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Biomass Energy Systems Program Summary

Information Current as of September 30, 1979

Published October 1980

Prepared for:

U.S. Department of Energy

Assistant Secretary for Conservation and Solar Energy

Under Contract No. DE-AC01-77ET 21059

MASTER

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Assistant Secretary for Conservation and Solar Energy
Washington, DC 20461

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PREFACE

On October 26, 1974, the Solar Energy Research, Development and Demonstration Act (Public Law 93-473) was signed into law, authorizing a vigorous Federal program of research, development, and demonstration. Its goal was to provide the nation with the option of using solar energy as a new source for meeting future requirements. In response to the mandates of this act, major efforts were made, within the Division of Solar Energy of the Energy Research and Development Administration (ERDA), to expeditiously develop and introduce economically competitive, environmentally acceptable solar energy systems.

These responsibilities were transferred to the newly organized U.S. Department of Energy (DOE) on October 1, 1977. At present, DOE's solar energy activities are divided into three distinct organizational components:

- Division of Central Solar Technology
  - Ocean Systems Program
  - Solar Thermal Power Systems Program
- Division of Distributed Solar Technology
  - Biomass Energy Systems Program
  - Photovoltaic Systems Program
  - Wind Energy Systems Program
- Office of Solar Applications
  - Heating and Cooling of Buildings Program
  - Agriculture and Industrial Process Heat Program
  - Technology Transfer Program

Both the Division of Central Solar Technology and the Division of

Distributed Solar Technology function as a part of the Office of Assistant Secretary for Energy Technology (SOLAR/ET), while the Office of Solar Applications functions as a part of the Office of the Assistant Secretary for Conservation and Solar applications (SOLAR/CS). An overview of the current DOE solar program organization is shown in Figure 1.

Program planning continues under the guidelines established by PL 93-473 and by three other legislative acts passed by the 93rd Congress: the Solar Heating and Cooling Demonstration Act of 1974 (PL 93-409), the Energy Reorganization Act of 1974 (PL 93-438), and the Federal Non-nuclear Energy Research and Development Act of 1974 (PL 93-577). Together these four laws grant DOE and other Federal agencies the authority to pursue a research program aimed at effective solar energy use. Under this authority, SOLAR/CS and SOLAR/ET are working to develop solar energy technologies and to complement efforts in the private sector to develop solar energy resources.

A program summary is issued for each solar program annually. Each summary provides an overview of the ongoing research, development, and demonstration efforts of the preceding fiscal year (FY).

This Program Summary describes each of the DOE's Biomass Energy Systems projects funded or in existence during fiscal year 1979 (October 1, 1978 through September 30, 1979) and reflects their status as of September 30, 1979. This document is a follow-up to the FY 1978 Program Summary (DOE/ET0022) published in 1979.

Figure 1. Current DOE Solar Program Organization

INTRODUCTION

Biomass includes animal manures, terrestrial and aquatic plant life, and forestry and agricultural residues. It receives and transforms solar energy into stored chemical energy. This energy can then be harvested into usable energy products. Sources of useful energy include all types of plants, trees, non-woody perennials, cultivated annuals or biennial crops and freshwater and marine plants. These resources can be collected and burned directly or converted by various technologies into liquid and gaseous fuels or energy intensive products. Biomass is considered partially renewable. To avoid depletion of our natural resources, nutrients and minerals must be returned to the aquatic or terrestrial environment.

The United States has extensive biomass resources available to help meet its energy needs. Such estimates have ranged from 8-10 quads*/year. Biomass currently provides approximately 1.5 quads of energy, or almost 2 percent of the total U.S. energy consumption. The major portion of this energy is in the form of process heat and electricity generated by the forest products and paper and pulp industries for their own use. Recent estimates indicate that the conversion of unused agricultural residues, forestry residues and non-commercial timber could provide 6 to 10 percent of the nation's energy needs on a sustained basis. Intensively managed growth of terrestrial and aquatic biomass crops on so-called "energy farms" could increase the biomass contribution to about 16 percent of the current U.S. energy needs.

---

*A quad is equal to a quadrillion (10^{15}) British Thermal Units and is approximately equal to 10^{18} joules. U.S. energy consumption in 1977 was approximately 77 quads.

Biomass is highly site specific and dispersed and occurs in a large variety of raw forms. It is bulky and contains from 50-90 percent moisture and is, therefore, difficult and uneconomical to transport. Under these conditions, it should either be used on the spot, or converted by various technologies into more portable materials. These processing options include conversion of biomass into such products as:

- Fuels
  - Liquid
  - Gaseous
  - Solids
- Petrochemical substitutes and other energy intensive materials
  - base industrial chemicals
  - intermediate chemicals
- Heat
  - residential space
  - industrial process
- Electricity

Appropriate commercial technologies are in various stages of development and commercialization. These technologies are:

- Direct combustion of wood to produce heat, steam and/or electricity.
- Thermochemical conversion to produce synthesis gas, fuel oil, methane, etc.
- Biochemical conversion including fermentation of starches and sugars to produce alcohol, and anaerobic digestion of manures, woody and soft-stemmed crops to produce biogas.

The number of different biomass resources and the number of feasible conversion processes permit many approaches for the production, conversion and use of biomass (Figure 2).

The Biomass Energy Systems (BES) Program of the Department of Energy is the center of activity aimed at increasing the development and utilization of biomass energy. The projects listed in the Program Summary are those to which funding commitments were made in Fiscal Year 1979 - from October 1, 1978, to September 30, 1979. The program emphasizes the identification of regional needs for biomass derived energy, matches these needs with available biomass feedstocks, and attempts to develop various conversion technologies. These conversion technologies and their applications have been grouped into different program elements according to the time frame in which they are expected to enter the commercial market.

- Technology Development and Application

Under this element, engineering development and environmental research support are provided to those technologies that are likely to be commercialized by 1985.

- Production Systems

This element supports exploratory and technology development to expand the biomass resource base by developing silvicultural, herbaceous and aquatic energy farm technology for utilization in the period between 1985 and 2000.

- Conversion Systems

Under this program element, biomass processing options are developed for use between 1985 and 2000. They include biochemical and thermochemical conversions that are expected to produce commercially clean fuels, petrochemical substitutes and other energy intensive chemicals.

- Research and Exploratory Development

This element supports applied research and exploratory development in advanced biochemical conversion techniques, plant breeding, phytobiology and land-based aquatic biomass production and conversion. These systems are likely to contribute to the nation's energy supply after the year 2000.

- Support and Other Activities

General support activities such as mission analyses, environmental assessment and administration will be supported under these elements.

Technologies expected to make significant near-term impact are (1) direct combustion of wood and wood residues to provide industrial process heat, electricity and residential heat; (2) fermentation of grain and sugar crops into ethanol, primarily for liquid transportation fuels; and (3) anaerobic digestion of manures to produce methane gas. Direct combustion of wood is now a dominant use with considerable potential for expansion.

Figure 2. Biomass Energy Systems Program Overview

THE BIOMASS ENERGY SYSTEMS PROGRAM

The Biomass Energy Systems Program develops concepts and procedures aimed at commercialization of various biomass energy conversion systems. The program contains the following elements and subelements:

- Technology Development and Applications
  - combustion systems
  - on-farm biomass conversion systems
  - alcohol production systems
- Production Systems
  - silvicultural
  - herbaceous
- Conversion Systems
  - biochemical conversion
  - thermochemical conversions
- Research and Exploratory Development
  - innovative conversion systems
  - advanced feedstocks
  - aquatic systems

Objectives

The overall objective of the Biomass Energy Program is to provide the technology base and to recommend incentives for the displacement of traditional liquid and gaseous fuels through direct biomass combustion and through substitution of biomass derived fuels and chemical feedstocks. Included in this objective is the assistance in the transfer of technology so that industry and commerce will be able to produce biomass and convert it into energy products that can compete in the marketplace. The various biomass conversion technologies, depending upon their economic competitiveness and commercialization potential, have been grouped into three different time frames--near-term, mid-term and long-term.

Goals

The near-term (before 1985) goal of the Biomass Energy Systems Program is to add annual production and use of 0.5-1.0 quads to the currently used 1.5 quads of biomass energy. This would be done through direct combustion and from alcohol and on-farm gas production systems. A recent directive from the President requires achieving a 500 million gallon alcohol fuel production capacity by 1981 which, if blended with gasoline, should meet 10 percent of the 1981 U.S. demand for unleaded gasoline.

The mid-term (before 2000) goal is to produce 5 - 7 quads of energy annually by expanding near-term technologies and adding improved biochemical and thermochemical energy conversion technologies. To achieve the Presidential goal of 20 percent contribution to the U.S. needs by solar and renewable technologies, biomass must supply 5½ quads annually.

The long-term (after 2000) goal is to provide at least 10 quads of energy annually, primarily through innovative research and exploratory development, to be initiated (or now in progress) on the concepts of terrestrial energy farms, photobiology, and plant breeding and on exotic crops for the production of hydrocarbons.

Strategy

The strategy by which the Biomass Energy Systems Program intends to achieve various objectives and goals has been developed using the characteristics of the resources and technologies. A key element of the strategy is to organize and manage the program elements according to the time period (i.e., near-, mid- and long-term) in which they will

first start to make an impact. Some activities will provide a crucial or new impact in a specific period, though they may occur during all the time phases of the program. For example, because of the long time frames involved, research and development on silviculture energy farming must be started now, although significant energy impacts will not come until after 2000. It is intended that this type of approach will bring out different opportunities and obstacles associated with biomass energy contributions in various time frames.

Near-term biomass energy strategy is to provide technology and marketing support to applications that are economically competitive or nearly competitive. This will include:

- Engineering development and support
- "Product support" to make technologies more competitive
- General technical expertise and planning support towards commercialization
- Information transfer to industry and public
- Support requiring environmental investigations to mitigate environmental problems

Mid-term energy strategy will primarily continue to identify markets and biomass technologies which have the most potential for additional displacement of conventional fuels. Biomass feedstocks that can be converted into fuel and chemical feedstocks by a variety of thermochemical and biochemical techniques will be further developed. The principal strategic element related to this mid-term area will:

- Continue to improve systems and market analysis to identify particular market opportunities.
- In particular, look for more complex chemicals produced by "biomass refining" which could displace petrochemicals.
- Identify the limitations on the use of biomass residue and wastes as resources.
- Continue development of a range of conversion technologies.
- Investigate contributions of decentralized small-scale potential biomass energy conversion.

Long-term biomass energy strategy includes providing a technological base for "energy farming" of herbaceous, silviculture and aquatic species which are not presently grown on any large scale. This strategy calls for:

- Developing a strong basic and applied research program.
- Encouraging laboratory-scale experiments for developing information for establishing large-scale facilities.
- Focusing long-term R&D efforts at SERI and universities.
- General management strategies, including broad involvement and coordination among government groups, industrial organizations, and consumer and user groups.

Participants

The participants in the Biomass Energy Systems Program are the following (no order of importance):

- Federal, state and local government agencies
- General industry
- Engineering companies
- Expert associations and consulting groups
- Universities
- National and private laboratories
- Specific interest groups such as farm cooperatives

TECHNICAL STATUS

Technology Development and Applications

This element supports technology and engineering development and environmental research for biomass applications expected to be competitive by 1985. Support under this program is directed towards three areas of anticipated biomass application: combustion systems, on-farm biomass conversion systems and alcohol production systems.

● Combustion Systems

The direct combustion sub-element supports process improvements and demonstration of the direct burning of wood or wood residues for increased use in the industrial process heat, electricity, residential and industrial markets. Associated with the development of direct combustion are related technologies, including low-Btu gasification and wood densification. While the use of wood for direct combustion is ages old, economical use requires resolution of several issues. Such issues include: assessing the availability of wood and wood residues; harvesting and collection technology; fuel upgrading, such as the use of the dessicated chips or pellets (densification); and the environmental effects of residue collection and direct burning.

● On-Farm Biomass Conversion Systems

These activities are conducted in collaboration with the USDA and SERI. The technologies identified under this sub-element include anaerobic fermentation of manure and agricultural residues to produce low- and medium-Btu gas and direct

combustion of crop residues to produce heat. The energy derived from these technologies will be directed towards the agricultural market to meet process and residential heat and electricity requirements. Although technologies of both processes are well understood, they are only marginally competitive as commercial energy sources. During FY 79, management of the anaerobic digestion program was transferred to SERI.

Among the projects underway is an experimental anaerobic digestion facility on a 10,000 head cattle feedlot in Bartow, Florida. The projected production of the gas would be enough to provide nearly all of the energy required for the feedlot and its slaughter and packing plant. As part of another project at Cornell, a simplified digester design, suitable for small dairy farms, is being developed.

● Alcohol Production Systems

The activities under this program are aimed at improving the process efficiency of current fermentation technologies without increasing the unit cost and the use of higher yield sugar crops (e.g., sweet sorghum) to replace more expensive feedstocks such as corn. Recently within DOE, the lead management responsibilities for production and use of alcohol fuels from renewable resources have been shifted to the newly created Office of Alcohol Fuels.

Ongoing activities under this sub-element include studies on production, harvesting, processing and conversion systems for sugarcane and sweet sorghum at universities and USDA research stations in a number of states in northern and central United States. Other activities

include assessment of the feasibility of installing an integrated facility for production and conversion of biomass to ethanol, using the latest off-the-shelf fermentation technology suitable for a fermentable crop production system.

Production Systems

The goal of this program element is to expand the biomass energy resource base beyond the existing residue feedstocks by producing the large and varied supply necessary for the conversion technologies expected to enter the market in the mid-term. A comprehensive systems study has concluded that at least 30 million of the nation's 1.3 billion acres of grasslands and forests could be made available for wood energy farms with an estimated productivity of 5-13 dry tons per acre per year depending upon species and site selection. The concepts of silvicultural, herbaceous and aquatic energy farms are, therefore, being investigated.

Efforts are being aimed at species identification, selection and potential for modification; determination of species specific production requirements; and development of crop management techniques and improvements for intensive biomass production.

● Silvicultural

The silvicultural sub-element of the production program includes field studies, test plots and test farms necessary to expand the forest resource base potentially available as biomass feedstocks from forest residues to silvicultural energy farms. Current efforts by the U.S. Forest Service, various universities and private industry are directed toward the isolation of species that

provide maximum energy content at minimum cost, including all outlays associated with growing the resource and delivery to the conversion points (e.g., harvesting, collecting, and storage). Two regional silvicultural energy farms of about 1200 acres each are planned. These farms are designed to evaluate the technical and economic feasibility of growing an assured supply of biomass in different parts of the country. To assist the development of energy farms, supporting contracts have been made with 27 universities, small business and industry across the nation to evaluate desirable species, determine optimum production systems and develop harvesting and transportation systems. Other silviculture efforts include the development of harvester machinery to achieve the most cost effective means of collecting woody biomass.

Several issues need further investigation. Among these are the cumulative environmental effects of an expanded silvicultural energy farming in the nation and optimal roles to be played by the public and private sectors in this effort.

● Herbaceous

Activities in the herbaceous research sub-element are focused on production of non-woody crops that are easily converted into liquid or gaseous fuels. The research objectives of herbaceous plants are similar to those for wood plants. These objectives include the selection of the most promising species, crop site preparation, establishment of growing stock, and appropriate management techniques to obtain optimal yields in terms of economics and energy production. Current tasks include the impact of row spacing, nitrogen fertilization, irrigation and frequency of harvest on the

yields of sugarcane and sweet sorghum crops.

Conversion Systems

The objective of this element is to establish and develop technologies capable of converting biomass feedstocks into clean fuels, petrochemical substitutes and other energy intensive products for market penetration before the year 2000. This element is organized by biochemical and thermochemical processes. The biochemical processes, both fermentation and anaerobic digestion, use micro-organisms to produce fuels and chemicals from biomass feedstocks. The thermochemical processes include gasification and liquefaction and employ a combination of catalysts, chemical reactants, high temperature and pressure to produce fuels and chemicals.

● Biochemical Conversion -Anaerobic Digestion

The objective of this sub-element is to increase the resource base for anaerobic digestion to produce methane, using manures and agricultural residues as feedstocks. Research is underway to develop pretreatment methods, establish data on gas yields for various feedstocks and to confirm process economics. One such study is on an environmental feedlot in Bartow, Florida, and is designed to determine the systems' cost of medium-scale anaerobic fermentation facilities as well as to demonstrate the use of a gas and protein-rich effluent. The gas is supplied to a nearby meat packing plant. Another project at Cornell is designing a simplified digester for on-farm use. Planned projects will

emphasize system studies of agriculture residue collection and use as a source of energy for agricultural processing. Development of a small-scale anaerobic digestion demonstration unit will be carried out in close cooperation with the USDA.

● Biochemical Conversion -Fermentation

The objective of this sub-element is to develop the technology to convert agricultural and forest residues and wood energy crops into ethanol. Currently, agricultural grains and sugar crops have been the feedstocks of choice, since they are more easily decomposed. Lignin-containing residues must undergo pretreatment before the anaerobic fermentation process can take place. Pretreatment involves additional costs that have an impact on the overall economics of conversion. Current efforts are concentrated on developing commercially feasible pretreatment and hydrolysis processes which yield fermentable sugars from woody materials. These investigations include acidic and enzymatic hydrolysis techniques. To scale-up laboratory designs, the Georgia Institute of Technology has completed a conceptual design of a process development unit (PDU) that will convert 3 oven-dry tons per day of lignocellulosic biomass residues (e.g., hardwood, corn stover and wheat straw) into ethanol. Various technical and economic parameters will be evaluated in an attempt to develop a commercial process for producing ethanol from lignocellulosic materials. Efforts will be made to bring the price of woody ethanol in line with ethanol from grains and sugar crops.

- Thermochemical Conversion - Gasification and Indirect Liquefaction

The aim of this sub-element is to develop a technology capable of producing synthesis gas or a medium Btu gas from biomass. This gas can be burned as a fuel or used as an intermediate for synthesis into fuels or energy intensive chemicals including SNG, methanol, ammonia, or petrochemical substitutes.

Several PDU scale studies are currently operational or soon to be on stream. Most vary from 0.5 to 3.0 tons per day with one unit capable of achieving 25 oven dried tons per day. In FY 79, one such study at the University of Missouri PDU at Rolla completed shakedown tests for gasification of 2.4 to 24 oven dry tons of wood per day. The gas produced showed an energy content of 150-200 Btu/scf.

Progress was also reported on catalytic gasification methods for wood gasification. This is likely to reduce the plant investment costs by 15-40 percent, while the overall process efficiency may be increased by 5-15 percent.

In FY 80, among the other gasification activities, efforts will continue to collect data on a large experimental facility (LEF) capable of handling 300 oven dried tons per day. This facility is large enough to establish data on the availability and costs of supplying the required biomass feedstocks, evaluate the reliability of PDU derived data, establish the cost of the gas and establish the basis for comparing the system to other means of energy production.

- Thermochemical Conversion - Direct Liquefaction

In the liquefaction process, biomass is converted to oil by reaction

with syngas (carbon monoxide and hydrogen) and catalysts under high temperature and pressure. This oil is of low grade and is suitable for use in turbines and as a boiler fuel. Research for upgrading the oil may identify other end uses.

Issues for this technology center on the cost of the fuel oil and the conversion efficiency and productivity of the liquefaction process. Different mixes of operating temperatures and pressures are under study to identify both a range of energy process inputs and the product mix.

