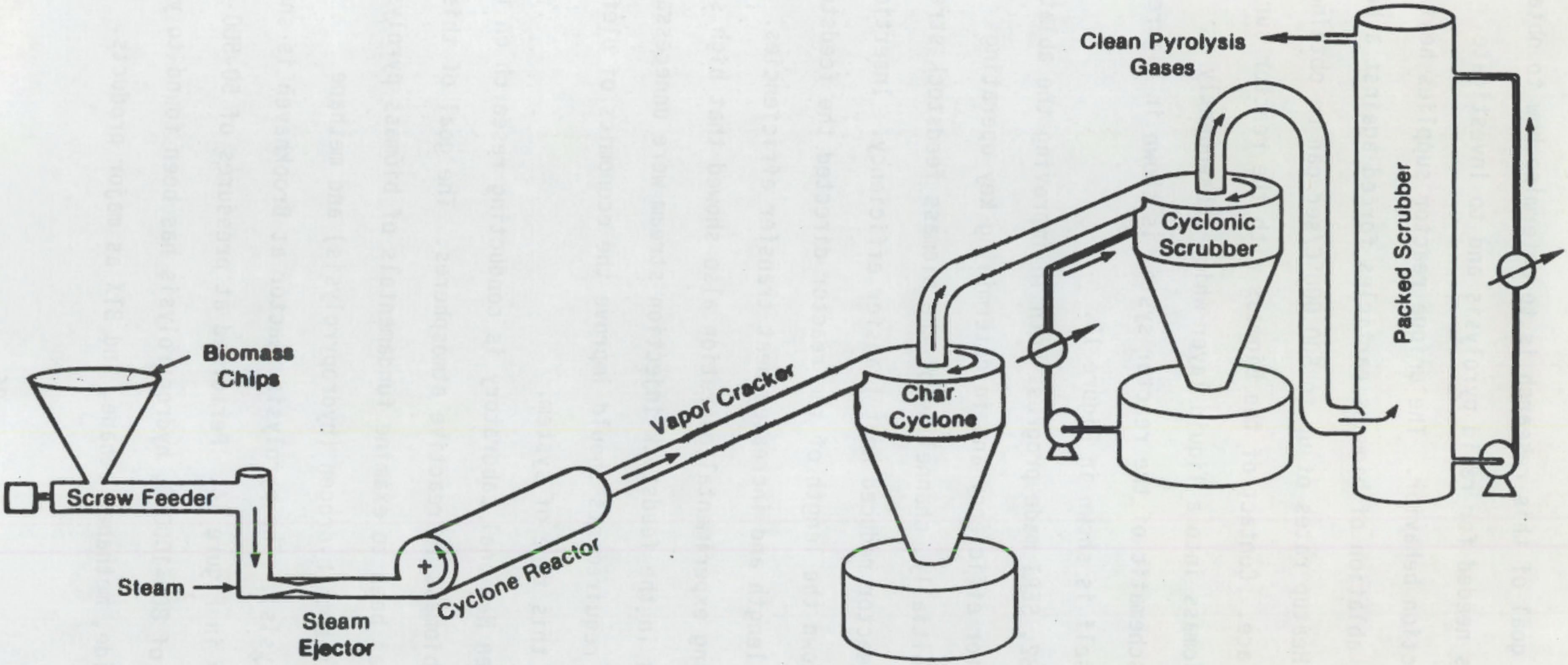


Figure 11. High Pressure Molecular Beam Sampling System to be Used With a Fast Pyrolysis Reactor

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 behavior. The unique reactor supplies heat for reaction by the ablation of biomass particles forced against a hot reactor wall. Heatup rates of up to 500,000°C/sec can be obtained at the sample surface. Contact of the biomass with the reactor surface converts the biomass into a liquid layer which subsequently is vaporized. A schematic of the reactor system is shown in Figure 12, and the reactor itself is shown in Figure 13.

During 1982, SERI made progress both in improving the ablative pyrolysis reactor efficiency and in determining key operating parameters. Initially, channeling of the biomass feedstock stream in the ablative reactor reduced heat transfer efficiency. Insertion of a helical coil down the length of the reactor directed the feedstock into a longer path length and increased heat transfer efficiencies. Data collected during experimental operation also showed that high steam to biomass ratios in the feedstock injection stream were unnecessary. Lowered steam requirements should improve the economics of olefin production in this type of system.

Brookhaven National Laboratory is conducting research on the rapid pyrolysis of biomass in reactive atmospheres. The goal of this work during 1982 has been to examine fundamentals of biomass pyrolysis in atmospheres of both hydrogen (hydropyrolysis) and methane (methanopyrolysis). The pyrolysis reactor at Brookhaven is shown schematically in Figure 14. Performed at pressures of 50-500 psi and temperatures of 800-1000°C, hydropyrolysis has been found to yield carbon monoxide, methane, ethane, and BTX as major products. Total



Rapid Pyrolysis Test Reactor - SERI

Figure 12. Schematic Diagram of Entrained Flow, Ablative Pyrolysis Reactor

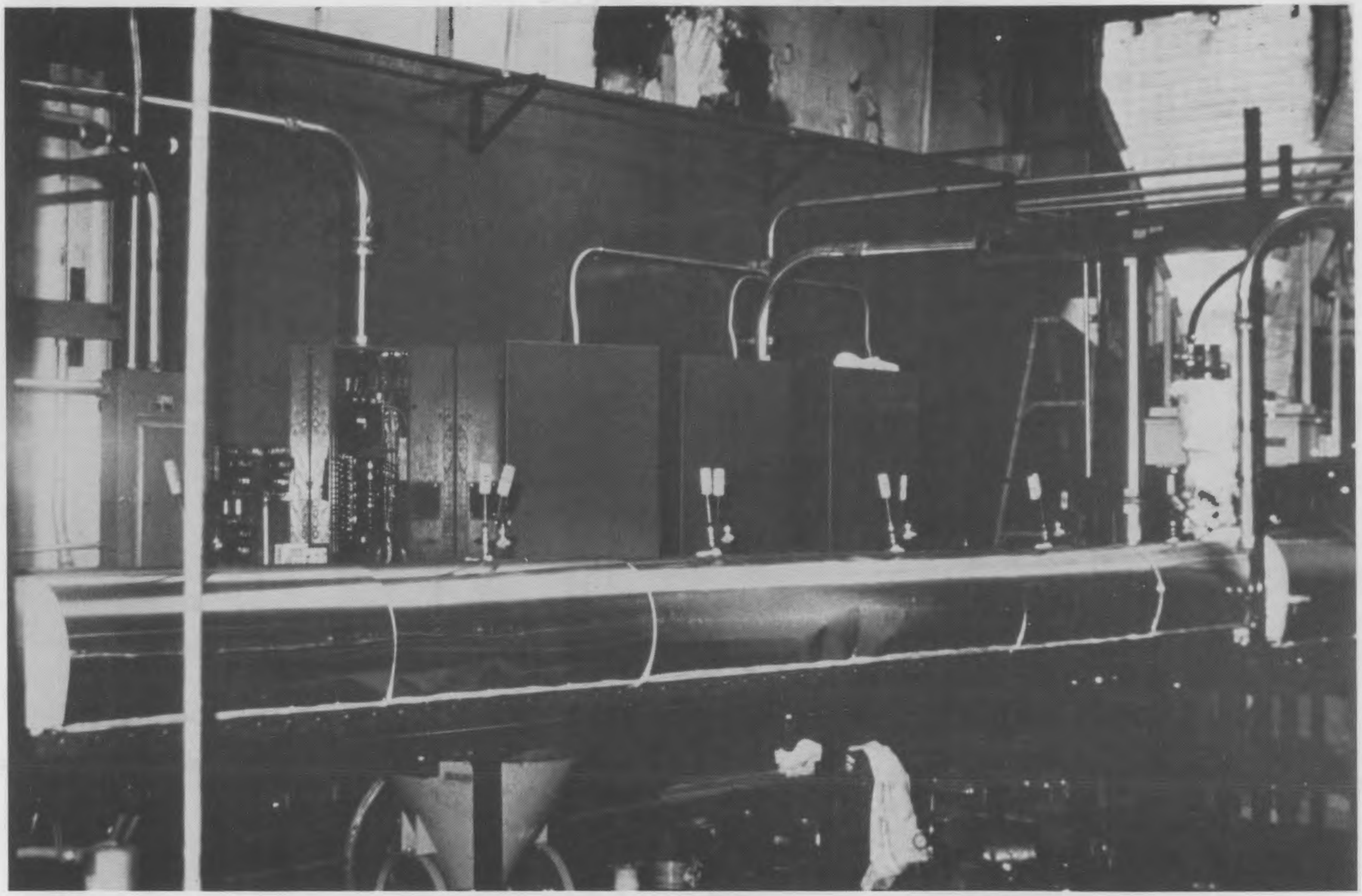
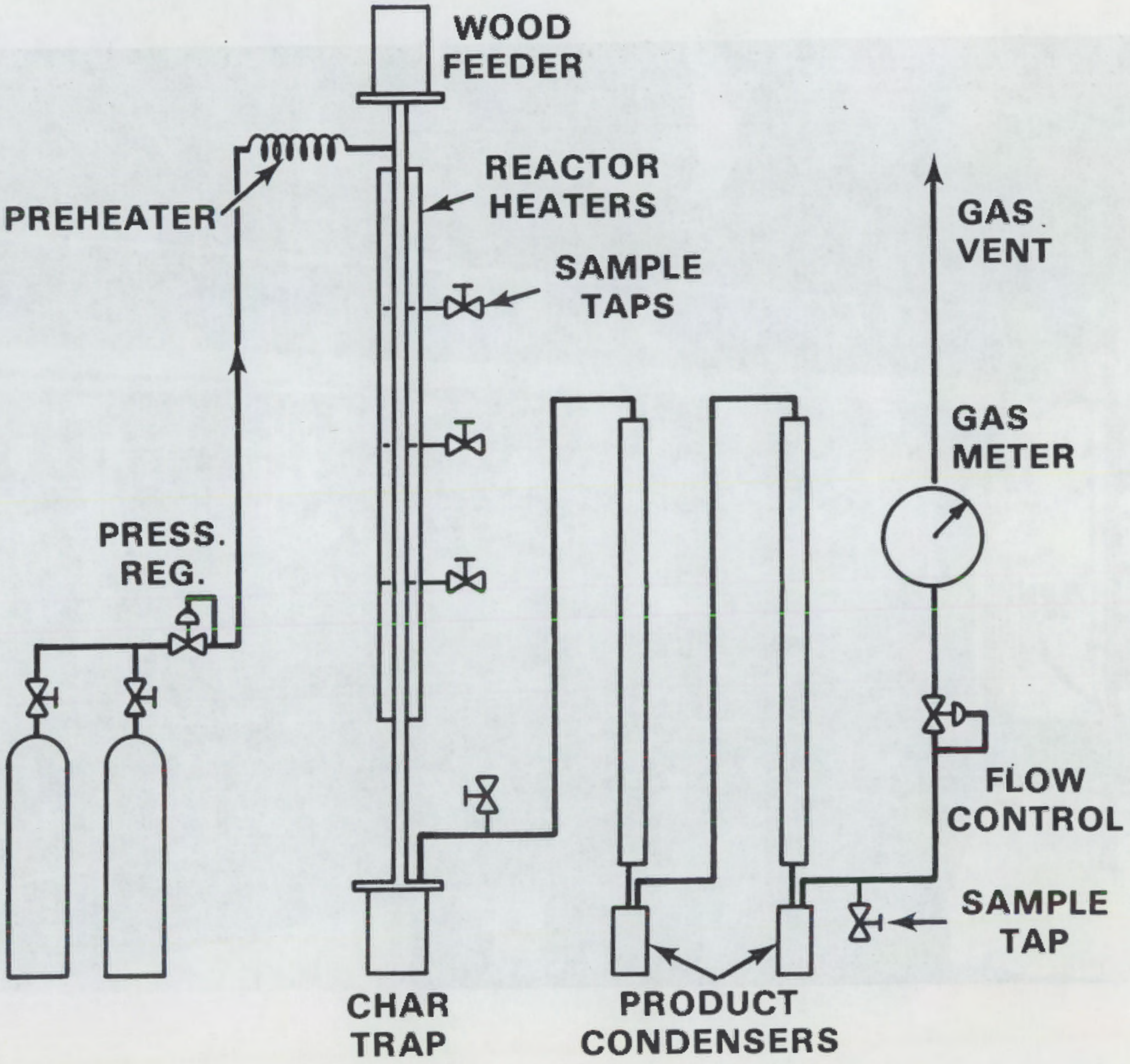


Figure 13. Ablative Pyrolysis Reactor Showing Feed Hopper and Reactor at the Rear, Vapor Cracker with Thermocouples, and Steam Generator (Parallel to Vapor Cracker)



SCHEMATIC FLOWSHEET OF BROOKHAVEN PYROLYSIS EXPERIMENT

Figure 14. Schematic Diagram of Fast Pyrolysis Reactor at Brookhaven National Laboratory

carbon conversions of over 95% are obtained. Brookhaven also discovered that methanopyrolysis leads to a quite different product slate. Major product yields included over 20% olefins and 10% BTX products for reactions at 1000°C. These yields are about double those achieved in inert atmospheres. This result is surprising since methane is not reactive under otherwise identical conditions when biomass is absent. Further research is currently being conducted to resolve the origin of this phenomena since the conversion of biomass to these high value products has positive implications for conversion economics.

Effects of pressure on biomass pyrolysis were investigated during 1982 in a project at the University of Hawaii. Using a special differential scanning calorimeter, heats of reaction for biomass pyrolysis were measured as a function of pressure. Experimental results showed that both anhydrocellulose and levoglucosan (intermediate products of the primary competitive reactions in cellulose hydrolysis) underwent subsequent competitive reactions. This information has allowed the proposed pyrolysis mechanism for cellulose to be expanded as shown in Figure 15.

Research in entrained rapid pyrolysis was also performed during 1982 at Georgia Institute of Technology. The overall goal of this research is to use rapid pyrolysis to generate products which are primarily liquids. Through 1982, design and construction of an entrained pyrolysis reactor was conducted. Rapid heat-up of the biomass feedstock in the entrained flow reactor is expected to result in pyrolysis oil yields of approximately 60% by weight. Fundamental studies on biomass pyrolysis were also performed to obtain necessary basic information on kinetic and thermodynamic parameters. Liquid