Current liquefaction activities consist of the operation of the Albany wood-to-oil PDU and other supporting R&D activities. The Albany facility permits the testing of various raw materials and process conditions. The facility is being managed by Wheelabrator Cleanfuels, and in FY 79 this facility, using a pre-hydrolysis technique developed at Lawrence Berkeley Laboratories (LBL) started producing wood oil. The data collected will be used for the conceptual design of a large facility capable of using 1000 ODT/day of feedstocks.

Research and Exploratory Development

This element of the BES Program is responsible for identifying and investigating areas of long-range R&D which will contribute new and innovative production and conversion technologies expected to make major contributions after the year 2000. These research activities are expected to establish a framework within which existing energy technologies can be expanded and developed to allow the full potential contribution of fuels and chemicals from biomass. Specific areas of study are advanced biochemical conversion systems (anaerobic digestion, fermentation and biophotolysis), plant improvement,

development of exotic plants for the production of hydrocarbons and biomass production from land-based aquatic systems.

- Innovative Conversion Systems

This sub-element includes research in such technical areas as the development of a strain of micro-organisms capable of single step fermentation of lignocellulosic materials into alcohols, as well as innovative techniques of converting woody biomass by anaerobic digestion into synthetic natural gas and medium Btu gas. Another example is the applied research underway at the University of California and the Solar Energy Research Institute in biophotolysis, a process using selected algal species in the presence of sunlight to generate hydrogen.

- Advanced Feedstock Development

Projects supported in advance feedstock development include the breeding and evaluation of exotic crops such as the latex-bearing plants, as well as applied research on plant improvement. Further research for development and selection of new plant varieties for use in biomass conversion will be based on the established genetic research techniques.

- Aquatic Systems

This sub-element includes applied and exploratory research for the development of aquatic resources and advanced conversion technologies. Marine and freshwater resources are considered significant because of their high growth rate and conver-

sion efficiency relative to terrestrial biomass resources. Present aquatic production studies include a detailed physiological study of the growth of giant kelp, an investigation of filamentous algal growth in ponds, an engineering design analysis of growing and harvesting algal biomass in a 10-square-mile system and an investigation of the cultivation of macroscopic marine algae and freshwater aquatic weeds.

- Support and Other Activities

The support element in the BES Program is designated to perform systems studies and environmental assessments in the course of providing general support. The initial mission has been completed for the biomass technology development programs. Market penetration projections have concluded that nineteen specific biomass technology applications could penetrate the market before the year 2020. This is a continuing effort, since technologies and potential markets for their application are continually changing. Environmental and resource assessments will receive other major portions of the support role. Environmental assessments will be scheduled in close conjunction with technology development.

Additional activities performed under this program element include program management, program planning, preparation and evaluation of program solicitations, and participation in technical evolutions of the program as well as coordination and monitoring. A data bank on the cost of biomass production and conversion systems is being developed.

BIOMASS APPLICATIONS

Biomass has large potential to displace or supplement many fossil fuels and chemical markets because of its adaptability to current energy needs. Various biomass conversion technologies are currently being developed by BES Program to meet energy needs. Almost all of these technologies are well suited for decentralized markets which are rich in biomass and remote from conventional and sometimes interruptible energy supplies. Currently, three conversion technologies--direct combustion, anaerobic digestion and fermentation--are commercial or near-commercial with specific feedstocks and in specific markets. These technologies have found several applications in the private sector, without any government assistance. With the price of conventional fuels rapidly escalating, these technologies are likely to be developed to their maximum potential and use applications. Examples of present usages include

combustion of wood mill wastes in the forest products industry, the ever-increasing marketing of gasoline/ethanol blends (gasohol) at service stations nationwide, and small-scale on-farm fermentation and anaerobic digestion.

In an attempt to accelerate the commercialization phase, the BES Program plans to continue industry involvement via its various resource managers, in all its research and development activities. Coordinated cost-shared and cooperative projects will receive higher priorities with the clear goal of commercialization. As technologies move into commercialization, efforts will continue to improve the economics, efficiency, safety, reliability and environmental acceptability of various biomass energy systems. Moreover, appropriate action would be recommended to overcome any emerging barriers and constraints.

ORGANIZATIONAL AND FUNCTIONAL RESPONSIBILITIES

The Division of Biomass Energy Systems Branch of the Department of Energy manages the Biomass Energy Systems (BES) Program. The branch is a part of the Office of Solar Applications for Industry. Moreover, at the time of the writing of this docu-

ment, as per the President's directives, a separate office of Alcohol Fuels was being established with the lead responsibilities for all department matters relating to alcohol fuels from biomass.

PROGRAM FUNDING

In FY 80, the program and funding levels (Table 1) will continue to match regional biomass energy feedstocks with regional and national energy related needs. Various biomass conversion technologies will be used where applicable to match these needs. Emphasis will be placed on developing new products such as chemicals from biomass to replace oil derived chemicals. New efforts will be

initiated to produce higher yields of biomass and to identify innovative, integrated and efficient conversion processes. Decentralized, small-scale biomass utilization and conversion systems will receive increased attention. Moreover, integrated systems will be evaluated and developed to maximize their near-term contribution.

Table 1
Summary of Baseline Funding for the Biomass Energy Systems Program

Program Element	FY 1978	FY 1979	FY 1980*
	\$ 000		
Technology Development and Applications	0	16,200	7,500
Production Systems	6,720	4,300	7,900
Conversion Systems	12,435	15,900	9,600
Research and Exploratory Development	0	4,700	8,000
Support and Other	1,085	1,400	0
Total Operating Cost	20,240	42,500	33,000
Total Capital Equipment	3,000	0	500
Total Program Cost	23,240	42,500	33,500

*Excludes \$22 million for alcohol fuels

PROJECTED CONTRIBUTIONS OF FISCAL YEAR 1979
BIOMASS PROJECTS LISTED ACCORDING TO PROGRAM
ELEMENT AND SUB-ELEMENT

Program Element: Technology Support

The goal of the Technology Support program element is to provide technical expertise and support, systems demonstration, and environmental research support for biomass conversion systems in order to achieve commercial competitiveness by 1985.

● Program Sub-Element: Direct Combustion Systems

The goal of the Direct Combustion Systems sub-element is the development and demonstration of direct combustion of wood and wood residues to produce industrial process heat, electricity, and residential heat.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
A-1	Wheelabrator Cleanfuel Corp. (Rust Engineering) Birmingham, Alabama	Advanced System Demonstration for Utilization of Biomass as an Energy Source	Determine the availability and cost of biomass feedstocks, and demonstrate the feasibility of utilizing forest residues and trees to produce steam and electric power in a cogeneration mode.
A-2	Aerospace Research Corp. Roanoke, Virginia	Development of Wood as an Alternative Fuel for Large Power Generation Systems	Provide the data for the design and fabrication of a prototype combustion module which will generate the design information for the retrofitting of large-scale oil- and gas-fired boiler systems to burn wood.

Program Element: Technology Support

The goal of the Technology Support program element is to provide technical expertise and support, systems demonstration, and environmental research support for biomass conversion systems in order to achieve commercial competitiveness by 1985.

● Program Sub-Element: On-Farm Systems

The goal of On-Farm Systems activities is to pursue the development and demonstration of anaerobic digestion of manures to produce medium- to high-Btu gas, and the direct combustion of crop residues to produce heat and low-Btu gas.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
B-1	Hamilton Standard Division United Technologies Corp. Windsor Locks, Connecticut	Fuel Gas from an Environmental Beef Cattle Feedlot	Produce fuel gas and other products from animal residues, and promote commercialization of the process.
B-2	U.S. Department of Agriculture Clay Center, Nebraska	Anaerobic Fermentation of Beef Cattle and Animal Residues	Recover high protein biomass and methane from beef cattle manure and crop residues through anaerobic digestion.
B-3	Cornell University Ithaca, New York	Anaerobic Fermentation of Agricultural Wastes--Potential for Improvement and Implementation	Develop and improve economic and technical factors which would lead to widespread implementation of digesters to produce biogas on small-scale agricultural operations.
B-4	Ecotope Group Seattle, Washington	Monitor, Test, and Evaluate an Operational Fermenter for 350 Cattle Units	Optimize digester performance in terms of net energy and operation time for full-scale dairy farm operations.
B-5	Dynatech R/D Co. Cambridge, Massachusetts	Engineering Evaluation of Programs in the Area of Methane from Residues/Biomass	Evaluate various methods of methane production and monitor technical anaerobic digestion projects.

Program Element: Technology Support

The goal of the Technology Support program element is to provide technical expertise and support, systems demonstration, and environmental research support for biomass conversion systems in order to achieve commercial competitiveness by 1985.

o Program Sub-Element: Alcohol Production Systems

Alcohol Production Systems activities are focusing on improving process efficiency of current fermentation technology and the use of higher yield sugar crops such as sweet sorghum.

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<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
C-1	Louisiana State University Baton Rouge, Louisiana	The Potential for Producing and Harvesting Sugar Cane and Sweet Sorghum as a Renewable Biomass Energy Resource	Develop harvesting machinery necessary to increase yields of sugar cane and sweet sorghum as energy crops.
C-2	Science Applications, Inc. McLean, Virginia	Development of Alternative Concepts for the Conversion of Biomass Energy Resources to Methanol	Evaluate alternative concepts for the conversion of biomass to methanol and the commercialization of biomass-based methanol productions.
C-3	U.S. Department of Agriculture Houma, Louisiana	Sugarcane Spacing Study and High-fiber Sugarcane Selection	Evaluate the effects of various agronomic parameters on the yield of sugarcane and breed and select high fiber sugarcane for energy production.
C-4	U.S. Department of Agriculture Meridian, Mississippi	Sweet Sorghum Energy Research	Evaluate yield and quality of sweet sorghum cultivars and increase seed supplies for energy research.
C-5	Battelle Columbus Labs. Columbus, Ohio	Biomass Production from Sugarcane and Sweet Sorghum	Evaluate methods of increasing the availability and reducing the cost of fermentable sugars to be converted to liquid fuels, leading to decisions on utilization of sweet sorghum and sugarcane.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
C-6	Battelle Columbus Labs. Columbus, Ohio	Evaluation of Feasibility of Sequential Fermentation for the Production of Ethanol	Identify yeast strains with ethanol tolerance or asmo-tolerance and reduce to practice an invention of a sequential semi-continuous fermentation process.
C-7	Stanford Research Institute (SRI) Menlo Park, California	An Evaluation of the Natick Enzymatic Hydrolysis Process for Use in the Production of Ethanol from Municipal Solid Waste (MSW) and from Wood	Evaluate techno-economic evaluation of Natick Enzymatic hydrolysis process using consistent sets of economic and design criteria developed previously by SRI.
C-8	Battelle Columbus Labs. Columbus, Ohio	Carbohydrate Crops as a Renewable Resource for Fuels Production	Evaluate the feasibility of using carbohydrate crops as a source of energy.
C-9	The MITRE Corporation McLean, Virginia	Biomass-Based Alcohol Fuels	Conduct two studies: the first to determine the potential of implementing a nationwide biomass-derived alcohol/gasoline fuel system and, the second to compare economic aspects of 28 ethanol facilities.

Program Element: Production Systems

The goal of the Production Systems is to expand the biomass energy resource base by developing specific species and management techniques for intensive biomass energy production. These efforts will focus on production systems which can make an impact before the year 2000.

● Program Sub-Element: Silviculture

Under the Silviculture sub-element, species screening studies, field test plot studies, regional silviculture energy farms, harvester development, and supporting research studies are aimed at maximizing crop yields while minimizing production cost of silvicultural biomass.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
D-1	Alabama A&M University Normal, Alabama	Recovery of Above-Ground Woody Biomass (Logging Residue) Using Operational Modifications of a Conventional Harvesting System	Modify conventional harvesting systems to economically remove and utilize presently unmerchantable woody biomass.
D-2	Garrett Energy Research and Engineering Co. Ojai, California	Woody Biomass Species for Fuel Production	Optimize growth of salt cedar and tamarisk shrubs under the influence of saline water and under intensive management techniques.
D-3	University of California Riverside, California	Collection, Propagation, and Evaluation of <u>Prosopis</u> Species for Growth Rate Under Controlled Moisture and Nitrogen Treatments	Determine vegetative propagation techniques for mesquite and identify genotypes with greater growth rates, higher heat tolerances, and cloning capabilities.
D-4	Stanford Research Institute Menlo Park, California	Water and Land Availability for Energy Farming	Evaluate the physical and economic availability of land and water resources for energy farming.
D-5	University of Florida Gainesville, Florida	Energy and Chemicals from Woody Species in Florida	Optimize growth and yield of <u>Melaleuca</u> , <u>Eucalyptus</u> , and <u>Pinus</u> on infertile sandy soils.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
D-6	University of Georgia Athens, Georgia	Increasing the Biomass Production of Short-Rotation Coppice Forests	Obtain high-yield biomass production from Sycamore, Sweetgum, and Alder trees in field trials.
D-7	Emory University Atlanta, Georgia	Screening of Non-Commercial Woody Plants as Biomass Fuel Producers	Identify and field test woody plant species suitable for fuel production on marginal soils of the Southern Piedmont and Upper Coastal Plain.
D-8	Bio-energy Development Corporation, Hilo Hawaii	Eucalyptus Plantations for Energy Production in Hawaii	Increase biomass production through intensive cultural treatments and evaluate a complete production collection, conversion system in relation to costs.
D-9	University of Illinois Urbana, Illinois	Woody Biomass Production for Solar Energy Conversion	Optimize production of Sycamore, autumn Olive, Alder, and eastern Cottonwood on marginal lands in central and southern Illinois.
D-10	Purdue Research Foundation W. Lafayette, Indiana	Species Selection for Woody Biomass Plantations on Reclaimed Mineland	Select species which show the greatest potential for use in silviculture energy farms.
D-11	Kansas State University Manhattan, Kansas	Great Plains Energy Forest Study	Optimize growth and yield of Cottonwood, Black Locust, and Catalpa on under-utilized land in Kansas.
D-12	University of Kentucky Lexington, Kentucky	Production of Black Locust Biomass on Surface-Mined Sites in the Southern Appalachians	Determine optimum management strategies to produce Black Locust on silviculture energy farms.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
D-13	U.S. Department of Agriculture New Orleans, Louisiana	Construction and Field Trials of a Prototype Forest-land Residue Machine (Mobile Hog) to Harvest Fuel from Forest Residues or from Energy Plantations	Evaluate a prototype harvesting machine designed to collect forest residues to be utilized as a fuel.
D-14	University of Massachusetts Amherst, Massachusetts	Assessment of Tree-Harvesting Machinery for Non-Commercial Timber	Evaluate current, commercially available wood chippers with consideration of their use in harvesting systems on problematic terrain and submarginal timber stands.
D-15	University of Minnesota Minneapolis, Minnesota	Use of Wetlands for Production of Woody Plants for Fuels and Petrochemical Substitutes	Select suitable species and determine their establishment, management, and productivity problems on wetland soils.
22 D-16	U.S. Forest Service St. Paul, Minnesota	Establishment of Populus Energy Plantations	Establish field plots to determine optimal stand establishment and management strategies for using hybrid poplar in energy farms.
D-17	Michigan State University, East Lansing Michigan	Tree Species and Management Strategy for Biomass Production in the Lake States	Determine species and management strategies to optimize growth on predominantly marginal sites in the North Central U.S.
D-18	Michigan Technological University Houghton, Michigan	Application of Sugar Maple and Black Locust to the Biomass Energy Farm Concept	Convert pole-sized sugar maple stands into short-rotation energy farms using coppice as a regeneration technique.
D-19	Mathtech, Inc. Princeton, New Jersey	Harvesting of Close-Spaced Short-Rotation Woody Biomass	Evaluate alternative strategies and techniques of harvesting which appear commercially viable for use on closely spaced short-rotation biomass farms.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
D-20	General Electric Co. Syracuse, New York	Energy Biomass Production Study	Optimize seedling growth in controlled environments to supply silviculture energy farms with planting stock.
D-21	North Carolina State University Raleigh, N. Carolina	Economics and Operating Characteristics of Various Handling Systems and Wood Fuels in Small- to Medium-Sized Boiler Facilities	Evaluate economics of harvesting, collection and transportation of wood fuels for use in wood boilers.
D-22	North Carolina State University Raleigh, N. Carolina	Species Selection and Silvicultural Systems for Producing Fuels from Woody Biomass in the Southeastern United States	Determine optimum silvicultural systems for maximizing energy yields using species most suitable for short-rotation management.
D-23	U.S. Forest Service Asheville, N. Carolina	Fuel Farm Research (Chemically Induced Oleoresin as a Petro- chemical Substitute)	Increase chemically induced lightwood formation in Pines and test commercial scale processing.
D-24	Pennsylvania State University University Park, PA	Feasibility of Using Municipal Wastewater and Waste Heat to Maximize Biomass Production in Energy Plantations	Maximize the production of hybrid Poplars using waste water for irrigation and waste heat for soil warming of energy farms.
D-25	Pennsylvania State University University, PA	Energy Sensitivity and Variability Analysis of <u>Populus</u> Hybrid Short-Rotation Energy Plantations in the Northeastern United States	Recommend management strategies for the growth of hybrid Poplars based on overall energy analysis.
D-26	Oak Ridge National Laboratory Oak Ridge, Tennessee	Management Support to the Fuels from Woody Biomass Program	Provide technical management support to DOE in the areas of species screening, stand establishment, and management strategies.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
D-27	University of Houston Houston, Texas	Cultural and Management Practices for the Chinese Tallow Tree as a Biomass Fuel Source	Optimize growth of Chinese tallow on marginal or non-agriculture lands, and in plantations and natural stands.
D-28	Energy Foundation of Texas Houston, Texas	Cultural and Management Practices for the Chinese Tallow Tree as a Biomass Fuel Source	Develop technology for woody biomass fuel production from species adapted to the poorly drained areas such as Texas coastal plains.
D-29	Utah State University Logan, Utah	Selection of High Producing Shrubs of the Western United States for Energy Biomass Production	Propagate and measure productivity of selected shrub biotypes for use as an energy feedstock under low cost cultural treatments.
D-30	University of Vermont Burlington, Vermont	Production of Biomass for Energy on Abandoned Farmlands in the Northeast	Demonstrate the potential for intensive short-rotation energy farming of hardwood species in the Northeast.
D-31	The MITRE Corporation McLean, Virginia	Near-term Use of Wood as a Fuel	Compare commercially available technologies for converting wood into usable forms of energy.
D-32	Virginia Polytechnic Institute and State University Blacksburg, Virginia	An Integrated Investigation of Procurement, Harvesting, Drying, Transportation, and Storage of Woody Biomass	Evaluate, mathematically and experimentally, alternative handling strategies to assist decisionmaking and to highlight the tradeoffs.
D-33	Washington State University, Pullman, Washington	Evaluating and Modelling Tree Biomass Yields from Small-Diameter Conifer Stands in the Inland Northwest	Provide biological data and simulation models for accurate assessments of energy potential in forest stands in the inland Northwest.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
D-34	University of Washington and Washington State University Pullman, Washington	Evaluation and Genetic Improve- ment of Black Cottonwood for Short-Rotation Coppice Culture	Identify superior clones of <u>Populus</u> <u>trichocarpa</u> and its hybrids with <u>P. deltoides</u> for fuel and for chemical uses.
D-35	Seattle City Light Seattle, Washington	Cultural Treatment of Selected Species for Woody Biomass Fuel Production in the Pacific North- west	Evaluate the performance of Red Alder and black Cottonwood under intensive management at different sites.