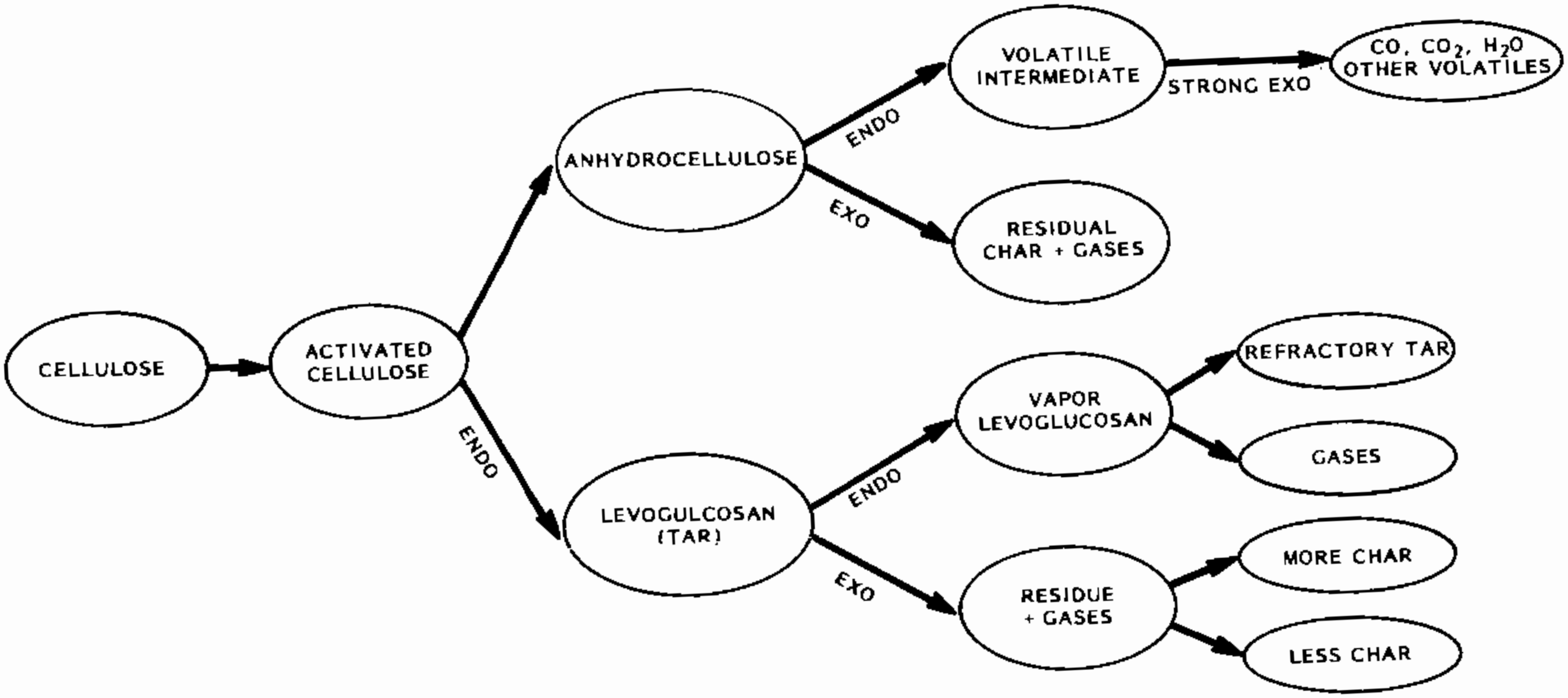


Figure 15. Competitive Reaction Mechanisms Proposed for the Pyrolysis of Biomass

product yields doubled in going from a batch wise reactor to a rotating tubular reactor which more nearly resembles entrained flow. These results support the possibility of obtaining large liquid yields in a cost effective manner from these types of systems.

Teledyne CAE has conducted research to determine the technical feasibility of burning biomass derived pyrolytic oil in a direct fired gas turbine. Combustion experiments were conducted using a test rig to simulate the combustion chamber of a J69 gas turbine engine. Other experiments were conducted to evaluate the effect of hot pyrolytic oil on the turbine fuel system materials of construction.

Teledyne concluded that pyrolytic oil could be burned in the J69 combustor with a combustion efficiency approaching 95 percent, which compares favorably with a combustion efficiency of 99 percent for JP-4 jet fuel. A fuel mixture containing equal parts of JP-4 and pyrolytic oil had a combustion efficiency of 99 percent. This suggests that pyrolytic oil may serve as an excellent supplement to JP-4 and possibly other petroleum fuels. Combustion tests using an 85% pyrolytic oil, 15% char mixture were unsuccessful due to the loss of combustion stability and subsequent blow out of the combustion flame. This suggests that char will probably be unsuitable as an additive to pyrolytic oil.

It was also found that hot pyrolytic oil causes damage to nonmetalic components and low alloy steels found in turbine fuel systems, due to its acidic nature. Consequently it may be necessary to protect fuel system materials from acidic attack if pyrolytic oil is to be used as a fuel in this type of turbine.

DIRECT LIQUEFACTION TECHNOLOGY

The Biomass Thermochemical Conversion Program is sponsoring research on the direct liquefaction of biomass. Direct liquefaction is defined in the broadest sense as any thermochemical conversion process which 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. In this direct liquefaction research, 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 the direct liquefaction program is to produce liquid products which could be used as substitutes for Nos. 2 and 6 fuel oils, and distillate fractions which could potentially be used for diesel fuels, octane enhancers, and other related uses. The liquefaction products have greater energy densities than the original biomass feedstock and can be readily transported. Liquid fuels have traditionally played a major role in the United States energy demand picture, and liquid products from biomass could be used directly for current liquid fuel needs without requiring major retrofit of existing equipment. The potential use of such liquid products, after some upgrading, as fuel extenders or substitutes also provides a possible source of transportation fuels which could contribute to national emergency preparedness.

During 1982, the main emphasis of DOE sponsored research in direct liquefaction has been focused on basic aspects of the liquefaction process. Projects sponsored in the area of direct liquefaction during 1982 are shown in Figure 16. The primary goal of this research has been to evaluate the technical feasibility of existing process concepts and to conduct research on new concepts which could lead to major technical advances in the field of direct liquefaction. This research includes examination of alternative catalysts systems and examination of advanced concepts for liquefaction reactor systems. In addition to this research, a final report from the multi-year operation of the Albany, Oregon, Biomass Liquefaction Facility was completed.

To date, research in direct liquefaction has been based on two primary process alternatives. The first is a concept initially proposed in work at the Pittsburgh Energy Research Center (PERC) and the second includes modifications originally suggested by Lawrence Berkeley Laboratory (LBL). Both concepts were previously tested at the Albany, Oregon Biomass Liquefaction Facility and have formed the basis for current research thrusts.

The PERC direct liquefaction flowsheet was based on a series of batchwise, bench scale biomass conversion experiments conducted by the Pittsburgh Energy Research Center of the U.S. Bureau of Mines in the early 1970's. In this flowsheet, biomass flour is mixed with recycle wood oil and sodium carbonate catalyst along with a reducing gas of H_2/CO mixtures. 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.

In the alternate LBL process flowsheet, wood is first prehydrolyzed with dilute sulfuric acid to form a pumpable aqueous slurry. The

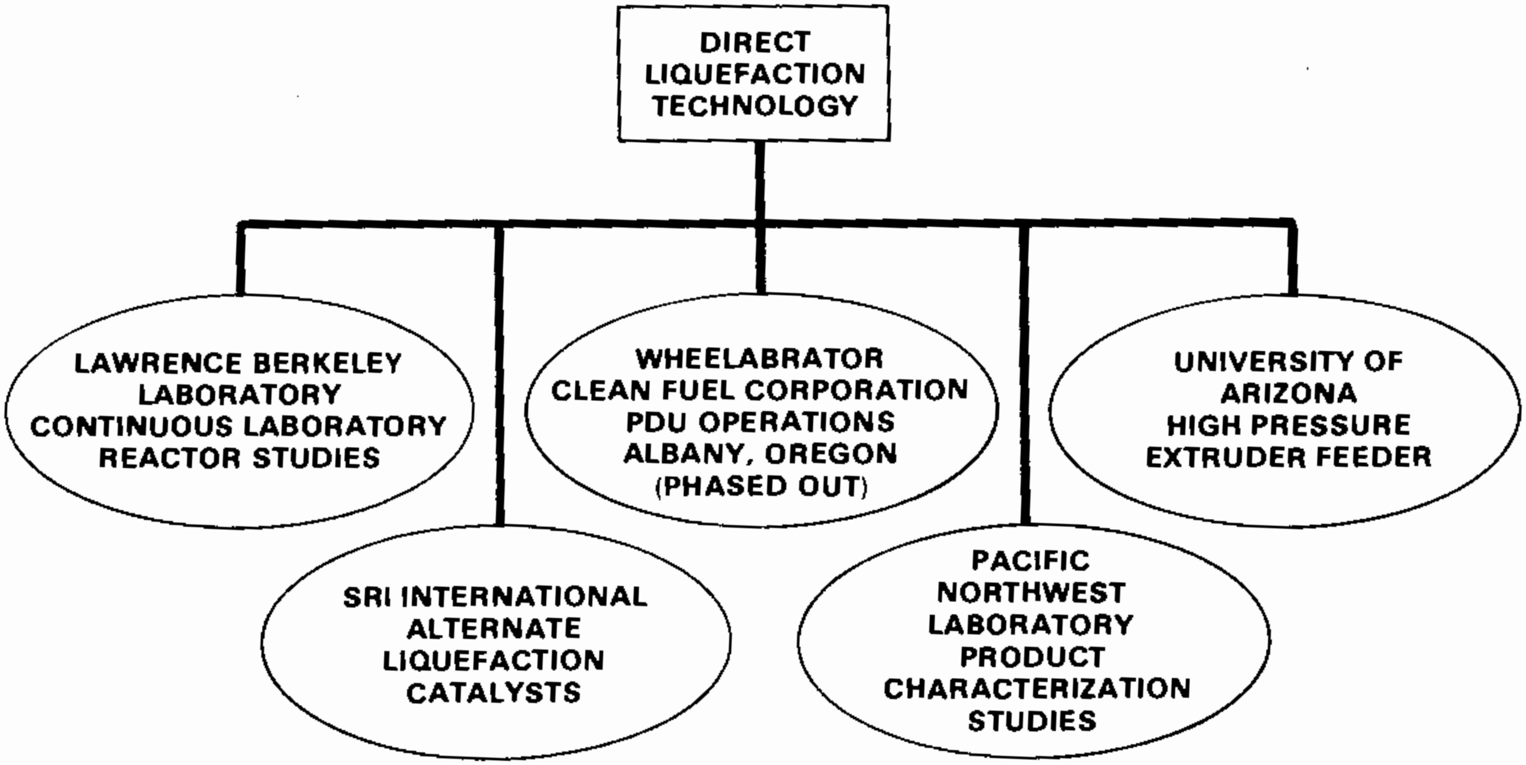


Figure 16. Direct Liquefaction Research Projects

aqueous slurry is then mixed with sodium carbonate catalyst and reducing gas and injected into the high pressure vessel. After reaction and pressure let-down, the product oil is separated from the aqueous phase.

At Lawrence Berkeley Laboratory, research during 1982 has been centered on developing a more complete understanding of the aqueous phase (LBL) liquefaction process. The goal has been to gain fundamental information about effects of process variables on product yields and quality. The research uses a bench scale, continuous reactor which is shown schematically in Figure 17. Research results show that either H_2, CO, or mixtures of both may be used as the reducing gas with little difference in this system. These results indicate that costly, high purity reducing gases would not be required.

The research results also point out differences between the oil slurry and aqueous slurry processes. In the aqueous slurry process, approximately 25% of the biomass feedstock is converted to water soluble products during the conversion. Analysis at LBL has shown that these products consist largely of low value acids including acetic, and propionic acids. These products are difficult to separate from the aqueous phase and reduce the overall yield of oil products as compared to the oil slurry (PERC) process. As a result, it appears that the aqueous phase process may be best suited to wet feedstocks where the loss in product yield is made up by reduced drying requirements. The research team at LBL has also succeeded in developing a gradient elution technique which is very useful in separating the liquefaction products into several fractions.

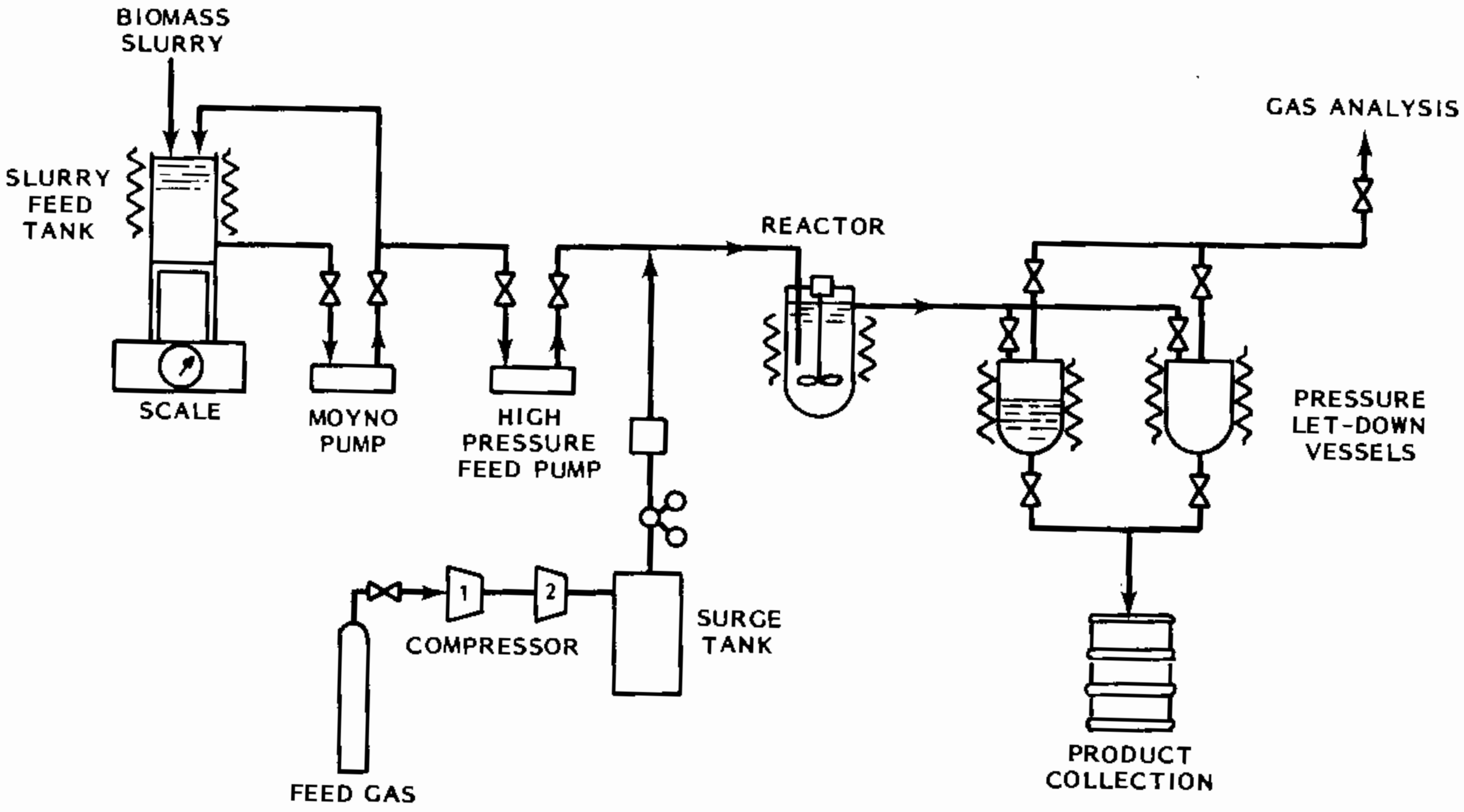


Figure 17. Schematic Diagram of the Bench-Scale Continuous Direct Liquefaction Reactor at Lawrence Berkeley Laboratory

Research on improved catalysts for biomass direct liquefaction was performed in 1982 by SRI International. The goal of this work was to examine a wide range of soluble, homogeneous salts for improved catalytic activity in the aqueous slurry (LBL) process. In total, fifteen transition metal salts were tested for activity in batchwise autoclave experiments. Of the metal ions tested, eight showed varying degrees of catalytic activity with potassium tetracyanonickelate being the most active. While this catalyst may not be economically feasible on a commercial scale, further in-depth studies revealed interesting mechanistic data on the involvement of the catalyst during the liquefaction reaction. These studies suggest that the metal ion is particularly important as a hydrogenation catalyst and that the attached cation is involved in the formation of formate. Understanding the fundamental reaction mechanisms should lead to additional progress on alternative catalysts.