Program Element: Production Systems

The goal of the Production Systems program element is to expand the biomass energy resource base by developing specific species and management techniques for intensive biomass energy production. These efforts will focus on production systems which can make an impact before the year 2000.

● Program Sub-Element: Herbaceous

The projects supported under the Herbaceous sub-element include species screening studies and herbaceous energy farming.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
E-1	University of Puerto Rico San Juan, Puerto Rico	Production of Sugarcane and Tropical Grasses as a Renewable Energy Source	Determine the agronomic and economic feasibility of mechanized, year-round production of sugarcane and napier grass, as well as screen and breed desirable energy crop progeny.
E-2	Arthur D. Little Co. Cambridge, Massachusetts	Herbaceous Species Screening Program - Phase I	Identify previously unexploited terrestrial annual and perennial herbaceous plants for use on energy farms.

Program Element: Conversion Systems

The goal of the Conversion Systems program element is to establish technologies which can convert biomass into clean fuels, petrochemical substitutes, and other energy-intensive products. Emphasis will be placed on the production of those products which have the potential to make market impacts before the year 2000.

● Program Sub-Element: Anaerobic Digestion

The goal of research efforts within the Anaerobic Digestion sub-element is to broaden the resource base for anaerobic digestion beyond manures, namely the utilization of agricultural and forest residues to produce Synthetic Natural Gas (SNG).

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
F-1	University of Illinois Urbana, Illinois	Biological Conversion of Biomass to Methane	Obtain experimental data on conversion efficiency to predict the cost of methane produced from various organic feedstocks, including corn stover and wheat straw.
F-2	Dynatech R/D Co. Cambridge, Massachusetts	Feasibility Study of Anaero- bic Digestion of Agricultural Crop Residues	Determine cost estimates for pretreatment/ digestion of crop residues to fuel gas.

Program Element: Conversion Systems

The goal of this program element is to establish technologies which can convert biomass into clean fuels, petrochemical substitutes, and other energy-intensive products. Emphasis will be placed on the production of those products which have the potential to make market impacts before the year 2000.

● Program Sub-Element: Fermentation

The objective of the Fermentation sub-element is to concentrate primarily on the utilization of agricultural and forest residues to produce ethanol. Emphasis is placed on developing pretreatment and hydrolysis techniques which increase the yield of fermentable sugars from lignocellulosic materials, optimizing processes for ethanol production, and investigating other fermentation processes.

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<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
G-1	Auburn University Auburn, Alabama	Acid Extraction of Hemi-celluloses from Biomass	Extract hemicelluloses from biomass in high yields in order to extract better quantities of fuels and petrochemical substitutes.
G-2	University of Connecticut Storrs, Connecticut	Immobilization of Beta-Glucosidase	Improve the hydrolysis step in the enzymatic conversion of cellulose to sugars for fermentation of alcohol.
G-3	Iotech Corporation Ottawa, Canada	Explosive Decompression of Lignocellulosic Biomass	Improve physical pretreatment for breaking the crystallinity of cellulose in order to increase sugar yields.
G-4	University of California Lawrence Berkeley Lab. Berkeley, California	Bioconversion of Cellulose and Production of Ethanol	Produce ethanol from fermentable sugars derived from the enzymatic hydrolysis of lignocellulosic biomass.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
G-5	Purdue University W. Lafayette, Indiana	Selective Solvent Extraction in Utilization of Solar Energy in Cellulosic Biomass	Develop selective solvents for the fractionation of cellulose, hemicellulose, and lignin components of lignocellulosic waste material.
G-6	Dartmouth College Hanover, New Hampshire	Acid Hydrolysis of Concentrated Slurries of Cellulosic Biomass	Optimize glucose yields from the acid hydrolysis of lignocellulosic biomass.
G-7	Rensselaer Polytechnic Institute Troy, New York	Fuels and Petrochemical Substi- tutes from Fermentation of Biomass	Perform technical monitoring and coordination of fermentation research and development.
G-8	Battelle Columbus Labs. Columbus, Ohio	Evaluation of the Feasibility of Sequential Fermentation for Production of Ethanol	Evaluate the feasibility of sequential, semi-continuous fermentation concept, in which different strains of yeast perform specialized functions within the overall process of converting sugars to ethanol.
G-9	University of Pennsylvania Philadelphia, Pennsylvania	Increasing the Efficiency of Ethanol Fermentation	Evaluate a method of ethanol removal during fermentation in order to prevent it from producing inhibitory effects.

Program Element: Conversion Systems

The goal of the Conversion Systems program element is to establish technologies which can convert biomass into clean fuels, petrochemical substitutes, and other energy-intensive products. Emphasis will be placed on the production of those products which have the potential to make market impacts before the year 2000.

● Program Sub-Element: Thermochemical -- Gasification and Indirect Liquefaction

The goal of the Gasification sub-element is to develop technology to produce medium-Btu gas (MBG) from biomass. A key issue is to select market applications in which biomass gasification-derived products can compete with products derived from large-scale oil, natural gas, or coal facilities.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
H-1	Catalytica Associates, Inc., Santa Clara, California	Catalytic Conversion of Biomass to Fuels	Review potential biomass conversion processes, identify key problems, and conduct a detailed assessment of the role of catalysts in the conversion of biomass.
H-2	Garrett Energy Research and Engineering Co., Ojai, California	Thermal Conversion of Biomass Materials into Medium Btu Gas	Demonstrate the feasibility of gasifying biomass materials in a specially designed multiple-hearth reactor.
H-3	Gorham International, Inc. Gorham, Maine	An Assessment of Technical and Economic Feasibility of Converting Wood Residues to Liquid and Gaseous Fuel Products Using State-of-the-Art and Advanced Coal Conversion Technology	Determine which coal gasification processes can be used most advantageously for the conversion of biomass to liquid and gaseous fuels.
H-4	Wright-Malta Corp. Ballton Spa, New York	Steam Gasification of Biomass	Develop and quantify process parameters for the gasification of biomass using a rotary-kiln gasifier.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
H-5	Battelle Columbus Laboratories Columbus, Ohio	Conversion of Forest Residues to a Methane-Rich Gas	Develop the design base for a high throughput, catalytic reactor to convert wood residues to MBG.
H-6	Gilbert Associates, Inc. Reading, Pennsylvania	Research and Evaluation of Biomass Resources Conversion - Utilization Systems (Market/Experimental Analysis for Development of a Data Base for Fuels from Biomass Model)	Develop a linear programming model which will be useful in determining the most profitable combination of biomass feedstocks and conversion processes to produce a desired fuel. Characterize at least 100 typical biomass feedstock materials.
H-7	Texas Tech University Lubbock, Texas	Application of SGFM Technology to Other Feedstocks (Phase II)	Optimize production of synthesis gas from manure and other biomass feedstocks, including woody and corn stover.
H-8	Battelle Pacific Northwest Laboratories Richland, Washington	Investigation of Gasification of Biomass in the Presence of Catalysts	Investigate the technical and economic feasibility of achieving the complete gasification of biomass using a catalyst and a special feed gas composition.

Program Element: Conversion Systems

The goal of the Conversion Systems program element is to establish technologies which can convert biomass into clean fuels, petrochemical substitutes, and other energy-intensive products. Emphasis will be placed on the production of those products which have the potential to make market impacts before the year 2000.

● Program Sub-Element: Thermochemical -- Liquefaction

The goal of the Liquefaction sub-element is to develop technology for converting biomass directly into liquid fuels.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
I-1	University of Arizona Tucson, Arizona	Modified Extruder for Feeding Fine-Ground Cellulosic Slurries to Pressure Systems	Demonstrate the feasibility of a modified screw extruder for feeding biomass into a pressurized reactor for use in the Albany, Oregon, pro- cess development unit (PDU).
I-2	University of California Lawrence Berkeley Laboratory Berkeley, California	Catalytic Liquefaction of Biomass	Assess the technical and economic feasibility of converting lignocel- lulosic materials into liquid fuels in support of the Albany facility.
I-3	Wheelabrator Cleanfuel Corporation Washington, D.C.	Operation of the Biomass Liquefaction Facility at Albany, Oregon	Obtain definitive process informa- tion, sufficient for commercial design and economic evaluation pur- poses, for the conversion of biomass to fuel oils.
I-4	Battelle Pacific North- west Laboratory Richland, Washington	Bench-Scale Research in Biomass Liquefaction in Support of the Albany, Oregon, Experimental Facility	Determine process changes, and pro- vide routine and specialized analy- tical support to facilitate fuel oil production at the Albany Biomass Liquefaction Experimental Facility (PDU).

Program Element: Research and Development (R&D)

The goal of the Research and Development element is to identify and investigate those biomass production and conversion technology R&D areas which are expected to contribute to the energy supply after the year 2000.

● Program Sub-Element: Innovative Conversion

The emphasis of the Innovative Conversion sub-element is on advanced biochemical processes and photo-electrolysis.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
J-1	Stanford University Stanford, California	Heat Treatment of Organics for Increasing Anaerobic Biodegradability	Increase the yield and reduce the cost of methane gas from the anaero- bic digestion of cellulosic biomass.
J-2	University of California Berkeley, California	Solar Energy Conversion Through Biophotolysis	Determine the feasibility of using nitrogen-fixing heterocystous blue- green algae in solar energy con- verters to produce hydrogen by bio- photolysis of water.
J-3	Dynatech R/D Co. Cambridge, Massachusetts	Liquid Hydrocarbon Fuels Production from Biomass	Produce acetic acid and other pro- ducts from biomass feedstocks based on controlled anaerobic fermentation.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
J-4	Massachusetts Institute of Technology Cambridge, Massachusetts	Degradation of Cellulosic Biomass and Its Subsequent Utilization for the roduction of Chemical Feedstocks	Degrade cellulosic biomass and convert it directly to ethanol.
J-5	Exxon Research and Engineering Co. Linden, New Jersey	Sensitized Photoelectrolysis of Water with Sunlight	Use heterogeneous catalyst for the sensitized photodecomposition of water to oxygen and hydrogen.
J-6	Rutgers University New Brunswick, New Jersey	Producing Mutants of <u>Trichoderma viride</u>	Produce higher yields of cellulase enzymes through the development of mutant strains of <u>Trichoderma</u> .
J-7	University of Pennsylvania Philadelphia, Pennsylvania	Biological Production of Liquid Fuels from Cellulosic Residues	Determine the economic potential of a multi-step fermentation process and derive glucose by enzymatic hydrolysis of cellulosic materials..

Program Element: Research and Development (R&D)

The goal of the Research and Development element is to identify and investigate those biomass production and conversion technology R&D areas which are expected to contribute to the energy supply after the year 2000.

● Program Sub-Element: Aquatic Systems

Efforts within the Aquatic Systems sub-element are aimed at developing freshwater and marine algae production and harvesting techniques, as well as large-scale marine biomass farming technology.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contribution</u>
L-1	University of California Berkeley, California	Large-Scale Freshwater Micro- algae Biomass Production for Fuel and Fertilizer	Develop cultivation technology of microalgae biomass for conversion to fuel using municipal sewage as the growth medium.
L-2	California Institute of Technology Pasadena, California	Biological Investigation of Marine Farms	Determine chemical and physical environmental requirements for Kelp production.
L-3	Woods Hole Oceanographic Institute Woods Hole, Massachusetts	Cultivation of Macroscopic Marine Algae and Freshwater Aquatic Weeds	Cultivate aquatic plants for the pro- duction of methane by anaerobic digestion.
L-4	Woods Hole Oceanographic Institute Woods Hole, Massachusetts	Bioengineering Aspects of Inor- ganic Carbon Supply to Mass Algal Cultures	Determine the inorganic carbon requirements for the production of algae under mass culture conditions.
L-5	Columbia University New York, New York	Algal Concentration by Ultra- filtration	Harvest microalgae by a non-fouling membrane system.
L-6	Columbia University New York, New York	Permselective Membrane Control of Algal and Wood Digesters for Increased Production and Chemical Recovery	Investigate permselective membrane control of algal and wood digesters.

Program Element: Support

The goal of the Support program element is to provide cross-cutting analyses and assessments of the Biomass Energy Systems Program.

● Program Sub-Element: Support and Analyses

The goal of the Support and Analyses sub-elements is to provide cross-cutting analyses of the Biomass Energy Systems Program.

<u>No.</u>	<u>Contractor</u>	<u>Project Title</u>	<u>Projected Contributions</u>
M-1	SRI International Menlo Park, California	Mission Analysis for the Federal Fuels from Biomass Energy Program	Prepare a broad-based biomass energy systems technology and cost data bank.
N-1	SRI International Menlo Park, California	Preparation of a Cost Data Bank for DOE/Biomass Energy Systems Branch	Determine which fuels from biomass conversion routes are most likely to lead to economically viable market penetration within the competitive fuels environment.
N-2	InterTechnology/Solar Corp. Warrenton, Virginia	Follow-on Studies of the Photo- synthesis Energy Factory	Make the Photosynthesis Energy Factory (PEF) model applicable to a variety of site situations; make PEF more cost-effective.
N-3	Battelle Pacific Northwest Richmond, Washington	Biomass Energy Systems (BES) Program Management Assistance	Provide management support to the BES program office.

PROJECT SUMMARIES

TECHNOLOGY SUPPORT

Contractor and Address *Wheelabrator Cleanfuel Corporation 1050 - 17th St. N.W., Suite 1100 Washington, D.C. 20036 *Rust Engineering Corporation Birmingham, Alabama	Title Advanced System Demonstration for Utilization of Biomass as an Energy Source Contract No. EG-77-R-06-1036
Principal Investigator Gary L. Allison S. Brown Milligan Dennis Meadows J.P. Rich (205) 254-4000	Period of Performance October 1977 to May 1979 Obligated Fiscal Year 1979 Funding
Work Location Birmingham, Alabama	\$28,453.88 Cumulative Funding thru Fiscal Year 1979 \$28,453.88
Project Summary This cost-sharing program is being conducted by Wheelabrator-Frye, Dartmouth College and selected professional forestry groups. Wheelabrator-Frye will provide the design, engineering and construction capabilities for the demonstration program. Dartmouth College will perform the environmental assessment, preparation and characterization. Identification and specifications of biomass inventory, procurement and delivery will be conducted by selected professional forestry groups. The planned output of the plant is 40 to 50 megawatts of electric power for the utility grid, with 100,000-200,000 pounds per hour of process steam to be exported to an industrial complex as a result of cogeneration. Specific tasks of Phase I are: 1) Selection of harvesting and/or collection systems to ensure the gathering and delivery of the required amounts of biomass fuel. The harvesting plan will use lower grades of wood, with better grades going into the lumber and the pulp and paper markets. 2) Preparation of detailed estimates of the costs of harvesting, collecting and delivering the fuel. 3) Selection of a suitable location for a plant to burn the biomass to generate steam for utility and industrial applications, and the engineering, design and specifications of the plant. After the Phase I is completed, construction of the plant will follow at an estimated cost of \$60 million. *Both corporations are subsidiaries of Wheelabrator-Frye Corporation.	

Element : Technology Support
Sub-Element: Direct Combustion Systems

A-2

Contractor and Address Aerospace Research Corporation 4 Jae Valley Road SE Roanoke, Virginia 24014	Title Development of Wood as an Alternative Fuel for Large Power Generating Systems
	Contract No. DE-AC05-78-ET20058
Principal Investigator Joseph T. Hamrick (703) 342-2961	Period of Performance 1/3/78 - 4/29/80
	Obligated Fiscal Year 1979 Funding \$347,741
Work Location Roanoke County, Virginia	Cumulative Funding thru Fiscal Year 1979 \$340,000

Project Summary

Experiments were carried out by Aerospace Research Corporation personnel to determine if a method could be devised to burn green wood efficiently and at such a rate as to allow retrofitting of gas or oil fired plants to burn wood. Results from the first phase of the work showed that green wood containing 43 percent moisture and pulverized to pass a screen with half inch diameter perforations can be burned in suspension in 1000° F air.

In a second phase of work, variations in secondary air whirl intensity, mixing duct length, burning rate, and wood particle size with various species of wood were investigated in the small combustion module constructed in phase I of the program. Further tests were conducted in a large-scale furnace that was constructed for determination of scale effects. The large-scale furnace was designed for green wood feeds ranging from 15,000 to 30,000 lb per hour. Experiments are still in progress on that furnace.

As part of the program, a survey was made to find potential users of the methods developed. The ultimate objective is to provide design information for retrofit of large systems, including retrofit of gas turbines.

Element : Technology Support
Sub-Element: On-Farm Systems

B-1

Contractor and Address Hamilton Standard Division of United Technologies Corporation Windsor Locks, Connecticut 16096	Title Fuel Gas From an Environmental Beef Cattle Feedlot
	Contract No. EG-77-C-01-4015
Principal Investigator Daniel J. Lizdas, Program Manager Warren B. Coe, Engineering Manager (203) 623-1621	Period of Performance September 1977 - February 1980
	Obligated Fiscal Year 1979 Funding \$707,800
Work Location Windsor Locks, CT and Bartow, FL	Cumulative Funding thru Fiscal Year 1979 \$1,380,700
	Project Summary The objective of the project is to evaluate the technical and economic feasibility of producing fuel gas from the residues of an environmental beef cattle feedlot via thermophilic anaerobic fermentation. Design of the 25 ton per day system began in October 1977. Construction was initiated in Bartow, Florida, at the Kaplan Industries, Inc. feedlot in February 1979 and was completed in December 1979. Checkout and startup were conducted during the first six months of 1979; stable fermentation was achieved by July 1979. System gas has been successfully fired in the system boiler and co-fired with oil in the Kaplan Industries wheat packing plant process steam boiler. A grid-connected 450 kW engine generator system with controls has been designed and will be installed in the first half of 1980. Feeding trials utilizing dewatered fermenter effluent as a cattle feed supplement are planned for 1980. It is expected that system operation during 1980 and 1981 will demonstrate that this process can produce a medium Btu gas suitable for close-couple utilization for less than \$3 per million Btu.

Element : Technology Support
 Sub-Element: On-Farm Systems

B-2

Contractor and Address Roman L. Hruska Meat Animal Research Center Science and Education Administration U.S. Department of Agriculture P.O. Box 166 Clay Center, NE 68933	Title Anaerobic Fermentation of Beef Cattle and Animal Residue
	Contract No. DE-A101-79ET20638
Principal Investigator Dr. Andrew G. Hoshimoto (402) 762-3241	Period of Performance January 1, 1979 to December 31, 1979
	Obligated Fiscal Year 1979 Funding \$60,000
Work Location Roman L. Hruska, U.S. Meat Animal Research Center	Cumulative Funding thru Fiscal Year 1979 \$170,000
Project Summary This project is in collaboration with the USDA. The overall objectives of this project are to assess the technical and economic feasibility of recovering high protein biomass through the anaerobic fermentation of beef cattle and crop residues. Design criteria for optimum production of methane would be developed and an economic assessment made on the feasibility of the anaerobic fermentation process for livestock operations, using manure and crop residues as feedstocks. The project has completed a pilot scale evaluation of thermophilic anaerobic fermentation of beef cattle manure. The pilot scale fermenter has been operated at 45°, 50° and 55° C and at loading rates ranging from 3.4 to 16.9 kg US/m³/day. The highest methane production rate (4.65L CH₄/L fermenter/day.) was produced at a retention time of 5 days, loading rate of 16.8 kg US/m³/day, hourly feeding, and fermentation temperature of 55° C. The methane production rate is the highest rate reported in the literature and about four times higher than any pilot or full-scale system fermenting livestock manure. An economic assessment of the thermophilic anaerobic fermentation process for beef feedlots with various biogas handling and use options was made. The fermentation plant size at which the electrical production costs equal current rates for natural gas (\$2.50/1000 ft³) and electricity (4.5¢/kWh) ranged between 24 to 91 metric tons of dried solids per day. This does not include any credit for dried effluents.	