Research on advanced concepts for direct liquefaction was performed in 1982 by the University of Arizona. The goal of this work has been to adapt a modified extruder for pumping very concentrated, viscous biomass slurries in the oil recycle (PERC) process. The extruder/feeder system is shown schematically in Figure 18. The modified extruder/feeder system has now been shown to be capable of handling slurries as concentrated as 60% wood solids in biomass oil. Conventional systems typically cannot handle slurries containing over about 25% wood. During 1982, the University of Arizona completed experimental work and detailed engineering analysis to evaluate the potential for using the extruder/feeder in an actual liquefaction system. The analysis showed that the extruder/feeder would potentially offer advantages over other

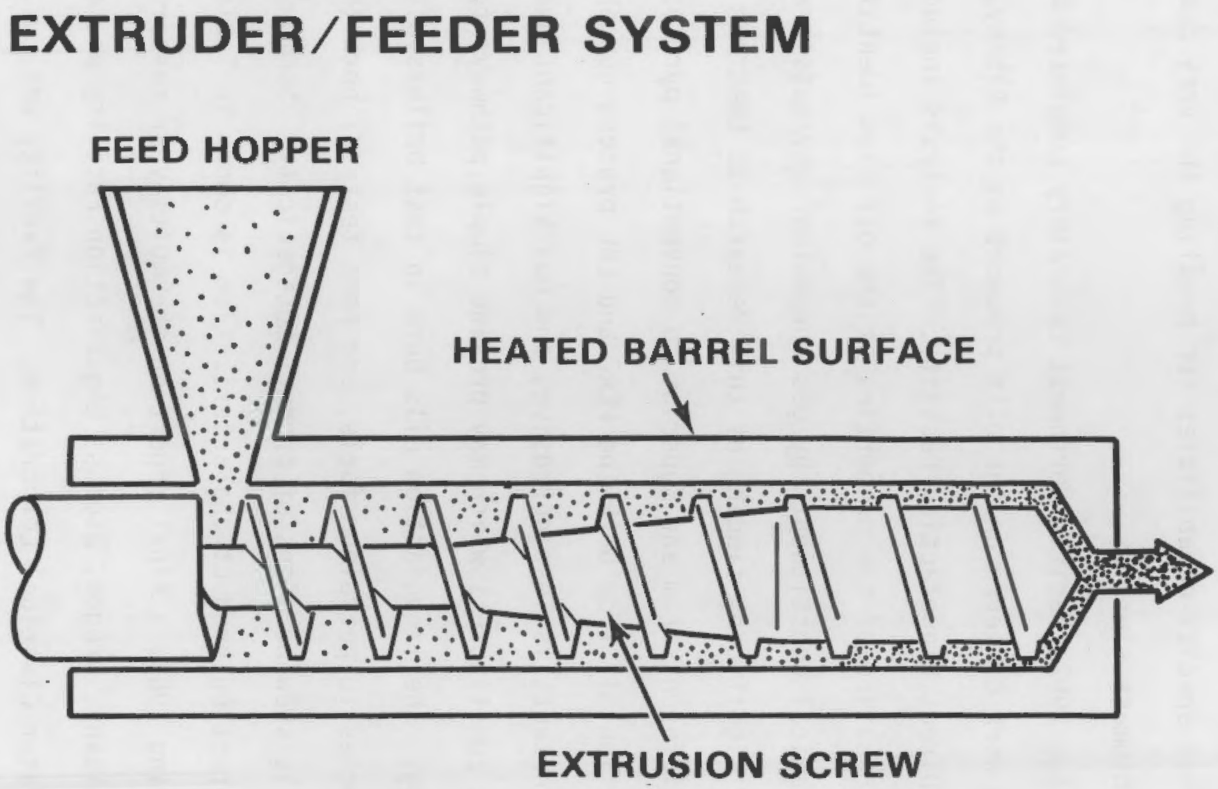


Figure 18. Extruder/Feeder System for Pumping Concentrated Biomass Slurries

systems by reducing overall energy requirements and by increasing throughput. During 1982, the University also designed an integrated extruder-reactor system. The system combines the advantages of the extruder/feeder system with a unique static mixer reactor. The reactor concept has special capabilities for handling the very concentrated, viscous biomass slurries.

During 1982, Pacific Northwest Laboratory completed detailed analysis work centered on the oils produced at the Albany, Oregon, Biomass Direct Liquefaction Facility. The analysis included extensive characterization of the properties of the oil plus identification of major chemical constituents by gas chromatography/mass spectrometry. The most significant finding of this research is that the liquefaction oil is different from and superior to conventional pyrolysis oils. The liquefaction oil from both the PERC and LBL process concepts has lower oxygen content, is less corrosive, and has significant quantities of phenolic constituents which may provide simple pathways for product upgrading. The liquefaction oils burn in test boilers with similar efficiencies to petroleum fuels, and Ames tests of both the LBL and PERC crude oils show no signs of product mutagenicity. Summary information on liquefaction product characterization is shown in Tables 1 and 2.

During 1982, a final report on the multi-year research activities at the Albany, Oregon, Biomass Liquefaction Facility was completed by Wheelabrator Cleanfuel Corporation. The Facility was built in 1976 to test the feasibility of biomass direct liquefaction on a continuous basis and is shown in Figure 19. The report describes operation of the facility beginning in 1978 through completion in 1981 and provides a detailed summary of the research conducted during this period. Since

Table 1. Physical Characteristics of Biomass Direct Liquefaction Oils Produced at Albany, Oregon. (Moisture-free basis)

	Water Slurry (LBL) process	Oil Slurry (PERC) Process	
	Test Run 7	Test Run 8	Test Run 12
Elemental Analysis %			
C	80.2	84.2	80.6
H	8.5	8.7	10.3
O	11.1	6.6	9.1
N	0.2	0.5	0
Heating value (Btu/lb)	15800	16300	15300
H/C Ratio	1.26	1.23	1.52

Table 2. Chemical Components of Biomass Direct Liquefaction Products as Determined by Gas Chromatography/Mass Spectrometry.