Element : Technology Support
 Sub-Element: On-Farm Systems

B-3

Contractor and Address New York State College of Agriculture and Life Sciences Cornell University Dept. of Agricultural Engineering Ithaca, New York 14853	Title Anaerobic Fermentation of Agricultural Wastes--Potential for Improvement and Implementation Contract No. DE-AS02-76ET20051 (formerly EY-76-S-02-2981)
Principal Investigator Dr. William J. Jewell (607) 256-4533	Period of Performance January 1, 1979 - December 31, 1979 Obligated Fiscal Year 1979 Funding \$240,000
Work Location Cornell University Ithaca, New York 14853	Cumulative Funding thru Fiscal Year 1979 \$910,264
Project Summary The general goal of this project, which began in 1976, has been to define the conditions which could enable development and implementation of simple, low-maintenance fermentation reactors. The latest phase of this project has centered around the following activities: (1) side-by-side comparison of the operation of a conventional technology municipal digester and low-cost simplified plug flow fermenter, both systems tested at varied HRT and at two temperatures, 25° C and 35° C; (2) operation of a pilot scale (5.6 m³) cubical, limited mix reactor (random mix) at varied HRTs, bedding compositions in the feed, and at 25° C and 35° C. This full-scale demonstration of the feasibility of producing biogas on a small dairy operation is the first large-scale, long-term demonstration of this technology in the United States. The full-scale units have operated successfully for over 1.75 years, and the data now provides a comprehensive base to evaluate the economic and technical feasibility of using this technology in American agriculture. Presently, computer models and the design of specific system components (reactor shape, volume, materials, insulation, etc.) and economic analysis and gas utilization considerations indicate that this system can be economically installed on many animal raising operations. Bench scale fermenters successfully demonstrated the concept of dry fermentation (of high solids substrate such as wheat straw and corn stalks). Substrate biodegradability prediction methods were also successfully developed in the last year of this project.	

Element : Technology Support
Sub-Element: On-Farm Systems

B-4

Contractor and Address Ecotope Group 747 - 16th East Seattle, Washington 98112	Title Monitor, Test and Evaluate an Operational Fermenter for 350 Cattle Units
	Contract No. EG-77-C-06-1016
Principal Investigator David Baylor (206) 322-3753	Period of Performance August 1977 to September 1979
	Obligated Fiscal Year 1979 Funding \$98,177.00
Work Location Monroe, Washington	Cumulative Funding thru Fiscal Year 1979 \$98,177.00
	Project Summary The objective of this project is to advance the knowledge of fermenter applications to full-scale dairy farm operations. Project tasks completed included monitoring, testing, and performing laboratory analyses on a 100,000-gallon anaerobic fermenter at the State Reformatory Honor Farm in Monroe, Washington. The system is a complete-mix mesophilic digester with a 12-day retention time. It is one of the few full-scale digesters operating on a farm in the United States. Based on test results, an operator's manual has been prepared for farm personnel, final reports evaluating system viability have been written, and engineering drawings have been updated to show the actual operating system. A final report entitled "Design and Operation of a 50,000-gallon Anaerobic Digester at the State Honor Farm Dairy, Monroe, Washington" was submitted in September 1979. The control of the the project has been transferred to State Reformatory Honor Farm.

Element : Technical Support
Sub-Element: On-Farm Systems

B-5

Contractor and Address Dynatech R/D Company Division of Dynatech Corporation 99 Erie St. Cambridge, Massachusetts 02139	Title Engineering Evaluation of Programs in the Area of Methane from Residues/Biomass
	Contract No. ET-78-C-02-5099, A000
Principal Investigator Donald L. Wise R.L. Wentworth (617) 868-8050	Period of Performance May 17, 1978 to June 30, 1979
	Obligated Fiscal Year 1979 Funding \$44,002
Work Location Cambridge, Massachusetts	Cumulative Funding thru Fiscal Year 1979 \$155,266
	Project Summary The objective of this program is to perform technical engineering evaluation and coordination for DOE's Biomass Energy Systems Program in the areas of methane from residues/biomass. To achieve this goal, the following tasks are required: a. Arrange quarterly meetings for review of progress and exchange of information by contractors active in this area. b. Hold meetings at contractors' sites in order to permit inspection of experimental facilities. c. Prepare summaries of contract status in bound report from following these meetings. d. Monitor overall program progress through visits to contractors and review of their formal reports. e. Prepare a comprehensive report dealing with the design and economics of facilities for generation of fuel gas from animal residues.

Contractor and Address Louisiana Agricultural Experiment Station Louisiana State University Baton Rouge, Louisiana 70803	Title The Potential of Producing and Harvesting Sugarcane and Sweet Sorghum as a Renewable Biomass Energy Resource
	Contract No. EG 78-G-05-6064
Principal Investigator Dr. Billy J. Cochran (504) 388-3153	Period of Performance July 1, 1978 - June 31, 1979
	Obligated Fiscal Year 1979 Funding \$50,000
Work Location Baton Rouge, LA	Cumulative Funding thru Fiscal Year 1979 \$50,000
	Project Summary Sugarcane is considered to be one of the most efficient plant converters of light energy into chemical energy. Previous research has shown that alternate methods of producing sugarcane and sweet sorghum will yield large increases in biomass over conventional production methods. The alternate production practices present mechanization problems. Modification or design of new field equipment is required to effectively produce high population sugarcane and sweet sorghum. Equipment for crop production including machines for seedbed preparation, planting, covering, cultivation and harvesting were designed, modified or evaluated under this project. A modified parabolic subsoiler operated more effectively with less energy; a wide furrow opener provided an optimum furrow shape for wide furrow planting; powered disk adequately covered the wide furrow planted cane; double bottom blades attached to an erect type sugarcane harvester were capable of harvesting wide furrow sugarcane and multiple drills of sorghum.

Contractor and Address Science Applications, Inc. McLean, Virginia 22101	Title Development of Alternative Concepts for the Conversion of Biomass Energy Resources to Methanol
Principal Investigator Dr. Edward I. Wan (703) 821-4300	Contract No. ET-78-C-01-3002 Period of Performance May 1978 to July 1979 Phase I Program
Work Location McLean, Virginia	Obligated Fiscal Year 1979 Funding \$217,500
	Cumulative Funding thru Fiscal Year 1979 \$217,500

Project Summary

This project involves a comprehensive engineering system study to assess various thermochemical processes suitable for converting biomass to methanol and other alcohol fuels. The project was pursued according to a three-phase program: Phase I - technical and economic feasibility study of current technology for the production of methanol from biomass, Phase II - conceptual process design and economic assessment of advanced and innovative thermochemical conversion process for producing alcohol fuels and gasoline from biomass, Phase III - pilot plant studies and process demonstration of commercially feasible advanced alcohol fuels and gasoline production processes. The Phased I program, the currently completed project, is directed toward the assessment of the application of conventional technology to produce methanol from biomass.

Initial efforts were undertaken to identify and evaluate the regional potential of biomass resources and to assess the market for methanol fuels. The near-term and long-term biomass availability and methanol supply and demand data were synthesized in an effort to prioritize the suitable methanol production areas in the country. In the conversion process analysis, detailed evaluation of each major processing step was attempted.

The results of the studies so far completed have indicated that currently the cost of methanol production from biomass ranges from 60 to 90 cents per gallon depending upon regional feedstock costs, the conversion plant size, the gasification process employed, and overall process energy integration and optimization. The following reports have so far been published:

- (1) "Evaluation of The State-of-the-Art of Biomass Based Methanol Process," Progress Report No. 1, August 14, 1978.
- (2) "Development of Biomass to Methanol System Algorithms and Models," Progress Report No. 2, March 25, 1979.
- (3) "Technical-Economic Assessment of the Production of Methanol from Biomass," Final Report, February 1980.

Element : Technology Support
Sub-Element: Alcohol Production Systems

C-3

Contractor and Address U.S. Department of Agriculture Agricultural Research Service U.S. Sugarcane Field Laboratory P.O. Box 470 Houma, Louisiana 70361	Title Sugarcane Spacing Study and High-Fiber Sugarcane Selection
	Contract No. EG-77-A-29-1077
Principal Investigator James E. Irvine (504) 872-6326	Period of Performance April 17, 1977 to September 30, 1979
	Obligated Fiscal Year 1979 Funding \$40,000
Work Location Houma, Louisiana	Cumulative Funding thru Fiscal Year 1979 \$40,000
	Project Summary Work on this project is being carried out on two levels: a. Farm-scale activities have been initiated. Large field plots, totaling 18 acres in area, have been planted with three configurations to determine the effect of narrow-row spacings on the yield of sugarcane. Preliminary results indicate yield increases on the order of 50 percent by decreasing the row spacing from 6 feet to 2 feet. Secondly, harvesting studies have been carried out to determine the feasibility of employing commercial harvesters on narrow-spaced material. b. Work has been initiated to breed and select cultivars of high-fiber sugarcane for energy production. Crosses were made and material was planted in nursery tests in the fall of 1978. Data will be collected during the fall of 1979.

Element : Technology Support
Sub-Element: Alcohol Production

C-4

Contractor and Address U.S. Department of Agriculture Sugar Crops Field Station USDA-SEA-FR-SR Route 10, Box 152 Meridian, Mississippi 39301	Title Sweet Sorghum Energy Research
	Contract No. ET-78-I-01-3148
Principal Investigator Kelly C. Freeman (601) 482-0611	Period of Performance August 1, 1978 to July 31, 1979
	Obligated Fiscal Year 1979 Funding \$2,000
Work Location Meridian, Mississippi	Cumulative Funding thru Fiscal Year 1979 \$5,000

Project Summary

The objectives of this project are as follows:

- a. Compare varieties and compare row spacings of sweet sorghum for biomass production.
- b. Plant, produce, and harvest 10 sweet sorghum cultivars within a randomized complete block design with four replications. Seed increase is to be obtained by bagging panicles on border rows. Yield and measurement data at harvest will include weight, stalk height and diameter, weight of component plant parts (seed, leaves and stalks), juice extraction percentage, and juice analysis data (measurement of Brix, sucrose, purity, and starch).
- c. Plant, produce, and harvest two varieties of sweet sorghum from 18-, 24-, 30-, 36-, and 42-inch-spaced rows and two on 42-inch-spaced rows for biomass yield comparison. Green weight and dry matter yields will be obtained for seed heads, leaves, and stalks. Mill samples will provide juice for determining extraction percentage, Brix, sucrose, purity, and starch components.

Harvesting has been completed. Results will be reported upon completion of milling, drying, and tabulation of acquired data.

Element : Technology Support
Sub-Element: Alcohol Production Systems

C-5

Contractor and Address Battelle Columbus Laboratories 505 King Ave. Columbus, Ohio 43201 Subcontractor: Univeristy of Florida AREC P.O. Drawer A Belle Glade, FL 33430	Title Biomass Production from Sugarcane and Sweet Sorghum Contract No. W-7405-ENG-92
Principal Investigator G.J. Gascho and S.F. Shih (305) 996-3062	Period of Performance 1979 Obligated Fiscal Year 1979 Funding
Work Location Agricultural Research and Education Center Belle Glade, Florida	Cumulative Funding thru Fiscal Year 1979 \$18,700 \$167,000
Project Summary Dry biomass, total sugars and fiber were obtained in sugarcane and sweet sorghum experiments designed to evaluate the effects of row spacings. Narrow inter-row spacings of 50 cm significantly increased dry biomass, total sugar, and fiber yields for sugarcane grown on with mulch and sand soils in comparison to wider inter-row spacings of 100 and 150 cm. Highest yields were 60, 26 and 31 metric tons per hectare of dry biomass, total sugars and fiber, respectively. Toma, Wray, Mer. 71-1 and Mer. 71-7 varieties of sweet sorghum were planted at row spacings of 40 and 80 cm. All varieties yielded best at the 40 cm spacing, and Roma was inferior to the other varieties. Highest yields obtained in a crop planted in April were 28, 10.3 and 10.8 metric tons per hectare of dry biomass, total sugars and fiber, respectively. A replanted crop in July yielded 24 to 64 percent of the first planting and a ratoon crop from the April planting yielded 25 to 50 percent of the April planting. Leaf area index was used to estimate the biomass of sugarcane. The technique devised could be useful as a research tool and as a guide for commercial harvest scheduling. A method of sampling sugarcane grown for biomass was also devised, based on the good fit of monthly stalk length increases to the log earson type III distribution. One of the reports published so far is as follows: LIPINSKY, E.S., et al. 1979. Carbohydrate crops as a renewable resource for fuels production. Vol. 1: Agricultural research. U.S.D.O.E. publication BMI-2031, 82 pages.	

Contractor and Address Battelle Columbus Laboratories 505 King Ave. Columbus, OH 43201	Title Evaluation of the Feasibility of Sequential Fermentation for the Production of Ethanol Contract No. Task 77-Con. W7405-Eng. 92
Principal Investigator John H. Litchfield (614) 424-7624	Period of Performance Aug. 1, 1978 - March 31, 1980 Obligated Fiscal Year 1979 Funding \$93,576
Work Location Columbus, Ohio	Cumulative Funding thru Fiscal Year 1979 \$93,576
Project Summary The primary objective of the research program is to evaluate the feasibility of the sequential, semi-continuous fermentation of sugars to ethanol. The concept relies on the use of different strains of yeast to perform specialized functions within the overall conversion process. From research completed, the following has been accomplished: ● Osmo-tolerant and ethanol-tolerant yeasts were evaluated. Nitrogen requirements and effective carbon/nitrogen ratios were determined to maximize ethanol production. ● In a single fermentation 16 percent wt/vol. ethanol was produced in 3 days. ● Combined high ethanol and high sugar concentrations are inhibitory. ● Production of alcohol is also related to cell density. Productivity appears to be greatest at cell concentrations of 10^7-10^8 per ml. ● Unless the effect of combined ethanol-sugar toxicity is addressed, sequential fermentations will yield less alcohol than conventional batch fermentations when high initial sugar (35-40 percent wt/vol.) is employed. ● Simple dilution, if performed early will counteract ethanol-sugar toxicity.	

Contractor and Address SRI International 333 Ravenswood Ave. Menlo Park, CA 94025	Title An Evaluation of the Natick Enzymatic Hydrolysis Process for Use in the Production of Ethanol from MSW and from Wood
Principal Investigator Jerry L. Jones, Director Environmental & Biochemical Engrg. Dept. (415) 326-6200	Contract No. DE-AC03-79ET23135 Period of Performance 7/16/79 through 1/15/80
Work Location SRI International Menlo Park, CA	Obligated Fiscal Year 1979 Funding \$22,686 Cumulative Funding thru Fiscal Year 1979 \$22,686
Project Summary SRI International prepared a technoeconomic evaluation of the Natick Enzymatic Hydrolysis Process. SRI was instructed to use a consistent set of economic and design bases previously developed by SRI International for use on other DOE funded projects. The techno-economic analysis included: • Consideration of facilities capable of producing 524.5 tons/day of C sugars from a wood feedstock and from processed municipal solid waste for use in production of 25 million gallons/year of fuel grade ethanol. • Consideration of production of ethanol by both batch and continuous fermentation. • Preparation of a process description and analysis section with: - Feedstock characteristics - Process design considerations and block flowsheet - Mass flows, and utility and operating requirements - A calculation of process efficiency - Plant investment cost estimates - Estimates of revenue requirements for both an industrial venture and a regulated utility venture. - A cost sensitivity analysis to demonstrate the effects of feedstock cost (or tipping fee) operating hours, and plant facilities investment cost on product price - A discussion of the current status of the technology and the availability of the process for commercialization	

Contractor and Address Battelle Columbus Laboratories 505 King Ave. Columbus, Ohio 43201	Title Carbohydrate Crops as a Renewable Resource for Fuels Production Contract No. W-7405-Eng-92
Principal Investigator E.S. Lipinsky T.A. McClure (614) 424-6526	Period of Performance June 15, 1975 to April 30, 1979 Obligated Fiscal Year 1979 Funding
Work Location Battelle Columbus Labs; Texas A&M U.; La. State U.; U. of Fla.; Kans. State U.; N. Dak. State U.; U. of Neb.; Farm Bureaus in Ohio, Ill., & Ia.; and Battelle's W. Jefferson, Ohio Facilities; USDA Field Stations in La. and Miss.	\$880,000 Cumulative Funding thru Fiscal Year 1979 \$2,800,000
Project Summary This project comprises a comprehensive study of the feasibility of using carbohydrate crops as sources of fuels. The program is a cooperative effort, including universities, USDA field experiment stations, research organizations, and engineering companies. Agronomic experiments have been conducted in Texas, Louisiana, Florida, and Ohio in previous years. In 1979, experiments with sugarcane and sweet sorghum were carried out in Florida, Texas, and Louisiana, and sweet sorghum row-spacing and cultivar trials were carried out in Ohio, Kansas, Nebraska, and South Dakota. In order to evaluate the ease of commercialization, sweet sorghum was also grown by members of farm bureaus in Illinois, Iowa, and Ohio. Work in 1979 concentrated on the development of sweet sorghum as an energy crop. Yield and composition from variety and plant configuration trials were evaluated, as was yield and composition response to major latitudinal and longitudinal gradients in the continental United States. Studies in plant breeding, growth regulation, and mycorrhizal associations were also conducted. Agricultural economics activities were organized to determine key indicators of the most efficient varieties, cultural practices, and geographic locations. Rotation of sweet sorghum with grains or other sugar crops also was considered in the economic evaluation. A preliminary study of the implications of current U.S. agricultural policy legislation for use of sugar crops and corn as energy resources was undertaken in 1978. Alternative policies for stimulating energy production from carbohydrate crops were identified and examined. A separate report on this study was submitted to DOE in 1979. The evaluation of the Tilby separation process continued. Tilby units were set up in Texas and Ohio and tested, using the 1979 harvests. The decision to proceed with development of this process depends on its ability to generate coproducts that reduce the net cost of fermentable sugars while consuming less energy than conventional milling.	

Contractor and Address The MITRE Corporation Metrek Division 1820 Dolley Madison Boulevard McLean, Virginia 22101	Title Biomass-Based Alcohol Fuels Contract No. ET-78-C-01-2854
Principal Investigator Wayne Park David Salo (deceased 3/4/79) (703) 827-7192	Period of Performance August 1, 1978 to April 1, 1979 Obligated Fiscal Year 1979 Funding
Work Location McLean, Virginia	\$51,049 Cumulative Funding thru Fiscal Year 1979 \$51,049
Project Summary This project has resulted in two studies. The first study addressed the potential of implementing a nationwide alcohol-gasoline fuel system based on alcohols derived from biomass resources. The technological and economic factors of the production and use of ethanol and methanol were calculated for 5 and 10 percent alcohol/gasoline blends by 1990. Although the cost would be substantially greater than gasoline, up to 5 percent methanol or ethanol blends with gasoline could be achieved by 1990, according to this study. The second study compared the economic aspects of 14 studies which were carried out between late 1976 and early 1978 by Battelle Columbus Laboratories, F.R. Schaeffer Associates, the University of Nebraska, the University of California at Berkeley, the MITRE Corporation, and SRI International. Twenty-eight ethanol facilities, previously described in published reports and papers, were considered. Major parameters such as production costs, method of financing, by-product credits, process efficiency, and capacity factors were determined from these reports for each facility. In some cases it was necessary to supplement published data with information obtained directly from authors of the reports. All cost data were reported in 1977 dollars, and units of measure were standardized to facilitate comparison of similar facilities. The "Systems to Project the Utilization of Renewable Resources" life-cycle costing model, developed by MITRE, was used in the evaluation.	