C_5-C_6 alcohols
cyclopentanones
cyclopentenones
C_7-C_9 cyclic Keytones

dihydroxybenzenes
C_8 alkylbenzenes

phenols
methylnapthols
guaiacols
high molecular weight
guaiacols and oxygenates

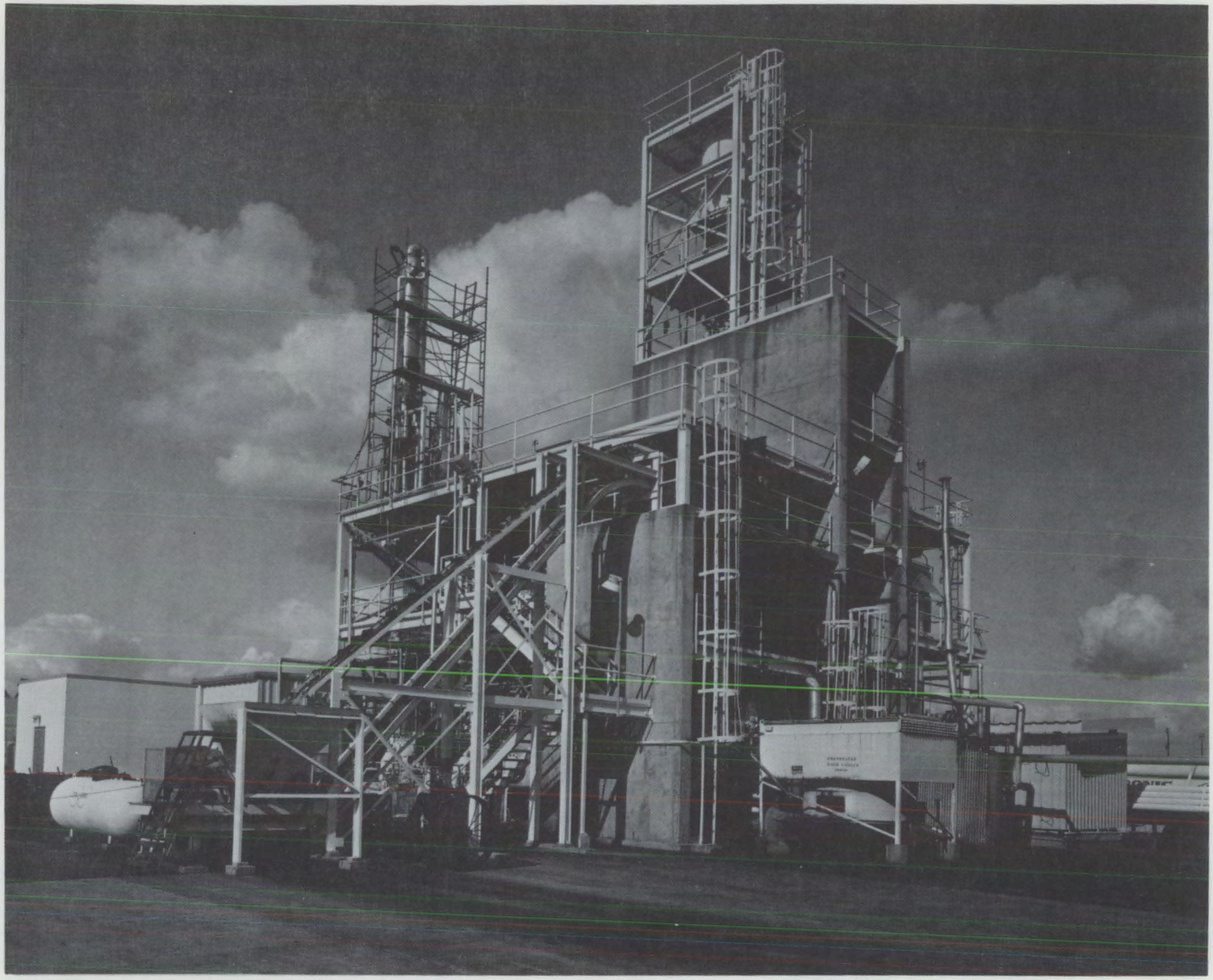


Figure 19. Biomass Liquefaction Facility, Albany, Dregon. Wood Feeder is Shown at Left. Pressurized Reactor Located Behind the Cement Shield. Fractional Distillation Unit is Shown at Left on the Upper Deck.

this facility was the first to produce multi-barrel quantities of biomass liquefaction oils, the final report serves as a reference volume for this benchmark effort. Major accomplishments include:

- First successful production of multi-barrel quantities of direct liquefaction oils on a continuous basis,
- Production of over 15,000 lbs of direct liquefaction oils for further testing and analysis,
- Verification of technical feasibility of the two major process alternatives with oil or aqueous transport slurries,
- Successful test firings of direct liquefaction oils in a small boiler unit with combustion efficiencies equivalent to petroleum fuels,
- Production of an oil product superior to conventional pyrolysis oils due to lower oxygen content, higher heating value and other factors.

The research at Albany clearly showed the technical feasibility of producing biomass derived liquids by this type of process. Both the oil slurry (PERC) and aqueous slurry (LBL) process options were shown to be feasible in the continuous unit. In one test run alone during 1981, over 11,000 lbs of direct liquefaction oils were produced by operation in the oil slurry mode (PERC). The equipment configuration for this test run is shown in Figure 20. The facility also made major contributions toward an understanding of the types of materials and reaction systems necessary for this type of work. The use of a high pressure, externally fired tubular reactor was shown to be feasible. The tubular reactor offers significant advantages in operational reliability and is easier to scale up than stirred tank reactors. Information on the types of valves, piping, and pumps necessary to handle both the feedstock slurries and the resulting products was also obtained. As indicated above, the product is substantially different from conventional pyrolysis oils and has many advantages over those products.

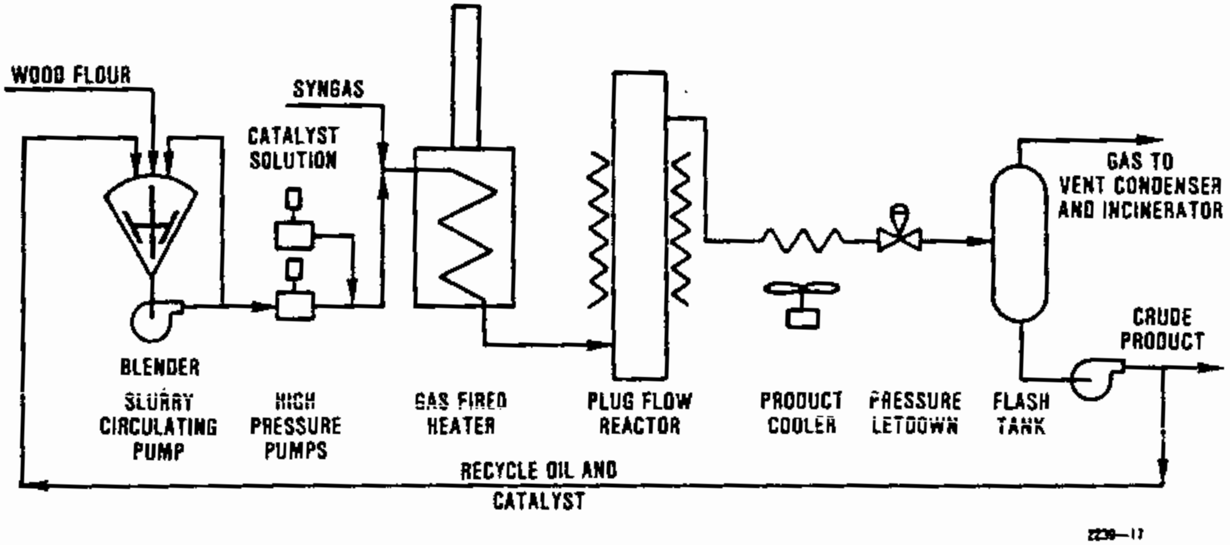


Figure 20. Equipment Configuration at Albany, Oregon, for Oil Slurry (PERC) Test Run Number Twelve

Despite the demonstrated technical feasibility, efforts to date at both Albany and at the bench scale have shown that the existing concepts are not currently economically feasible. The economic problems arise from large capital expenditures necessary for the complex facilities presently required and from process considerations such as large product oil recycle requirements. As a result, future research in direct liquefaction will be conducted on the fundamental level to generate the technical advances required before this conversion approach can be considered ready for engineering development.