PRODUCTION SYSTEMS

Element : Production Systems
Sub-Element: Silviculture

D-1

Contractor and Address Dept. of Natural Resources Alabama A&M University Normal, Alabama 35762	Title Recovery of Above-Ground Woody Biomass Using Operational Modifications of a Conventional Harvesting System
	Contract No. ET-78-6-01-3041
Principal Investigator John W. Herschelmann (205) 859-7410	Period of Performance May 1978 to September 1980
	Obligated Fiscal Year 1979 Funding \$51,237
Work Location Huntsville, Alabama	Cumulative Funding thru Fiscal Year 1979 \$107,573

Project Summary

The utilization of woody biomass is becoming a vital part of the nation's energy budget. Means of harvesting and transporting this material must be developed that are not only financially attractive, but are also energy efficient and environmentally beneficial.

The purpose of this project is to: (1) develop a pre-harvest evaluation system which will allow individuals to determine product merchandising strategy to maximize both utilization of total biomass and profit, and (2) evaluate operational modifications of conventional harvesting systems to determine efficient methods of utilizing total available biomass.

The emphasis of this study is on harvesting woody biomass to be used as an energy product; however, traditional forest products (pulpwood, cross ties, sawtimber, etc.) must also be evaluated as to the broad supply and demand relationship between all forest products. The nation's forests are expected to supply both material and energy needs; unless wood supplies are extended through maximum utilization of available wood biomass and intensive forest management practices, the forest resources of the nation could become over utilized. A determination of the environmental effects of complete utilization of woody biomass for a given site will also be studied. This will include how such practices could influence management of forest lands by non-industrial private landowners.

Element : Production System
Sub-Element: Silviculture

D-2

Contractor and Address Garret Energy Research and Engineering Co., Inc. 911 Bryant Place Ojai, California 93023	Title Woody Biomass Species for Fuel Production
	Contract No. ET-78-C-01-3077
Principal Investigator Donald E. Garrett 805-646-0159	Period of Performance May 1978-May 1979
	Obligated Fiscal Year 1979 Funding \$75,000
Work Location Hanford, California	Cumulative Funding thru Fiscal Year 1979 \$75,000
	Project Summary The objective of this project is to determine growth and production rates of Athel (salt cedar) and Tamarisk shrub under various conditions and schedules of planting, watering (including varying salinity), fertilizing and harvesting. Athel (salt cedar) and Tamarisk shrub are species which thrive under these conditions of poor soil fertility and exposure to brackish or saline water. These species grow from clones and will coppice. Results of the work will include evaluation of best species, optimum fertilization schemes, influence of saline water, optimum growth and harvest cycles, and net energy recovery.

Element : Production Systems
 Sub-Element: Silviculture

D-3

Contractor and Address The Regents of the University of California Dept. of Soil & Environmental Sciences University of California Riverside, CA 92521	Title Collection, Propagation and Evaluation of <u>Prosopis</u> Species for Growth Rate Under Controlled Moisture and Nitrogen Treatments
	Contract No. ET-78-G-01-3074
Principal Investigator Dr. Peter Felker 714-787-1012	Period of Performance 1 April 1978-30 January 1980
	Obligated Fiscal Year 1979 Funding \$76,977
Work Location University of California, Riverside	Cumulative Funding thru Fiscal Year 1979 \$167,030
	Project Summary The leguminous tree mesquite (<u>Prosopis</u> spp.) occurs naturally on 71 million acres of semi-arid land in the southwestern United States. Three mesquite field screening trials are underway in Southern California, and seedlings for a varietal trial have been established in Khartoum, Sudan, in cooperation with the United Nations Development Program. In a differential irrigation treatment study, the fresh biomass production for the first two seasons' growth ranged from 1.3 to 22.5 T ha⁻¹ yr, with the best accession performing best under the driest treatment. A screening trial with 55 accessions (varieties) at a hot location in Imperial Valley (July daily maximum of 107° F) found individual accessions to range in average biomass from 0.1 to 9.7 kg/tree. Small plots in Imperial Valley with four of the most productive lines ranged in fresh biomass production from 17.5 to 28.2 T ha⁻¹ for the first growing season. Almost all the species native to ranges of Texas, New Mexico and Arizona are among the most non-productive accessions, while the accession from South America possesses the highest biomass production. Field trials designed to screen for cold tolerance at 1500 m elevation have found many individuals which could survive the coldest temperature to date, e.g., a 5.6° C freeze. Pod yield on trees in their third growing season ranged from 0 to 4.8 kg/tree. Some trees produced pods in Imperial Valley only 5 months after transplant. A wild tree with 36 percent sugar in pod and 40.8 percent sugar in pod minus seed has been identified. Methods for rooting mesquite cuttings have been developed which currently yield 70-100 percent success at the right time of year, but all-year-round vegetative propagation and propagation of mature trees remains difficult. Nitrogen fixation has been unequivocally demonstrated in 12 <u>Prosopis</u> species and a 10-fold range in nitrogen fixation between species was observed. Mesquite wood or pod yields of 4,000 kg ha⁻¹ are projected as an average figure for mesquites' 72 million acre range in the United States.

Contractor and Address SRI International 333 Ravenswood Avenue Menlo Park, CA 94025	Title Water and Land Availability for Energy Farming
	Contract No. ET-78-6-01-3142
Principal Investigator F. Schooley 415-326-6200	Period of Performance October 1979 to April 1980
	Obligated Fiscal Year 1979 Funding \$170,000
Work Location Menlo Park, California and 10 Survey Sites in United States	Cumulative Funding thru Fiscal Year 1979 \$170,000

Project Summary

This study assisted the Department of Energy in determining the physical and economic availability of land and water resources for energy farming. The overall objective was to rank selected water areas possessing favorable land and water availabilities according to their overall potential for biomass production. To accomplish this objective, SRI International:

- Evaluated the current water availability in each of the 99 continental U.S. water sub-basins.
- Projected water demands in each sub-basin and determined how water use competition may affect the amount of water available for energy farms.
- Determined the availability of U.S. land resources for biomass farming based upon the regional cost of crop production and the projected return to the farmer.
- Ranked selected sub-basins of favorable land and water availability according to their overall potential for biomass production.

The results of this work were a consistent and comprehensive analysis of water resources as well as a systematic comparison of the potential and economic viability of alternative energy farm sub-basin locations. The draft final report was completed in November, 1979.

Element : Production Systems
Sub-Element: Silviculture

D-5

Contractor and Address University of Florida Institute of Food and Agricultural Sciences School of Forest Resources and Conservation Gainesville, Florida 32611	Title Energy and Chemicals from Woody Species in Florida
	Contract No. ET-78-6-01-3040
Principal Investigator Dr. Wayne H. Smith, Director Center for Environmental Programs 904-392-1511	Period of Performance April 17, 1978 to April 16, 1983
	Obligated Fiscal Year 1979 Funding \$228,945
Work Location Gainesville, Florida	Cumulative Funding thru Fiscal Year 1979 \$327,027

Project Summary

This project is running in its second year and is designed to assess the potential of woody species in Florida for the sustained production of fuel and chemicals as alternative sources of fossil fuels and petrochemicals.

Initial studies of land availability and productivity potential will estimate the quantity and quality of land available for woody biomass production by species. Test candidates will be drawn from the best known performers of Eucalyptus and Pinus families or from field selections of superior trees of Melaleuca and Casuarina. Energy and silvicultural yield per unit of biomass will be measured for existing plantations and for selected cultural treatment combinations of field experiments.

Subsequently, the proposed field research will assess the effects of site preparation, fertilization, and cropping on biomass production. Site effects of such biomass-farming on water use and nutrient conservation will be evaluated for selected cultural treatments. Program level evaluations of rotation age and economic and energetic efficiencies will be made during the later phases of the proposed research.

Current progress includes mapping of a 25 percent sample of the land area of the state, according to current land use, soil potential, and ownership. This effort, with refinements currently in progress, allows estimation of the land area potentially available for biomass production, the projected productivity of that land, as well as the current use and ownership of the land.

Promising genetic strains have been selected for seven species: from analysis of existing studies sand pine, slash pine, Eucalyptus grandis, and E. viminalis; and from field selections of superior trees of Melaleuca, Casuarine equisetifolia, and C. cunninghamiana. Seeds from all selections were established in greenhouse and/or nursery plantings.

Element : Production Systems
Sub-Element: Silviculture

D-6

Contractor and Address University of Georgia School of Forest Resources Athens, GA 30602	Title Increasing the Biomass Production of Short Rotation Coppice Forests
	Contract No. DE-AS09-77ET20006-M2&3
Principal Investigator Klaus Steinbeck Claud Brown 404-542-1376	Period of Performance July 1, 1978 through Sept. 30, 1979
	Obligated Fiscal Year 1979 Funding \$295,409
Work Location Athens, GA	Cumulative Funding thru Fiscal Year 1979 \$554,224
	Project Summary The objective of the short rotation coppice forestry program at the University of Georgia is to find ways to increase biomass yields per unit land area and time. The various species are being screened for their production potential, and their reaction to cultural practices. Genetic improvement through field trials and mass cloning in tissue culture is underway for the more promising tree species. By the end of 1979, two plantations, each approximately 40 acres in size, were successfully established in Georgia. They are designed to evaluate the growth and yield responses of five hardwood species to various rotation ages, species mixtures, fertilization, irrigation and weed control. Soil and plant nutrient levels, energy inputs and outputs, carbohydrate levels in the plants and other variables are being monitored. Some hardwoods with superior growth or better site adaptation advantages have been selected. Tissue culture techniques are being utilized for the rapid multiplication of superior selections. The genetic phase of the biomass project will receive greater emphasis in the coming season because of the completion of a nursery whereby material can be collected, maintained and observed for evaluation and experimentation.

Element : Production Systems
Sub-Element: Silviculture

D-7

Contractor and Address Emory University Biology Department Atlanta, Georgia 30322	Title Screening of Non-Commercial Woody Plants as Biomass Fuel Producers
	Contract No. ET-78-G-01-3185
Principal Investigator H.L. Ragsdale 404-329-4218 J.N. Skeen 404-378-4311	Period of Performance June 1, 1978 to May 31, 1979
	Obligated Fiscal Year 1979 Funding \$81,760
Work Location Atlanta, Georgia	Cumulative Funding thru Fiscal Year 1979 \$81,760
	Project Summary The objectives of this project are to identify and field-test woody plant species suitable for biomass fuel production on marginal Piedmont and Upper Coastal Plain soils of the southeastern United States. Potential woody biomass fuel species have been identified from literature analysis by species adapted to marginal soil habitats and by species which colonize urban habitats. A list of the most promising woody biomass fuel species has been prepared from the larger list of possible species. An intensive literature analysis focusing on physiological, ecological, and other pertinent characteristics of the most promising species is in preparation. This analysis was used to select woody species for field trials. Field screening of woody biomass species has been conducted at a favorable Piedmont site, and at marginal sites in the Piedmont and Upper Coastal Plain. At each site, the species selected for screening will be statistically compared to species of known potential (Cottonwood and Sycamore) for growth and fuel yield to reveal the most promising woody biomass fuel species. Final report on the contract entitled "Screening of Non-Commercial Woody Plants as Biomass Fuel Producers" has been sent to Oak Ridge National Lab, that monitored the contract. Another paper, entitled "Non-Commercial Woody Plants as Potential Biomass Fuel Producers; an Ecological Rationale for Their Selection," was presented in October 1979 at the 3rd Annual Biomass Energy System Proceeding, SERI/TT-33-285, at SERI, Golden, Colorado.

Element : Production Systems
Sub-Element: Silviculture

D-8

Contractor and Address BioEnergy Development Corporation P.O. Box 1801 Hilo, HI 96720	Title Eucalyptus Plantations for Energy Production in Hawaii
	Contract No. DE-FC03-78ET20074
Principal Investigator R.H. Hughes, Executive Vice President C. Brewer and Company, Ltd. P.O. Box 1826 Honolulu, Hawaii 96805 808-544-6193	Period of Performance 9/30/1978 to 12/31/1979
	Obligated Fiscal Year 1979 Funding \$335,000
Work Location Ka'u and Hamakua districts on Island of Hawaii	Cumulative Funding thru Fiscal Year 1979 \$335,000
	Project Summary A planned 5-year, 850 acre demonstration project to determine potential of eucalyptus tree farming as a renewable alternative energy source in the form of woodchips.

Contractor and Address Department of Forestry University of Illinois Urbana, Illinois 61801	Title Woody Biomass Production for Solar Energy Conversion Contract No. ET-78-C-01-3067
Principal Investigator Dr. Gary L. Rolfe 217-333-7489	Period of Performance May 1978-continuing Obligated Fiscal Year 1979 Funding \$79,000
Work Location Urbana, Illinois and Simpson, Illinois	Cumulative Funding thru Fiscal Year 1979 \$79,000

Project Summary

The major project objective is to evaluate the feasibility of using marginal agricultural lands for solar conversion through producing woody biomass at close spacings using short rotations. The technology and economics of harvest, transportation and utilization will not be investigated as part of this research program.

Specifically, this research will:

- 1) Determine optimum species and spacing alternatives
- 2) Determine stand establishment and maintenance requirements
- 3) Determine production capability for a range of site qualities
- 4) Evaluate the environmental and site impacts
- 5) Develop an energy budget for short rotation woody biomass production on a range of marginal lands in southern and central Illinois.

A systems approach with a biological basis has been chosen to accomplish this major research effort, thus considering environmental and site impacts along with establishment, maintenance and production techniques. The final evaluation of the success or failure of biomass plantations on marginal lands is the energy budget. For example, what are the energy inputs required to maximize energy conversion while maintaining site quality? These data will result in rational decisions concerning use and selection of marginal lands for woody biomass production in the Midwest.

Element : Production Systems
Sub-Element: Silviculture

D-10

Contractor and Address Purdue University Department of Forestry and Natural Resources W. Lafayette, Indiana 47907	Title Species Selection for Woody Biomass Plantations on Reclaimed Mineland
	Contract No. ET-78-G-01-3196
Principal Investigator Walter F. Beineke 317-494-8760	Period of Performance June 1978 - December 1980
	Obligated Fiscal Year 1979 Funding \$38,000
Work Location W. Lafayette, Indiana	Cumulative Funding thru Fiscal Year 1979 \$38,000
	Project Summary The objective is to screen a large number of hardwood tree species for use in energy plantations on reclaimed mineland in Indiana. Four sites have been located for sampling, two on reclaimed mineland in southwestern Indiana and two on old fields in the southeastern part of the state. Eighteen species will be investigated initially and harvesting and sampling of five trees of each species at each location began in mid-October. Field measurements include height, diameter and green weight. Sample discs from each stem as well as branch wood are being studied to determine tree age, moisture content, and Btu values. Four species which show the greatest potential for use in energy plantations, based on growth rate and wood characteristics, will be selected, and the inherent rootability of cuttings from the selected species will be investigated. Means to promote or enhance rooting with hormonal treatments or manipulation of environmental conditions will also be studied.

Element : Production Systems
 Sub-Element: Silviculture

D-11

Contractor and Address Department of Forestry, Call Hall Kansas State University Manhattan, Kansas 66506	Title Great Plains Energy Forest Study
	Contract No. ET-78-G-01-3042
Principal Investigator Wayne A. Geyer 913-532-5752	Period of Performance April 3, 1979 to April 2, 1980
	Obligated Fiscal Year 1979 Funding \$76,066
Work Location Manhattan, Kansas	Cumulative Funding thru Fiscal Year 1979 \$76,066
Project Summary The goal of this project is to determine the best species, the optimum planting density, the optimum field management techniques, and the optimum harvest age. Specifically, our objectives are to determine and evaluate productivity of selected hardwood tree species adaptable to short rotation management schemes for fuel wood production in the Great Plains; first approximation of the cost (financial and energy) of growing trees in above type program comparing mechanical and herbicide weed control techniques; and the effectiveness of selected herbicides in controlling a broad spectrum of unwanted vegetation on a variety of sites and the toxicity to desirable tree species. The following have been established as the major milestones: May 1979 Experimental planting completed April 1980 First and second year herbicide toxicity to planted trees and weed control evaluated March 1981 Establishment of additional upland field plots April 1981 Second and third year yields estimated March 1982 Single tree yield curves completed April 1982 Third and fourth year yields determined using single tree yield curves April 1983 Fourth and fifth year yield determined April 1984 Fifth year yield determined for western Kansas plots. Economic and energy ration analyses completed for 5-year rotations. Field plots have been established at 5 locations in central and western Kansas on both upland and bottomland sites. Two herbicides have been compared; Ronstar and Casoron, with the latter being the best. Siberian elm, black locust, catalpa and cottonwood basic data have been gathered for small tree yield tables. Black locust is at least 50 percent greater in Btu's and weight than cottonwoods. Preliminary energy and economic analyses indicate an energy ratio of 79/1 at \$26 Dry Ton Equivalent (DTE).	

Contractor and Address Department of Forestry University of Kentucky Lexington, Kentucky 40546	Title Production of Black Locust Biomass on Surface-Mined Sites in the Southern Appalachians
	Contract No. ET-78-G-01-3039
Principal Investigator Dr. Stanley B. Carpenter 606-258-4608	Period of Performance 4-17-78 to 4-16-79
	Obligated Fiscal Year 1979 Funding
Work Location Southern Appalachian Region Kentucky, West Virginia, Tennessee	None
	Cumulative Funding thru Fiscal Year 1979 \$70,130 (Fiscal year 1978 only)
Project Summary The project was initiated in 1978 to determine the biomass production of black locust on surface-mined sites in the Southern Appalachians. This project was funded by DOE in fiscal year 1978 only. Since that time, the project has continued on a limited basis with funding from the Institute for Mining and Minerals Research, the McIntire-Stennis Cooperative Forestry Research Program and the Mt. Drive Coal Company of Middlesboro, Kentucky. This study is divided into three phases. First, a sampling was taken of the biomass produced in previously established stands of black locust which were direct seeded. Yields in these unmanaged stands have ranged from 6 MT/ha for 2-year-old stands to 67 MT/ha for 13-year-old stands. Stand densities ranged from over 28,000 stems/ha for 2-year-old stands to 2,000 stems/ha for 13-year-old stands. The biomass production of black locust on surface mines is significantly influenced by the clay content of the spoil material and the slope of the terrain. Biomass production is directly related to clay content and inversely related to slope percent. Second, harvesting a 5-year-old stand of black locust to measure coppice growth and the effects of fertilization, insecticide applications, mulching, and irrigation. First year coppice production ranged from 2 to 10 MT/ha/year. Average coppice yields are two to three times greater than the original stand. Third, measurement of the heat content of black locust biomass to determine the Btu content produced per hectare was carried out. The high Btu values for black locust wood are a result of its high density and extractive content. Btu varied with site, genetic, and within-tree in black locust wood. Dense 2-year-old stands of black locust produce nearly 112 million Btu/ha on surface-mined land. This is equivalent to 33.1 million Btu/cord. Moreover, 2 black locust fuel plantations were established on lands of the Mt. Drive Coal Company of Middlesboro, Kentucky. In these plantings, studies are being made on biomass production as influenced by seeding rate, seedling spacing, irrigation, and the planting of additional groundcover legumes as a source of nitrogen. In two other fuel plantations in cooperation with the National Arboretum and the Falcon Coal Company of Jackson, studies on genetic variation in biomass production and insect resistance are also being carried out.	

Element : Production Systems
Sub-Element: Silviculture

D-13

Contractor and Address U.S. Department of Agriculture Forest Service Southern Forest Experiment Station Room T-10210 U.S. Postal Service Building 701 Loyola Ave. New Orleans, Louisiana 70113	Title Construction and Field Trials of a Prototype Forestland Residue Machine (Mobile Hog) to Harvest Fuel from Forest Residues or from Energy Plantations
	Contract No. EX-76-A-29-1045
Principal Investigator Dr. Peter Koch (318) 445-6511	Period of Performance April 30, 1976 to January 31, 1980
	Obligated Fiscal Year 1979 Funding \$35,000
Work Location Forest Products Utilization Research Southern Forest Experiment Station 2500 Shreveport Highway Pineville, Louisiana 71360	Cumulative Funding thru Fiscal Year 1979 \$235,000
	Project Summary A harvesting machine and auxiliary equipment are being developed to recover logging residues as chips for fuel and fiber, and to deliver these chips to mills at about \$18 per green ton including 30 percent pre-tax profit on the equipment investment. The harvester, a 575-horsepower tracked mobile chipper equipped with a front-mounted felling bar, was field-tested on red alder stands (<u>Alnus rubra</u> Bong.) north of Seattle, Washington, during July and August 1979. On the basis of these preliminary tests, the institutions and companies cooperating in the development have scheduled extensive southern field trials for 1980. If the machine meets its performance goals, it could harvest 30,000 tons of green cull wood from about 1,500 acres annually. Southern field trials commenced during March 1980 near Auburn, Alabama.

Element : Production Systems
Sub-Element: Silviculture

D-14

Contractor and Address University of Massachusetts Amherst, Massachusetts 01003	Title Assessment of Tree-Harvesting Machinery for Non-Commercial Timber (in southern New England Hardwood stands)
	Contract No. DE-ET-78-S-01-3143
Principal Investigator Professor F.R. Erskine Crossley Department of Civil Engineering (413) 545-2827	Period of Performance July 27, 1978 to July 26, 1980
	Obligated Fiscal Year 1979 Funding \$34,193
Work Location Amherst, Massachusetts	Cumulative Funding thru Fiscal Year 1979 \$62,168
	Project Summary Visits have been made to Michigan, Vermont, Finland and Sweden, gathering information on wood-chipping systems in operation and the available machinery. The foremost problem in southern New England appeared clearly to be the poor market; i.e., a paucity of users (burners) of wood chips. A study is near completion on the conversions by three local industrial enterprises from oil-burning boilers to chip-burning, including their economics and technical problems encountered. The study of household-sized wood-chip-burning furnaces and district-heating plants in Sweden and Finland has been written up and will appear as a lead article in "Mechanical Engineering" in May 1980. An article of the Finnish system for harvesting of brush and small trees, for use by both farmers and industry, will shortly appear in the "Northern Logger." A collection of descriptions of all commercially available chippers is being prepared for publication. A statistical and geographic study of the terrain slopes and afforested areas in a sample Western Massachusetts county shows that 60 percent of all forests stand on land with over 20 percent slope. We are proposing a new low-capital system for two men to harvest cordwood and chips on New England terrain, accomplishing slash cleanup after logging, cell removal and TSI; and hope to test its economical operation soon.

Element : Production Systems
Sub-Element: Silviculture

D-15

Contractor and Address University of Minnesota Minneapolis, MN 55455	Title Use of Wetlands for Production of Woody Plants for Fuels and Petrochemical Substitutes
	Contract No. ET-78-G-01-3082
Principal Investigator Rouse S. Farnham (512) 373-1447	Period of Performance June 1, 1979-May 31, 1980
	Obligated Fiscal Year 1979 Funding \$51,584.00
Work Location Dept. of Soil Science University of Minnesota St. Paul, Minnesota 55108	Cumulative Funding thru Fiscal Year 1979 \$115,927.00

Project Summary

This biomass project in Minnesota has as its principal objectives, the establishment of stands and productivity studies of selected woody shrub species suitable for growth in wetland sites and for conversion to fuels and chemicals.

Vegetation and soil studies during 1979 fiscal year have included the evaluation of the productivity of 36 native wetland shrub stands throughout Minnesota. Data collected on these stands have included total standing crop yields, age classes, soil and silt factors related to productivity. Computer programs have been developed for complete data analyses suitable for correlating plant biomass data and soil suitability.

Two nurseries have been established on suitable wetland areas to evaluate the best propagation techniques and management practices for establishing stands. Species include hybrid Aspen, Poplars, native Salix, native Alder, European black Alder, and some exotic willow species from Sweden (*Salix aquatica*, *Salix alba*, and *Salix viminalis*).

Propagation studies include evaluating techniques for rotting cuttings, seeding alder, and tissue culture methods for quick establishment of selected clones.

Inventory of wetlands available for biomass plantations in Minnesota is nearly complete. This study includes availability of lands for biomass production, suitability for production, ownership of lands, and assessability of wetlands.

One important discovery is that there is estimated to be over 10,000,000 acres of wetlands in Minnesota not being used for either forestry or agriculture, but would quite possibly be suitable for biomass production.

Another highlight of this research is that many of the exotic species from Europe presently being evaluated (alder, willow, hybrid poplar), appear to be well suited to Minnesota soil conditions and climate and these are potentially good biomass energy crops.

Contractor and Address U.S. Forest Service North Central Forest Experiment Station 1992 Folwell Avenue St. Paul, Minnesota 55108	Title Establishment of <u>Populus</u> Energy Plantations Contract No. Interagency Agreement EG-77-A-29-1094
Principal Investigator David H. Dawson Program Manager Maximum Yield Research and Development Program (715) 362-7474	Period of Performance June 1977 - June 1980
Work Location Forestry Sciences Laboratory P.O. Box 898 Rhinelander, Wisconsin 54501	Obligated Fiscal Year 1979 Funding \$275,000
	Cumulative Funding thru Fiscal Year 1979 \$768,000
Project Summary The research and developmental work performed under this interagency agreement is part of an interdisciplinary Research and Development Program funded by the U.S. Forest Service. Specifically the DOE funded work serves to accelerate research as it is directed toward developing the technology of planting (establishing) large plots and areas. With proper establishment techniques, selection or breeding of better genotypes, furnishing of optimum water and nutrient needs and growing the trees at the optimum spacings and cuttings cycles, at least 5 to 10 times the biomass of northern "natural" forests can be obtained. To date no large acreages (over several hundred acres) of <u>Populus</u> or other intensively cultured deciduous tree plantations exist in north central United States, <u>except those established by cooperators of this program during the last three years.</u> Progress on the problems to make possible the successful establishment of these large-scale plantings includes establishing weed control techniques, including cultivation, cover crops and herbicides; modification of planting machinery; production of vegetatively propagated planting stock techniques; and identification of inserts and pathogens affecting establishment. Continued work is necessary to increase reliability of plantation establishment, better survival, etc., in order to meet the increased yield objectives.	

Element : Production Systems
Sub-Element: Silviculture

D-17

Contractor and Address Michigan State University Department of Forestry East Lansing, Michigan 48823	Title Tree Species and Management Strategy for Biomass Production in the Lake States
	Contract No. ET-78-G-01-3078
Principal Investigator James W. Hanover (517) 355-0090	Period of Performance June 1, 1978 to May 31, 1980
	Obligated Fiscal Year 1979 Funding \$73,166
Work Location East Lansing, Michigan	Cumulative Funding thru Fiscal Year 1979 \$148,811
	Project Summary This project is studying approximately 30 tree species which may have potential for use in biomass plantations in Michigan. Native and introduced species and hybrids which fit a set of criteria for rapid growth and site adaptability are included with both conifer and hardwood species represented. Planting stock is being raised from seed or, if appropriate, cuttings. Seeds have been collected from field selections of above average phenotypes where possible, or obtained through co-operative research agreements or through commercial seed dealers. Seedlings are being grown in greenhouse facilities under accelerated conditions to produce large planting stock within a few months. Growth is being programmed so that various species are ready for outplanting in either spring or fall of 1979, seedlings being grown in square containers 5 cm x 5 cm x 27 cm deep. Plantings will be made at 10 locations that have been properly prepared, using proven mechanical and chemical techniques. Each plantation will consist of approximately 2 hectares divided into 42 plots replicated 4 times in the species trial and small-scale spacing study.

Element : Production Systems
Sub-Element: Silviculture

D-18

Contractor and Address Michigan Technological University Department of Forestry Houghton, Michigan 49931	Title Application of Sugar Maple and Black Locust to the Biomass Energy Farm Concept
	Contract No. ET-78-G-01-3071
Principal Investigator R.L. Sajdak Yuan C. Lee Glen D. Mroz (906) 487-2338	Period of Performance June 1, 1978 to May 31, 1984
	Obligated Fiscal Year 1979 Funding \$92,000
Work Location Houghton, Michigan	Cumulative Funding thru Fiscal Year 1979 \$164,000
	Project Summary The major objective of this program is to (1) investigate the feasibility of using pole-sized maple stands for energy plantations, (2) measure the extent of sugar maple sprouting as an energy efficient regeneration method, and (3) determine the energy input, output of the system (Btu content of the product vs. energy expended). This study is in the Upper Peninsula of Michigan, established on state forest land and consisting of three sites representing high, medium, and low productivity levels. A characterization of site productivity was made, which included complete volume and biomass estimates as well as stem analysis information. Selected plots were fertilized in June, and foliage was collected (fall 1978) for analysis to determine if fertilizer uptake did occur in the trees. Roots will be analyzed for carbohydrate content, and collected samples of seedling and sprout material will be evaluated in terms of biomass production, specific gravity, calorific value and chemical composition. Currently, black locust stands are being evaluated. Seed and root nodules are being collected. Differences in root nodulation have been observed, and the nodules will be used to culture <u>Rhizobium</u> bacteria to obtain selections of bacteria strains with improved nitrogen-fixing abilities. An annual report has been submitted to Oak Ridge National Laboratory, the management agency for this contract.

Contractor and Address Mathtech, Inc. P.O. Box 2392 Princeton, New Jersey 08540	Title Harvesting of Close-Spaced Short-Rotation Woody Biomass
	Contract No. ET-78-C-01-3068
Principal Investigator Daniel E. Cullen William J. Barr (609) 799-2600	Period of Performance April 1978 - October 1979
	Obligated Fiscal Year 1979 Funding \$81,277
Work Location Princeton, New Jersey	Cumulative Funding thru Fiscal Year 1979 \$81,277

Project Summary

In order to maximize harvest yields of energy tree farms, variations in standard equipment and practices currently employed by woodlands and agricultural farms is necessary. Conventional and innovative methods of harvesting, collecting, transporting, and storing young hardwoods are considered, and particular emphasis is placed on evaluating their energy-consumption characteristics. Modeling of alternative harvesting techniques will be applied to determine the effectiveness of various harvesting systems.

Data have been obtained on some existing stands of young close-spaced hardwoods as well as on a number of agricultural crops such as sugarcane regarding their growing characteristics and harvesting methods. Performance and cost data and machine characteristics have been secured on woodlands and agricultural equipment as well as on some specialized equipment for operation under non-standard conditions.

Mathematical models of a number of harvesting and collecting systems have been formulated.

Contractor and Address General Electric Company The Controlled Environment Agriculture Operation Court Street Plant 2, Room 1 Syracuse, New York 13221	Title Energy Biomass Production Study
	Contract No. ET-78-C-02-4909
Principal Investigator Kenneth Foote (315) 456-7740	Period of Performance September 1978 to April 1980
	Obligated Fiscal Year 1979 Funding \$240,000
Work Location Syracuse, New York	Cumulative Funding thru Fiscal Year 1979 \$240,000
	Project Summary The objective of this study is to research and evaluate techniques for optimizing growth in plants needed for energy biomass plantations and to produce large numbers of seedlings with high survival rates for use in establishing and replanting biomass farms. This is a feasibility study in which the cost effectiveness of mass producing seedlings for the establishment and replenishment of energy farms will be studied. Seedling containers and tree species have been selected. Identification of optimum conditions for growing seedlings or cuttings within large controlled environment growth chambers is almost complete. Conditions required for hardening of selected species have been identified, and testing of growing mediums is receiving additional study. Production of planting stock is expected to begin in the spring and winter of 1979. Planting stock will be field tested under cooperative agreements arranged by G.E. with the College of Environmental Science and Forestry, State University of New York at Syracuse and Arkansas State University. Candidate species for biomass seedlings in this study are <u>Acer saccharinum</u>, <u>A. negundo</u>, <u>A. Rubrum</u>, <u>Liquidambar styraciflua</u>, <u>Liriodendron tulipifera</u>, <u>Larix sp.</u>, <u>Robinia pseudoacacia</u>, <u>Platanus occidentalis</u>, <u>Prunus serotina</u>, and <u>Populus</u> hybrids. General Electric has previous experience in producing garden vegetables in controlled environments on a large scale. Results from this work indicated that such an approach may offer a solution to the problem of providing great numbers of hardwood and softwood plants that would be required in maintaining an energy biomass farm.

Contractor and Address School of Forest Resources North Carolina State University Raleigh, NC 27607	Title Economics and Operating Characteristics of Various Materials Handling Systems and Wood Fuels in Small to Medium Sized Boiler , Facilities Contract No. ET-78-G-01-3081
Principal Investigator Michael P. Levi (919) 737-3386	Period of Performance July 1, 1978 to June 30, 1980 Obligated Fiscal Year 1979 Funding \$68,135
Work Location Raleigh, North Carolina	Cumulative Funding thru Fiscal Year 1979 \$90,847
Project Summary This study is intended to evaluate the economic and technical feasibility of burning wood as a fuel in non-wood products industries. The fuels of principal interest are whole tree chips, bark, sawdust, and wood pellets, all used to produce steam by direct combustion. A test burn of hardwood whole tree chips (WTC) was conducted at a 60,000 pound per hour spreader stoker water tube boiler to compare WTC and bark as fuel. The WTC has a higher moisture content than the bark but also a more uniform size and only one-tenth the ash. These characteristics accounted for all the significant differences in operation of the boiler. With the exception of the slowness of the boiler response to rapid load changes, there were no major problems in burning WTC. Wood pellets were burned for an extended period in a small coal fired boiler at a public school in Wake County. The boiler was successfully operated on the pellets and was cleaner and easier to maintain than on coal. Though there is no firm data, it is believed that the wood fired boiler was substantially more efficient than when fired on coal. It is planned to undertake additional, extended test burns with WTC and wood pellets. Development of a handbook on "Wood as a Fuel for Non-wood Products Industries and Institutions" is almost completed. This handbook will consider procurement, storage, handling, combustion, pollution control, and economics for wood fired systems in the range 20 million to 200 million Btu/hr. It is anticipated that it will be available by June 1980.	

Contractor and Address North Carolina State University School of Forest Resources Hardwood Research Cooperative Raleigh, NC 27650	Title Species Selection and Silvicultural Systems for Producing Fuels From Woody Biomass in the Southeastern United States
	Contract No. ET-78-6-01-3038
Principal Investigator Dr. Douglas J. Frederick Dr. Robert C. Kellison Mr. William E. Gardner 919-737-2891	Period of Performance June 1, 1978 to March 1, 1980
	Obligated Fiscal Year 1979 Funding \$89,523
Work Location Raleigh, N.C. and numerous field locations in the South	Cumulative Funding thru Fiscal Year 1979 \$190,098
Project Summary This project is being coordinated by the N.C. State Hardwood Research Cooperative. Objectives include screening and identification of species for high growth and energy potential, identification of optimum levels of intensive culture for energy plantations, and implementation of present and refined genetics breeding programs to locate and/or develop suitable trees to be grown for energy production. From existing species-site tests within the Cooperative, loblolly pine shows superior growth over hardwood sites, sweetgum was the most adaptable hardwood tested, and all hardwoods show potential for plantation culture but must receive intensive care until well established for acceptable growth and development. A coppicing study with sycamore has shown best coppicing to occur when cutting occurs during the dormant season in October and poorest coppicing to occur in June and April. During 1979, ten species were planted in new species-site tests by our industrial cooperators. Species included green ash, willow oak, loblolly pine, sweetgum, sycamore, European black alder, cottonwood, cypress, black locust, and white ash. Eucalyptus spp and European black alder are being intensively tested for plantation culture for biomass and energy. Eucalyptus species performing best include <u>E. viminalis</u>, <u>E. nova-anglica</u>, <u>E. macarthurii</u>, and <u>E. camphora</u>. Over 110 sources of European black alder will be screened by cooperators across the South during 1980. Two experimental energy plantations were planted in North Carolina during 1979. The first, on a Piedmont upland site, contained 4 species and the second, on a bottom land, had 7 species. Spacings included: .75 x 1.5m, 1.5 x 1.5m, and 2.5 x 1.5m. Fertilization, herbicides, and intensive cultivation were used. In 1980, a third planting was machine planted in southeastern Georgia using 7 species, which included <u>E. viminalis</u> and <u>E. macarthurii</u>.	

Project Summary (Continued)

D-22

Selections were being made to identify the best hardwood genotypes for growth and energy production. We currently have over 600 selections representing 25 species in seed orchards and clone banks. Most recent selections have been with Eucalyptus spp.

Overall the project is on schedule, and all projected milestones have been reached.

Contractor and Address U.S. Department of Agriculture Forest Service Southeastern Forest Experiment Station P.O. Box 2570 Asheville, North Carolina 28802	Title Fuel Farm Research (Chemically induced Oleoresin as a Petro- chemical Substitute) Contract No. DE-A109-76SR00903
Principal Investigator Dr. Elizabeth Goodson 803-725-3965	Period of Performance October 10, 1975 to September 30, 1980
Work Location Aiken, South Carolina	Obligated Fiscal Year 1979 Funding Solar Energy: \$216,000 DBER* : \$ 75,000 Cumulative Funding thru Fiscal Year 1979 Solar Energy: \$383,000 DBER* : \$579,000

Project Summary

The objective of this project is to develop optimum treatment techniques for lightwood production (resin-soaking) in southern pines in order to increase oleoresin yields and Btu content, reduce costs and insect hazards, and enable induced lightwood technology to come into commercial use as rapidly and efficiently as possible.

A research program consisting of two elements is being conducted at DOE's Savannah River Plant in Aiken, South Carolina. Program element I involves proof-of-concept experimentation. By using current research information, the feasibility of producing and processing chemically induced lightwood on a commercial scale is being ascertained. For these large-scale studies, data is gathered both from woodlands operations and actual production runs in pulp mills. Goals include (1) the determination of oleoresin yield, degree of insect pest protection required, and costs in dollars and energy and (2) the solving of technical problems both in woodland and plant operations. It is expected that this approach will stimulate industry toward rapid application of existing lightwood technology. In 1979, the required field work was completed.

Program element II is concerned with (1) exploratory research to test new ideas in lightwood technology and (2) studies covering a range of biological and environmental factors that complement the work of program element I.