DIRECT COMBUSTION TECHNOLOGY

Direct combustion of biomass feedstocks, particularly wood, is already widely practiced by the private sector, especially in the forest products 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 portion of their energy needs. In the current era of expensive energy, there is wide spread 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 utilizing 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 in small scale combustion engines. 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 the small engines to operate economically. Research sponsored by the program is directed towards finding ways to efficiently replace petroleum fuels and natural gas in these small systems. As shown in Figure 21, the Biomass Thermochemical Conversion

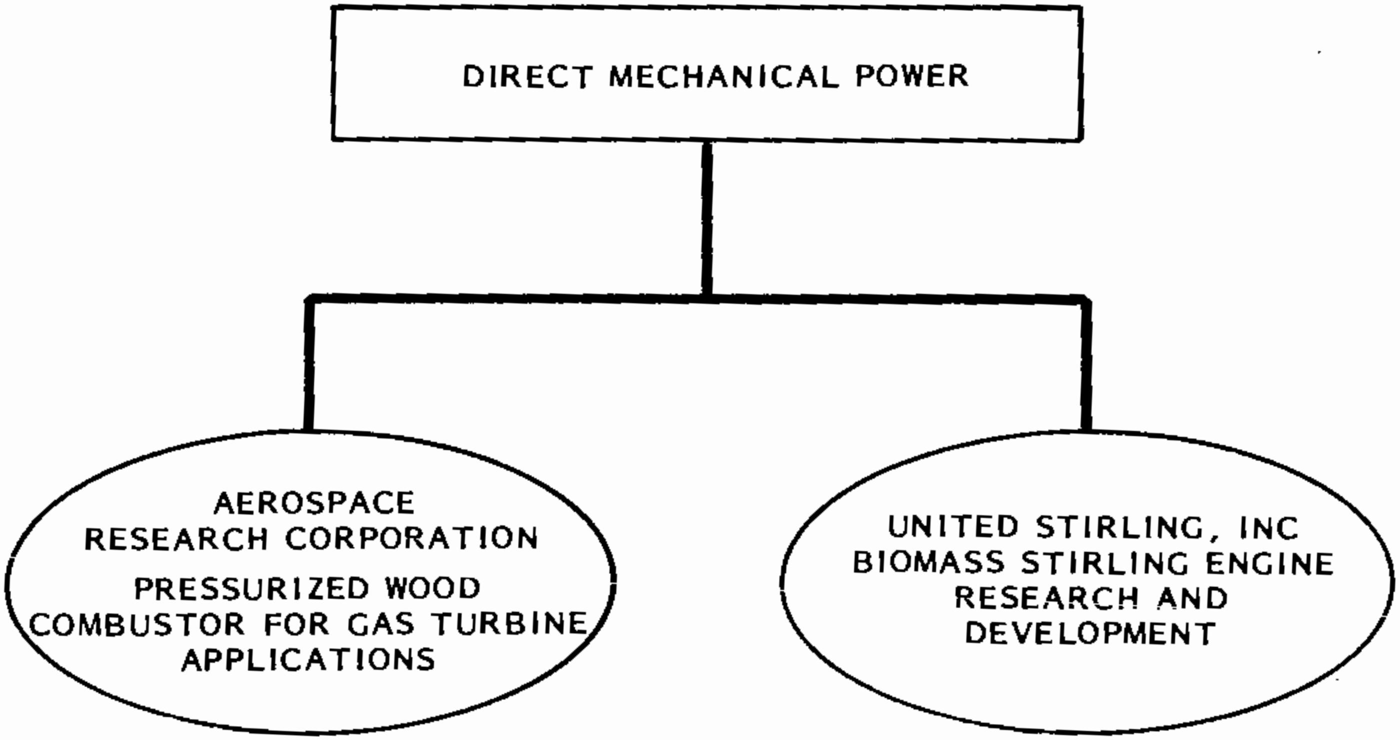


Figure 21. Direct Combustion Research Projects

Program is currently sponsoring two research projects for using direct combustion of biomass in combustion engines.

United Stirling Inc., is conducting research on biomass fueled 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 the development of improved Stirling engines. The scope of this project is limited to the adaptation of Stirling engines to biomass fuels.

This project has been directed toward determining the technical feasibility of heating the Stirling engine heat exchanger, shown in Figure 22, with the hot flue gases from a small cyclonic combustor. Work to date has shown that wood ships as large as 3/8 inch have suitable combustion characteristics in the cyclonic combustor and can be reasonably metered with a small screw feeder. Current research is focused on methods of ash removal from the combustor and on reduction of ash deposition on the heat exchanger.

Aerospace Research Corporation is conducting research on a directly fired gas turbine system using wood feedstocks. 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. Tests using the 300 Kw combustion turbine system shown in Figure 23 are being conducted to determine the amount of erosion and corrosion to the turbine buckets and stators, and the effects of wood type, moisture

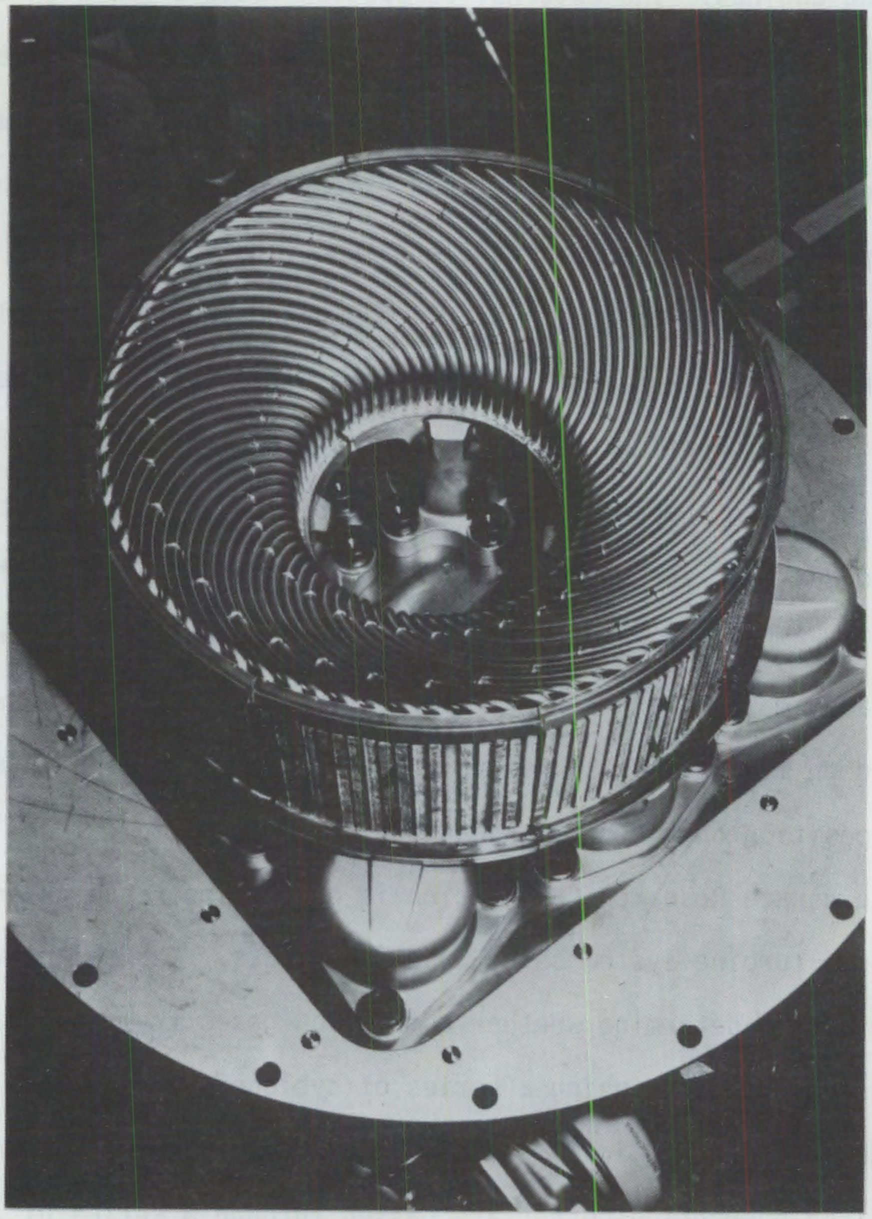


Figure 22. Involute Heat Exchanger on 4-95 Stirling Engine

Figure 23. Wood Combustor/Gas Turbine-Generator System at Aerospace Research Corporation