*Division of Biological and Environmental Research

Contractor and Address The Pennsylvania State University Land and Water Research Building University Park, PA 16802	Title Feasibility of Using Municipal Wastewater and Waste Heat to Maximize Biomass Production in Energy Plantations Contract No. ET-78-G-01-3066
Principal Investigator William E. Sopper Dr. David DeWalley 814-863-0291	Period of Performance 5/15/78 to 8/31/80 Obligated Fiscal Year 1979 Funding \$70,055
Work Location State College, PA	Cumulative Funding thru Fiscal Year 1979 \$153,404
Project Summary The objectives of the project were to (1) evaluate the effect of municipal wastewater irrigation and waste heat on woody biomass production in hybrid poplar energy plantations, (2) evaluate the effect of growing space, (3) evaluate the use of wastewater as a commercial fertilizer substitute, (4) evaluate the efficiency of the plantations to renovate the wastewater, and (5) evaluate the energy budgets for each of the energy plantation management strategies proposed. Initial results indicate that wastewater irrigation significantly increased diameter growth and almost doubled tree height growth. Wastewater irrigation more than doubled woody biomass production at all growing spaces. Mean annual biomass production was 16.7, 11.6 and 7.4 dt/ha for the 0.09, 0.19, and 0.37m² of growing space in the wastewater irrigated plantation. In the control plantations, mean annual biomass increment was 5.7, 4.5, and 1.8 dt/ha for the same spacings. Weed control during the first year is necessary to control tree mortality and to obtain maximum first year diameter and height growth. Applications of waste heat did not further increase biomass production over that resulting from wastewater irrigation alone. Wastewater was satisfactorily renovated by the ecosystems and produced percolating water of potable quality for direct recharge to the groundwater reservoir. Wastewater irrigation provided all the plant nutrients needed for maximum tree growth. Most of the nutrients taken up by the trees were deposited in the foliage. The nutrients are recycled back to the site annually via leaf fall. Thus, it is doubtful that period harvesting at 3 to 5 year intervals would result in any nutrient depletion of the site. The results of the study indicate that there is a common relationship between the two concepts of land treatment of municipal wastewater and silvicultural energy farms. The combination of the two concepts should provide for a beneficial cost-effective solution.	

Contractor and Address The Pennsylvania State University 307 Old Main University Park, PA 16082	Title Energy Sensitivity and Variability Analysis of <u>Populus</u> Hybrid Short- Rotation Plantations in Northeastern United States Contract No. ET-78-G-01-3070
Principal Investigator T.W. Bowersox P.R. Blankenhorn 814-865-4841	Period of Performance 9/1/78-8/30/79 (one year)
Work Location University Park, PA	Obligated Fiscal Year 1979 Funding \$45,521.95 Cumulative Funding thru Fiscal Year 1979 \$47,852.00
Project Summary The main objective of this project is to evaluate the energy sensitivity and variability analysis of short rotationed <u>Populus</u> hybrids in the northeastern United States. Various management strategies such as fertilization and irrigation were evaluated for different biomass production that ranged from 7.9 to 17.1 odt/ha/yr. Over this range of potential yields, the energy inputs for: ● Plantation establishment energies varied from 0.88 to 2.53% of the total input energy. ● Fertilizer and/or irrigation manufacturing energies varied from 8.46 to 31.9% of the total input energy. ● Fertilizer and/or irrigation application energies varied from 0.16 to 5.87% of the total input energy. ● Harvest and chipping energies varied from 9.31 to 15.56% of the total input energy. ● Transportation energies varied from 2.19 to 3.44% of the total input energy. ● Drying energies varied from 50.42 to 79.18% of the total input energy. Although native fertility and rainfall (control), fertilization, irrigation, and fertilization/irrigation may have application in site-species specific situations, the most promising management strategy from the net energy and land area values for <u>Populus</u> hybrids in the northeastern United States would be fertilization, particularly if there is an amendment carry-over effect of increased yield into the second generation. Fertilization in dense plantations that are grown on short rotations will produce substantially more energy than consumed. The best net energy value and the least land required to sustain a given energy output will be for the production of usable heat or process steam.	

Contractor and Address Oak Ridge National Laboratory (ORNL) P.O. Box X Oak Ridge, Tennessee 37830	Title Management Support to the Fuels from Woody Biomass Program
Principal Investigator R.I. Van Hook 615-574-7374	Contract No. Period of Performance October 1, 1977-October 1979
Work Location Oak Ridge, Tennessee	Obligated Fiscal Year 1979 Funding \$150,000
	Cumulative Funding thru Fiscal Year 1979 \$300,000

Project Summary

In the areas of fuels and chemicals from woody biomass, ORNL is managing several contracts for the Department of Energy. The tasks include establishing improved management strategies and improved methods of collection and transportation. The various contracts that come under ORNL are run at several state universities and research stations. These include:

1. Alabama A&M University	17. University of Minnesota
2. Univ. Arkansas-Monticello	18. North Carolina State University
3. Univ. California-Riverside	19. North Carolina State University
4. Emory University	20. Penn State University
5. BioEnergy Development Corp.	21. Penn State University
6. University of Florida	22. Purdue University
7. Garrett	23. Seattle City Light
8. G.E.	24. Texas Energy Foundation
9. University of Georgia	25. U.S. Forest Service, Portland, OR
10. University of Illinois	26. U.S. Forest Service, Rhinelander, WI
11. Kansas State University	27. U.S. Forest Service, Pineville, LA
12. University of Kentucky	28. Utah State University
13. Mathtech	29. University of Vermont
14. Mississippi State University	30. Virginia Polytechnic University
15. Michigan State University	31. University of Washington
16. Michigan Tech. University	32. Washington State University

Contractor and Address University of Houston 3800 Cullen Blvd. Houston, Texas 77004	Title Cultural and Management Practices for the Chinese Tallow Tree as a Biomass Fuel Source
	Contract No. EF-78-6-01-3037
Principal Investigator Joe R. Cowles H.W. Scheld 713-749-3135	Period of Performance May 1, 1978 to April 30, 1980
Work Location University of Houston Coastal Center Hitchcock, Texas	Obligated Fiscal Year 1979 Funding \$43,500
	Cumulative Funding thru Fiscal Year 1979 \$80,000

Project Summary

The purpose of this program is to develop a woody biomass fuel source which will contribute to the Western Gulf Coast's future energy needs. A number of studies have been initiated with the objective of defining properties and cultural characteristics of the Chinese Tallow tree, Sapium sebiferum.

In plots established in existing tallow stands to assess the growth rate of tallow under release and coppice management with and without fertilization (200 lb/acre), some coppiced sprouts reached heights up to 12 ft and a total biomass per acre of 2.2 tons (0.81 MT/ha) at the end of the first season. In the second season, some plants exceeded 18 ft in height, and standing crop ranged up to 10.4 tons per acre (3.82 MT/ha) of biomass.

Major differences among the treatments were apparent after one season of growth, and profound differences were evident at the end of the second season in plots established with 6-week-old seedlings to study the effect of spacing (2', 4', and 6'), fertilization (0, 200, and 500 lb/acre of 13-13-13) and irrigation upon growth rate. The unfertilized plots were virtually stagnant; widely-spaced plantings exhibited reduced height and diameter growth, caused primarily by competition of weeds and grasses. Estimated biomass on plots with 2' basal diameter of 1.57 inches (34.6 mm) and a mean height of 9.28 ft (2.83 m). Irrigation was not evaluated during the second season because of high rainfall (>70").

In plots established to evaluate the effectiveness of direct seeding and site preparation in stand initiation, germination/survival rates compared to intensively-cultivated treatments were 39%, 51%, 24%, and 4% in lightly-cultivated, strip cultivated with herbicide treatment, strip-cultivated without herbicide treatment, and uncultivated (control) plots, respectively. Seedlings were unable to compete effectively with the grass in the control, lightly-cultivated, or strip-cultivated plots.

Project Summary (Continued)

D-27

Land availability for tallow or other woody species was surveyed for the Texas Gulf Coast region and certain bordering counties having an annual rainfall exceeding 25". An estimated 29,000,000 acres of land are available in the 89-county area.

Mean specific gravity was 0.45 and the caloric content was 4221 kcal/kg in a sample of 8 representative trees averaging approximately 20 years of age.

Element : Production Systems
 Sub-Element: Silviculture.

D-28

Contractor and Address Energy Foundation of Texas 4800 Calhoun Street Houston, Texas 77004	Title Cultural and Management Practices for the Chinese Tallow Tree as a Biomass Fuel Source
	Contract No. EF-78-6-01-3037
Principal Investigator Joe R. Cowles	Period of Performance Two years
	Obligated Fiscal Year 1979 Funding \$45,663
Work Location University of Houston Houston, Texas	Cumulative Funding thru Fiscal Year 1979 \$83,971
Project Summary The overall objective of this project is to develop a technology for woody biomass fuel production from species adapted to the poorly drained areas of the Texas Coastal Plains. Specific goals include assessing the biomass production potential of existing Chinese tallow stands under all-aged management and even-aged management systems; experimenting with methods site preparation and stand establishment; establishing new stands of tallow to study cultural variables; establishing clonal stands initiated to evaluate the potential for genetic improvement; investigating potential fuel production from seeds of Chinese tallow trees; and assessing the land availability for fuel production in the Texas Gulf Coastal Region. Milestones include establishment of new tallow stands (Years 2, 3, 4, and 5); initiation of new coppice regrowth studies (Years 3 and 4) and seed production studies (Years 3 and 4); and initiation (Year 5) and completion (Year 6) of land usage studies. Growth measurement and genetic improvement studies will be continuing efforts throughout the project. This study is in the second year of a planned six year program. During the first year (Fiscal Year 1978-79), eighteen plots for studying management treatments and coppice regrowth were established in existing 10-12 year old tallow stands at the University of Houston Coastal Center. Treatments initiated included understory removal, fertilizers, and pruning. Seed germination studies were begun, and new experimental plots established. During the second year (Fiscal Year 1979-80), growth on the coppiced and treated 10-12 year old plots was measured. Survival and growth monitoring in seedling plots and indirect seedling plots continued. A land usage study was initiated.	

Contractor and Address Utah State University. Institute for Land Rehabilitation Logan, Utah 84322	Title Selection of High-Producing Shrubs of the Western United States for Energy Biomass Production
	Contract No. ET-78-G-01-3076
Principal Investigator Cyrus M. McKell Gordon Van Eppes 801-750-1000	Period of Performance 4/1/78-9/30/82
	Obligated Fiscal Year 1979 Funding \$24,271
Work Location Logan, Utah and Nephi Field Station	Cumulative Funding thru Fiscal Year 1979 \$84,673
Project Summary The objectives of this contract are to select large biotypes from shrub populations in the arid intermontane West, measure their productivity under natural conditions, propagate the selected biotypes, and plant their progeny on a dryland research station for growth and yield comparison as biomass for energy under low-cost cultural treatments. Indigenous locations of these shrubs are being determined. Actual plant measurements and ecological data are being obtained at each site, along with plant samples for laboratory analysis. Propagation material such as wildings, cutting, and seeds are being/will be obtained, depending on availability and season. Two visits to some sites may be necessary to obtain the necessary propagation material. Wildings, cutting, or germinated seeds will be grown during winter in a greenhouse prior to field planting in early spring of 1979. Adaptation and growth comparisons of the various species and biotypes will be made following field planting; necessary cultural and management practices will be carried out. Desired results will be dependent upon plant growth of the various biotypes and how they respond when removed from their natural habitat and planted in a uniform comparison nursery. The following report has been published: "Energy Biomass From High-Producing Rangelands Shrubs of the Inter-Mountain United States," March 1980.	

Element : Production Systems
Sub-Element: Silviculture

to be for

D-30

Contractor and Address University of Vermont and State Agricultural College Burlington, Vermont 05405	Title The Production of Biomass for Energy on Abandoned Farmlands in the Northeast
	Contract No. ET-78-G-01-3075
Principal Investigator Frederick M. Laing 802-656-2930	Period of Performance 4 years
	Obligated Fiscal Year 1979 Funding \$72,315.00
Work Location Northern Vermont	Cumulative Funding thru Fiscal Year 1979 \$139,893
	Project Summary The project is intended to demonstrate the potential for intensive, short-rotation energy farming of hardwood species in the Northeast. Variables include species (12), sites (8), spacings (3), fertilizer levels (3). Data from first full growing season now being analyzed. Demonstration of economic yield will provide additional fuel sources for large (power generation) and small, diverse uses. Substantial acreages not now in agriculture, much reverting to scrub woodland, are seen as potential croplands. A high interest in wood and various wood residue fuels in Northeast is seen at present.

Contractor and Address The MITRE Corporation Metrek Division 1820 Dolley Madison Boulevard McLean, Virginia 22101	Title Near-Term Use of Wood as a Fuel Contract No. EG-77-C-01-4101
Principal Investigator David Salo (deceased 3/4/79) Abu Talib 703-827-7192	Period of Performance June 1, 1978 to May 31, 1979
Work Location McLean, Virginia	Obligated Fiscal Year 1979 Funding \$70,500 Cumulative Funding thru Fiscal Year 1979 \$70,500
Project Summary Two studies are being conducted to compare commercially available technologies for converting wood into usable forms of energy. The processes being compared include direct combustion, gasification, pyrolysis, and densification. The first study describes the technologies and estimated costs which can expand the use of wood residues and standing forests. Regional availability of wood supplies is compared and the costs of conversion products are computed. Possible near-term incentives to encourage the use of wood for energy are evaluated, including retirements and investment tax credits. A list of industries selling industrial wood energy equipment is included in the report, "Near-Term Potential of Wood as a Fuel," which resulted from this study. A subsequent study, which is being carried out, will elaborate on the market readiness of gasification, pyrolysis, and densification technologies. A report, expected to be published in June 1979, will include a review of low- and medium-Btu gas-producing systems which are operating. These systems range from bench-scale to commercial-scale units with background, process descriptions, schematics, and economic data. The study will address the status of wood densification and will describe a pellet mill manufacturer, a wood pellet producer, and a pellet fuel user. The report will present conclusions and make recommendations regarding technological status, generic process comparisons, and issues associated with further evaluation and development efforts.	

Contractor and Address Virginia Polytechnic Institute and University Department of Forestry & Forest Products	Title An Integrated Investigation of Procurement, Harvesting, Drying, Transportation and Storage of Woody Biomass Contract No. ET-78-01-3069
Principal Investigator T.A. Walbridge, Jr. W.B. Stuart (703) 961-6391	Period of Performance June 1, 1978 to May 31, 1980 Obligated Fiscal Year 1979 Funding
Work Location Blacksburg, Virginia	\$281,658 Cumulative Funding thru Fiscal Year 1979 \$281,658
Project Summary The objective of this work is to evaluate alternative methods of harvest, storage, transport, and preparation of woody materials as a source of energy for three plant types: a. Plants specifically designed to operate using woody material as a primary fuel on a full-time basis. b. Plants using woody material to augment other energy forms on a full-time basis. c. Plants using woody fuels as an alternative during shortages of their primary fuel. The woody materials considered may originate from residues created from conventional harvesting operations, from silvicultural treatments on lands held for timber production, and from stands established specifically for energy production. The research will be divided into four sub-parts: a. Severance and field drying. b. In-woods processing, transportation, and storage. c. Procurement, transportation, and storage between forest and plant site. d. Receiving facilities and preparation of material at the plant site. Three major product forms will be considered: roundwood; full tree; and segmented stems, chips, and bales.	

Contractor and Address Washington State University Department of Forestry and Range Management Pullman, Washington 99164	Title Evaluating and Modeling Tree Biomass Yields from Small-Diameter Conifer Stands in the Inland Northwest Contract No. ET-78-G-01-3079
Principal Investigator Roger Chapman Rod Clansnitzer (509) 335-5296	Period of Performance May 15, 1978 to May 14, 1983 Obligated Fiscal Year 1979 Funding none
Work Location Coleville, Washington	Cumulative Funding thru Fiscal Year 1979 \$224,000
Project Summary The major objective of the project is to estimate the biomass yield of small-diameter conifers in the inland Northwest of Washington State. Species of the conifer trees that are being considered are Western Larch, Ponderosa Pine, Douglas Fir and Lodge Pole Pine. Current progress includes harvesting of approximately 223 acres in order to get appropriate data. This program is likely to be transferred to USDA and for lack of funding, no work was done in 1979 on this project.	

Contractor and Address University of Washington College of Forest Resources Seattle, Washington 98195 and Washington State University Pullman, Washington 99163	Title Evaluation and Genetic Improvement of Black Cottonwood for Short- Rotation Coppice Culture Contract No. ET-78-G-01-3065
Principal Investigator Reinhard Stettler Paul Heilman (206) 543-2723	Period of Performance June 1, 1978 to May 31, 1984 Obligated Fiscal Year 1979 Funding \$76,000
Work Location Pullman, Washington	Cumulative Funding thru Fiscal Year 1979 \$84,801
Project Summary The proposed work addresses two issues: - the genetic improvement in which field trials will be conducted on contrasting soil types, testing early productivity of pure cottonwood stands versus 1:1 mixtures of cottonwood with red alder; - the evaluation of quality criteria for fuel and/or chemical use of black cottonwood (<u>Populus Trichocarpa</u>) and its hybrids with <u>P. Deltoides</u>. An 8-year old black cottonwood plantation will be harvested and analyzed. The grantees share the cost of this project. Current progress includes selection of 50 clones from 10 natural populations in the Pacific Northwest, and the average height ranged from 1.72-3.07 meters. So far, a total of 10,000 seedlings have been planted, and interspecific hybridizations have been performed involving eight black cottonwood parents and four <u>P. Deltoides</u>.	

Contractor and Address Seattle City Light Mechanical Engineering Department 1815 Third Avenue Seattle, Washington 98104		Title Cultural Treatment of Selected Species for Woody Biomass Fuel Production in the Pacific Northwest
		Contract No. ET-78-01-4126 and 01-79-ET-205.93.001
Principal Investigator Project Manager Chief Investigator Linda Sutliff Dolan Dr. Chadwick Oliver Seattle City Light University of (206) 625-3000 Washington		Period of Performance August 1, 1978 to present (projected term - 5 years)
		Obligated Fiscal Year 1979 Funding \$160,278
Work Location Cedar River Watershed and Lee Experimental Forest, Washington		Cumulative Funding thru Fiscal Year 1979 \$185,268
Project Summary Seattle City Light, third largest municipal utility in the nation, was mandated by the Seattle City Council in 1976 to fully assess all renewable resource options available for meeting the growing energy needs of its citizenry. The biomass project began in 1978 as an outgrowth of that mandate and includes the following objectives: a. To determine within broad levels the cultural treatments necessary for optimum biomass production, i.e., cultivation, fertilization, irrigation, spacing, rotation, and species mixture. b. To more narrowly define the economics of such production in terms of the dry weight costs of the fuel, including energy costs associated with production. c. To quantify environmental impacts associated with such intensive production. d. To make the fuel user cognizant of the fuels production process and the implications of its use on thier system. During fiscal year 1979, two project sites were established to study the effect of various cultural treatments on the growth behavior of black Cottonwood and red Alder. Cottonwood cuttings obtained from U.S. Forest Service land near Skykomish, Washington, were cut into 18-20 inch lengths and outplanted in March and April. Alder was obtained from logging roads near the plantation site as wildlings and transplanted immediately after pulling. Both species were planted in pure plots, mixes of 1:1, and mixes of 2:1 with spacings of 2 x 4, 4 x 6, and 6 x 8 feet. Row cultivation was perfomed three times during the growing season. Fertilizer and irrigation were not applied due to logistical problems. The work is continuing.		