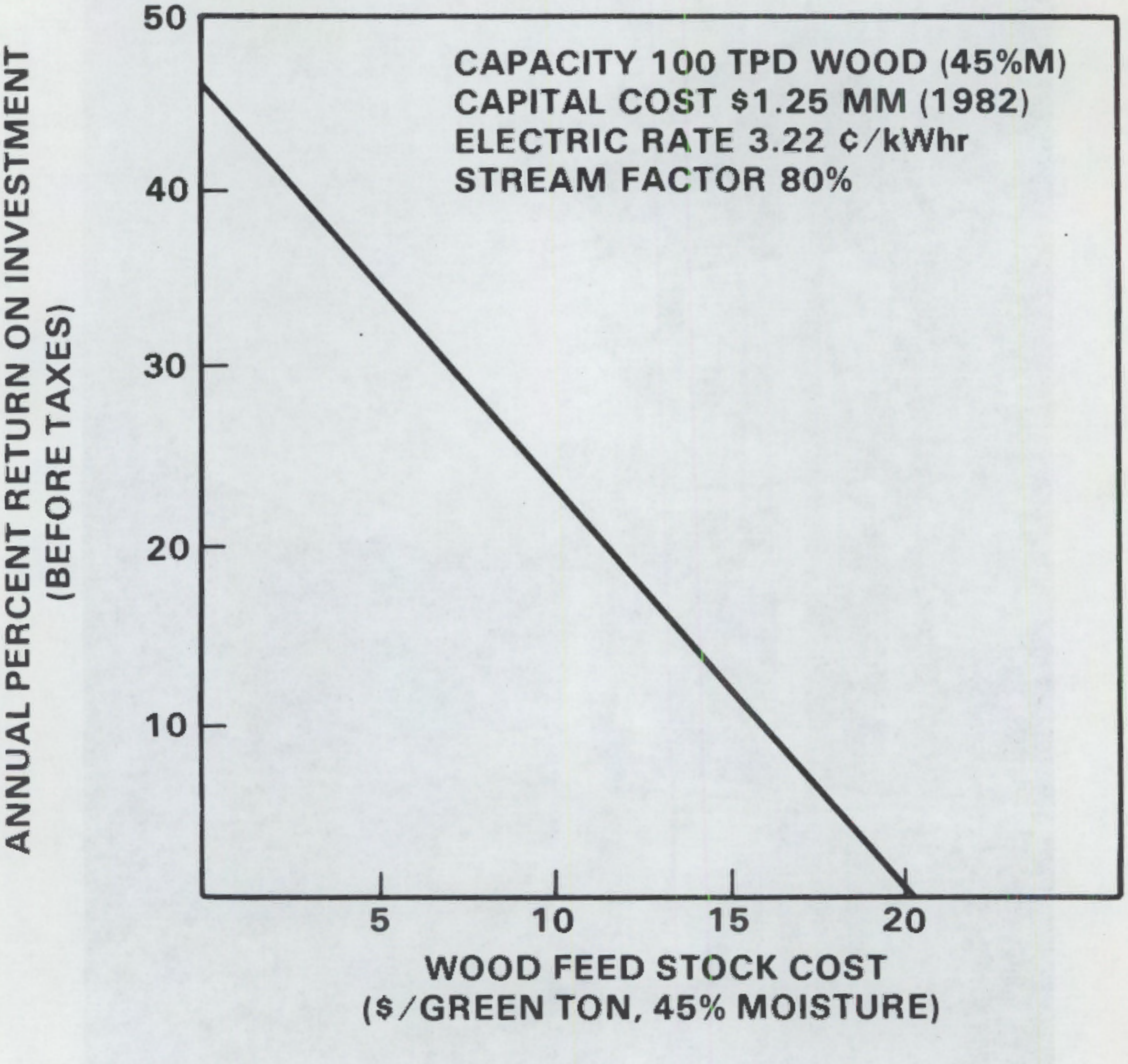


Figure 24. Return on Investment For a 3 MW Wood Combustor/Gas Turbine Generator System

content, and particle size on system performance. Disassembly and examination of the turbine components following 200 hours of operation showed no significant signs of corrosion and only a soft, water soluble deposit which was easily removed. A total of 1,000 hours of testing is planned before final examination of the turbine components. Tests were also conducted to determine the mass concentration and particle size distribution of the wood combustion particulates entering the gas turbine. Data collected using an Anderson impactor showed that 80 to 90 percent of the particle mass was less than 0.5 m in diameter. The particulate loading entering the turbine ranged from 0.038 to 0.056 grains per dry standard cubic foot. These results and the results of the 200 hour test suggest that turbine erosion may be less of a problem than originally anticipated.

Projected economics for a complete three megawatt generating system are shown in Figure 24.

PROGRAM SUPPORT ACTIVITIES

During 1982, the Thermochemical Conversion Program sponsored additional research activities with the goal of supporting major program elements. This research includes evaluation of technoeconomic factors, evaluation of feedstock availability, and cataloging of major research activities in biomass conversion. Program support research projects are described below.

Science Applications, Inc., (SAI) has conducted an engineering and economic study to assess the applicability of five advanced biomass gasification concepts for the production of methanol. Alternative biomass-to-methanol flowsheets were developed for a conceptual 500 TPD grass roots methanol plant. The flowsheets were based on preliminary experimental data from small scale process research units at Pacific Northwest Laboratory, Wright-Malta Corporation, Texas Tech University, Battelle Columbus Laboratory and SERI. Capital and operating costs were estimated for twenty possible process configurations based on the five gasification concepts. Production costs were estimated for both private and utility financing. The results of this study showed that for a wood feedstock cost of $34/dry ton, methanol production costs ranged from $0.70 to $1.14 per gallon using utility financing and from $0.85 to $1.37 per gallon using private financing. Average production costs for the twenty alternative configurations were $0.83 and $1.02 per gallon for utility and private financing, respectively. This price range is comparable to a gasoline cost between $1.22/gal and $1.46/gal on an energy equivalent basis when a 20% increase in engine efficiency from burning methanol, instead of gasoline, is taken into account. These results suggest that further research is warranted for developing advanced gasification processes for producing methanol synthesis gas.

Pyros Inc., is conducting research to determine the potential for supplying wood feedstocks to intermediate size (500-2000 tons/day of wood) conversion facilities in the Northeastern and Southeastern United States. This study is based in part upon the experience gained by the Burlington Electric Department in setting up a wood supply infrastructure for a 50 MW electric power plant in Vermont. This information is being used to estimate the potential for developing wood supply infrastructures in each region based on resource availability. The study will ultimately determine the potential for siting intermediate sized wood conversion facilities in both the Northeastern and Southeastern United States.

SRI International completed a final report on the technoeconomic evaluation of biomass utilization processes. The goals of the "Solar Cost Data Bank" study was to develop projected economic costs for biomass feedstock/conversion technology options, to develop cost competitive goals for biomass technologies, and to identify options for achieving these cost goals. The final report presents technoeconomic evaluations for 25 biomass conversion processes ranging from gasification to ethanol production.

SRI concluded that biomass combustion offered the greatest potential near-term impact on U.S. energy supplies. SRI also identified and commented on several impediments to the development of biomass utilization including: 1) uncertain future prices of natural gas, 2) difficult access to biomass feedstocks on federal lands, 3)

potentially adverse environmental impacts of biomass production on marginal lands, and 4) the safe disposal of bioconversion process wastes.

EnergyTrack, Inc., has been compiling a catalog of biomass thermochemical conversion projects. The goal of this work is to identify biomass conversion efforts on the national, regional, state, and local levels. The catalog will be used in FY-83 as a planning document both to identify sources of technical expertise and to avoid unnecessary duplication of effort within the Thermochemical Conversion Program.

APPENDIX A

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