Element : Production Systems
Sub-Element: Herbaceous

E-1

Contractor and Address UPR Center For Energy and Environment Research Caparra Heights Station San Juan, Puerto Rico 00935	Title Production of Sugarcane And Tropical Grasses as a Renewable Energy Source
	Contract No. DE-AS05-78ET20071
Principal Investigator Alex G. Alexander (809) 767-9705	Period of Performance June 1, 1979 to May 31, 1980
	Obligated Fiscal Year 1979 Funding \$307,000
Work Location UPR Agricultural Experiment Station P.O. Box "H" Rio Piedras, Puerto Rico 00928	Cumulative Funding thru Fiscal Year 1979 \$769,000
	Project Summary The project has several distinct phases of greenhouse screening, growth and maturation curve evaluation, field-plot testing (plant density and harvest intervals), and field-scale testing (mechanized operations). These have come along to give plant materials and information pool with two important benefits: (a) Proven species are available to sustain year-round fuels production on agricultural lands, both in mixed rotations with food crops and long-term production of biomass; and (b) a pool of species is available for year-round fuels production on marginal lands unsuited for food crops. Field-plot tests on intensive cane management began with conventional sugarcane varieties but responded with unexpectedly high yields of total dry matter and fermentable solids. Our maximum yield of 36 oven-dry tons/acre/year is about 370% higher than the PR sugar industry average, and was attained at a cost only 44% higher than the industry average (25.65/OD ton, or about \$1.70/106 Btu's). <u>Management</u> , rather than row spacing, variety, or increased water and fertilizer has been the decisive factor to date. The increased yields were accompanied by significant decline of sucrose, but not of total fermentable solids. Because of the management and sucrose changes, we have begun to refer to these plants as " <u>energy cane</u> " rather than sugarcane. The principal products would be fiber (for boiler fuel) and high-test molasses (for alcohol). In Puerto Rico some of the molasses would divert to rum rather than motor fuel. In mechanization studies, the mechanical harvest of high-density biomass is a decisive phase of the project. The project's work plan has centered on two types of harvest machinery: (a) The rotary scythe-conditioner, hopefully to harvest standing green biomass up to 45 tons/acre; and (b) modified (Klass) sugarcane harvester handling green materials from, 45 to 120 green tons/acre. The upper densities for each machine are roughly three times the level for which conventional harvest equipment is normally sold. Most sugarcane harvester designs, for example, encounter major difficulty with standing cane of about 60 tons/acre. To date, harvest trials with the rotary scythe have encountered no difficulty with short-rotation grasses (NK hybrids, 20-22 green tons/acre) or young intermediate-rotation grasses (immature Napier grass, about 25 green tons/acre). The project's bulk baler (producing 1500 pound round bales), has performed entirely as designed.

Contractor and Address Arthur D. Little, Inc. 35 Acorn Park Cambridge, MA 02140	Title Herbaceous Species Screening Program--Phase I
	Contract No. ET-78-C-02-5035-A000
Principal Investigator Robert E. Lee Kathryn A. Saterson	Period of Performance October 1978-October 1979
Work Location Cambridge, MA	Obligated Fiscal Year 1979 Funding \$112,000
	Cumulative Funding thru Fiscal Year 1979 \$112,000
Project Summary The objective of this program was to identify herbaceous plant species with potential for high biomass production on terrestrial energy farms in different regions of the U.S. The emphasis was on previously unexploited, non-woody, annual and perennial species and included consideration of developed agricultural crops with potential for high whole-plant biomass productivity. The U.S. was divided into ten regions, based on the SCS Land Resource Areas, and the six that appear to offer the most potential or commercial biomass production were identified. A literature review and field interviews generated a list of 280 promising species, on which botanical as well as supplemental economical screenings were conducted for nine of the ten regions. The results of the screening is a list, for each region, of up to 20 species that appear to have potential for high biomass productivity and should be considered for inclusion in Phase II field screening. A total of 70 different species were included in the nine regional lists. The 79 recommended species include previously unexploited species with undetermined agronomic needs such as redroot pigweed, lambsquarters, Colorado River hemp, and ragweed as well as species which have been developed as crop plants such as Bermuda grass, Kenaf, Reed Canary grass and Sudan grass. Most species offer potential in more than one region, and 12 species are recommended for 4 or more regions. They are redroot pigweed (<u>Amaranthus retroflexus</u>), giant ragweed (<u>Ambrosia trifida</u>), common mildweed (<u>Asclepias syriaca</u>), smooth brome grass (<u>Bromus intermis</u>), Bermuda grass (<u>Cynodon dactylon</u>), orchard grass (<u>Dactylic glomerata</u>), tall Fescue (<u>Fescue arundinacea</u>), Kochia (<u>Kochia scoparia</u>), Alfalfa (<u>Medicago sativa</u>), switchgrass (<u>Panicum virgatum</u>), common timothy (<u>Phleum pratense</u>) and a Sorghum hybrid (<u>Sorghum sudnaese XS. bicolor</u>).	

Project Summary (continued)

E-2

Data productivity, management needs and physiological tolerances are not available for many of the agronomically uncertain species, and although yields were obtained for 57 of the 70 recommended species, each reflects a different environment and management regime. There is a need for a research program that will produce consistent and comparable results for each test species.

Final report issued July 1979. Phase II Field Screening will be managed by the Solar Energy Research Institute (SERI).

CONVERSION SYSTEMS

Element : Conversion Systems
Sub-Element: Anaerobic Digestion

F-1

Contractor and Address University of Illinois Department of Civil Engineering Urbana, Illinois 61801	Title Biological Conversion of Biomass to Methane
	Contract No. EY-S-02-2917
Principal Investigator John T. Pfeffer Professor of Sanitary Engineering (217) 333-1000	Period of Performance June 1, 1976 - January 31, 1980
	Obligated Fiscal Year 1979 Funding \$235,430
Work Location Urbana, Illinois	Cumulative Funding thru Fiscal Year 1979 \$710,665
	Project Summary The object of this study is to evaluate the potential for recovery of methane, a fuel gas, from various sources of organic residue and crops. A semipilot-scale conversion system was used to obtain data on the effect of process variables on the product (methane) yield. Variables investigated include retention time, fermentation temperature and pretreatment techniques. Data concerning the materials handling properties of the process slurries are being collected. Characteristics of the residue as related to the processing for reclamation or ultimate disposal are being investigated, and the dewatering properties of the fermented slurry are being determined. Organic residues investigated included beef feedlot manure, corn stover and wheat straw. Data collected in these studies will be used to evaluate the economic feasibility of converting the various feedstocks into a fuel gas.

Contractor and Address Dynatech R/D Company 99 Erie Street Cambridge, Massachusetts 02178	Title Feasibility Study of Anaerobic Digestion of Agricultural Crop Residues
	Contract No. SERI-Subcontract XR-9-8157-1
Principal Investigator Dr. D.L. Wise Dr. E. Ashare (617) 868-8050	Period of Performance April 1, 1979 - September 30, 1979
	Obligated Fiscal Year 1979 Funding \$83,404
Work Location Cambridge, Massachusetts	Cumulative Funding thru Fiscal Year 1979 \$83,404
Project Summary The objective of this study was to provide cost estimates for the pretreatment/digestion of crop residues to fuel gas. A review of agricultural statistics indicated that the crop residues wheat straw, corn stover, and rice straw are available in sufficient quantity to provide meaningful supplies of gas. Engineering economic analyses were performed for digestion of wheat straw, corn stover, and rice straw for small-farm, cooperative, and industrial scales. The small-farm scale processed the residue from an average size U.S. farm (400 acres), and the other sizes were two and three orders of magnitude greater. The results of the analyses indicate that the production of fuel gas from these residues is, at best, economically marginal, unless a credit can be obtained for digester effluent. The use of pretreatment can double the fuel gas output but will not be economically justifiable unless low chemical requirements or low cost chemicals can be utilized. Additional development is necessary in this area. Use of low cost "hole-in-the-ground" batch digestion results in improved economics for the small farm size digestion system, but not for the cooperative and industrial size systems. Recommendations arising from this study are continued development of autohydrolysis and chemical pretreatment of agricultural crop residues to improve fuel gas yields in an economically feasible manner; development of a low cost controlled landfill batch digestion process for small farm applications; and determination of crop residue digestion by-product values for fertilizer and refeed.	

Contractor and Address Auburn University Auburn, Alabama 36830	Title Acid Extraction of Hemi-celluloses from Biomass
	Contract No. DE-AS05-79ET23051
Principal Investigator Robert P. Chambers Y.Y. Lee (205) 826-4827	Period of Performance February 1979 - January 1980
	Obligated Fiscal Year 1979 Funding \$263,510.00
Work Location Auburn, Alabama	Cumulative Funding thru Fiscal Year 1979 \$263,510.00

Project Summary

The broad goals of this research are to extract hemicellulose from biomass in high yields and to ferment the resulting pentose solutions to valuable products such as fuels or petrochemical substitutes.

This program will focus on:

- a. Selective Acid Extractive Hydrolysis for Hemicellulose Recovery. The objective is to develop an acid hydrolysis process which can selectively extract and recover the hemicellulose fraction of the biomass in the form of constituent sugars, primarily pentoses.
- b. Selective Acid Hemicellulose Hydrolysis and SO₂ Treatment for Improved Enzymatic Hydrolysis of Cellulosic Biomass. The objective is to evaluate the hemicellulose hydrolysis step and SO₂ treatment as a pretreatment process for the subsequent enzymatic hydrolysis of the cellulosic biomass to produce glucose.
- c. Fermentation of Pentoses to Fuels and Chemicals. The objective is to develop a fermentation process for the conversion of pentose sugars derived from selective hemicellulose hydrolysis to fuels or chemicals.

The experimental results and the mathematical models derived above shall be used to design a large-scale fermentation plant for fermenting pentose sugars obtained from selective acid hydrolysis of biomass. A detailed economic analysis shall be made, based upon projected commercial scale plant and including all cost factors (operating costs, investment, depreciation, interest, etc.) of such an analysis.

Element : Conversion Systems
Sub-Element: Fermentation

G-2

Contractor and Address University of Connecticut Storrs, Connecticut 06268	Title Immobilization of Beta-Glucosidase
	Contract No. ET-78-S-02-5141
Principal Investigator Herbert E. Klein (203) 486-2756	Period of Performance December 1978 - January 1980
	Obligated Fiscal Year 1979 Funding \$59,000.00
Work Location Storrs, Connecticut	Cumulative Funding thru Fiscal Year 1979 \$59,000.00
	Project Summary This project aims at improving the hydrolysis step in the enzymatic conversion of cellulose to sugars for fermentation to alcohol. There is a mixture of enzymes which hydrolyze cellulose in stages, one of which is the splitting of dimers and short chains to glucose. Immobilization of beta-glucosidase should speed this reaction and improve yields, thus lowering costs. Immobilized enzymes have enhanced stability and prolonged service life, thus lowering enzyme costs. The objectives of this project are: a. To test new carriers of beta-glucosidase and to improve immobilization rates. b. To design and operate reactors for hydrolysis of cellulose to glucose. c. Economic feasibility for a production-scale operation.

Contractor and Address Iotech Corporation, Ltd. 220 Liurier Ave., W., Suite 305 Ottawa, Canada K1P5Z9	Title Explosive Decompression of Lignocellulosic Biomass Contract No. DEIC02-ET 23050.000
Principal Investigator John Davis (613) 338-4126	Period of Performance April 1979 to December 1979
Work Location Ottawa, Ontario and Subcontractors	Obligated Fiscal Year 1979 Funding \$397,474 Cumulative Funding thru Fiscal Year 1979 \$397,474
Project Summary Hydrolysis of carbohydrate polymers in biomass is impeded by the highly ordered crystallinity of cellulose and protective matrix of hemicellulose and lignin. Either chemical or physical treatment can reduce this crystallinity and rupture the matrix, resulting in greatly increased yields of sugars from lignocellulosic biomass. These sugars can then be fermented to ethanol or other potential fuels or substitutes for petrochemicals. Iotech intends to use an improved physical pretreatment for lignocellulosic biomass to accomplish better yields and lower costs of sugars from biomass. The project's objectives include: a. Optimization of feedstock particle size where there is a trade-off of faster reaction with finer particles against increased subdivision cost. b. Determination of best moisture content. c. Improvement of die design and configuration. d. Evaluation of various potential feedstocks. e. Identification and removal of any substances found inhibitory to cellulose hydrolysis. A number of wood species and agricultural residues that are considered prime candidates as feedstock for energy will be evaluated in this study.	

Element : Conversion Systems
Sub-Element: Fermentation

G-4

Contractor and Address Lawrence Berkeley Laboratory University of California Berkeley, California 94720	Title Bioconversion of Cellulose and Production of Ethanol
	Contract No. W-7408-ENG48/4763-01
Principal Investigator C.R. Wilke H.W. Blanch (415) 642-1387	Period of Performance 1/10/78 to 9/31/79
	Obligated Fiscal Year 1979 Funding \$150,000
Work Location Lewis Hall University of California Berkeley, California	Cumulative Funding thru Fiscal Year 1979 Cumulative Funding through Fiscal Year 1979
	Project Summary Biomass represents a large renewable resource which may be viewed as a form of stored energy. The conversion of biomass to its component sugars and their subsequent fermentation to ethanol is the prime objective of this research. Ethanol may be either used directly or blended with gasoline for use as a transportation fuel. Various types of biomass are examined as raw material sources. These include whole trees and agricultural residues. The conversion of these biomass feedstocks to sugars requires basic information on the mechanism and rates of depolymerization of the hemicellulose and cellulose components. This hydrolysis can be accomplished either enzymatically or using a range of acids. The basic information obtained can then be used to develop optimal, low-cost, processing schemes for ethanol production. In addition, this basic information yields insights into the hydrolysis of other insoluble polymeric materials. Further, kinetic and nutritional studies on high rate fermentation processes are examined to provide information to be used in the development of the ethanol fermentation and other related chemical feedstock production.

Contractor and Address Purdue University Laboratory of Renewable Resources West Lafayette, Indiana 47907	Title Selective Solvent Extraction in Utilization of Solar Energy in Cellulosic Biomass
	Contract No. ET-78-S-02-4658
Principal Investigator George T. Tsao (317) 749-2591	Period of Performance January 1978 - December 1979
	Obligated Fiscal Year 1979 Funding \$180,000
Work Location L.O.R.R.E., Purdue University	Cumulative Funding thru Fiscal Year 1979 \$350,000
	Project Summary Cellulose is the most abundant organic material in the world. Most plants consist of 50-60 percent cellulose. Conversion of cellulose to ethanol and other products for utilization of stored energy essentially involves a two-step process: (1) hydrolysis of cellulose to glucose by enzymes or acid and (2) fermentation of glucose to ethanol. The hydrolysis step is limiting with present technology because of the difficult accessibility of acid (or enzymes) to the crystalline (or lignified) cellulose. The objectives of this project are aimed at increasing the yield of glucose by enhancing this accessibility to crystalline cellulose. This, in turn, is expected to significantly improve the economics of cellulose conversion into ethanol. The two major areas of activity at present are: 1) Hydrolysis of hemicellulose to simple saccharide and fermentation of the hemicellulose hydrolysates to 2,3 butanediol and ethanol. 2) Use of solvents to dissolve cellulose and hydrolysis of re-precipitated cellulose. After a solvent treatment, cellulose crystalline structure is disrupted. Afterward, cellulose becomes easily hydrolyzable by either acids or cellulase enzymes and their reaction kinetics.

Contractor and Address Trustees of Dartmouth College for the Thayer School of Engineering Hanover, New Hampshire 03755	Title Acid Hydrolysis of Concentrated Slurries of Cellulosic Biomass
	Contract No. EG 77-S-01-4061
Principal Investigator Hans E. Grethlein (603) 646-2239	Period of Performance 26 September 1977 to 30 September 1979 with extension to 1 March 1980
Work Location Thayer School of Engineering Dartmouth College Hanover, New Hampshire 03755	Obligated Fiscal Year 1979 Funding \$98,157
	Cumulative Funding thru Fiscal Year 1979 \$207,400
Project Summary A continuing plug flow reactor has been designed and built for the study of a continuous acid hydrolysis of cellulosic biomass. Over the two-year study, design improvements have been made so that the reactor can operate at steady state isothermal conditions. A range of the operating variables is: temperature 160° to 240° C, acid concentration 1 to 2.0% H₂SO₄ in the slurry, reaction time 6 to 15 seconds, substrate slurry concentration 5 to 15%, substrate particles size 60 to 100 mesh, and pressure 500 to 800 psig. Kinetic data have been obtained for Solka-Floc, a purified wood cellulose, newsprint, and corn stover. The kinetic parameters are developed as a function of temperature and acid concentration. The kinetic model is useful for process engineering design studies for obtaining the economic optimum process. Work is in progress on poplar. Preliminary economic analysis of continuous hydrolysis is being prepared. A renewal proposal (for two years) is pending to continue the work in the following areas: 1) Use of plug flow reactor for acid pretreatment of poplar and pine for subsequent enzymatic hydrolysis. 2) Chemical modification of hydrolysis environment. 3) Compare one and two stages of hydrolysis. 4) Determine effect of shear rate on hydrolysis. 5) Prepare process design concept for best acid hydrolysis process for pentose and hexose recovery.	

Contractor and Address Rensselaer Polytechnic Institute Troy, New York 12181	Title Fuels and Petrochemical Substitutes from Fermentation of Biomass Contract No. ET-78-G-01-3108
Principal Investigator Dr. H.R. Bungay (518) 270-6376	Period of Performance January 1, 1977 to August 31, 1980 Obligated Fiscal Year 1979 Funding \$75,000
Work Location Department of Chemical and Environmental Engineering	Cumulative Funding thru Fiscal Year 1979 \$213,300
Project Summary Studies at RPI during the 1979 contract period included coordination, analysis, reporting and planning of research on fermentation of biomass to fuels and petrochemical substitutes. Editing the "Biomass Refining Newsletter," gathering information for DOE fermentation contractors and dissemination of biomass program information were also responsibilities of the RPI group. Research was conducted in the area of fermentation reactor design. The main effort during this period was the transition of coordinating duties to SERI. Joint site visits between SERI and RPI staff to the fermentation contractors eased this transition. Activities to continue for the remaining contract period include: information dissemination, program assistance to SERI, assistance to contractors and fermentation reactor design research.	

Element : Conversion Systems
Sub-Element: Fermentation

G-8

Contractor and Address Battelle Columbus Laboratories 505 King Ave. Columbus, Ohio 43201	Title Evaluation of the Feasibility of Sequential Fermentation for Production of Ethanol
	Contract No. W-7405-ENG-92
Principal Investigator John J. Litchfield (614) 424-7624	Period of Performance August 1978 to September 1979
	Obligated Fiscal Year 1979 Funding \$93,575
Work Location Columbus, Ohio	Cumulative Funding thru Fiscal Year 1979 \$93,575
	Project Summary The primary objective of the project is to evaluate the feasibility of the sequential, semi-continuous fermentation concept, in which different strains of yeast perform specialized functions within the overall process of converting sugars to ethanol. To achieve this overall objective, the following sub-objectives will be included: a. Use crude brewers yeast from the United States collection at Northern Regional Research Center (NRRRC), U.S. Department of Agriculture and elsewhere and, if possible, from Brazil to obtain osmo-tolerant and alcohol tolerant strains for demonstration of the sequential, semi-continuous process on a laboratory scale. b. Using both molasses and purified media derived from grains, operate the sequential, semi-continuous process on a laboratory scale and measure differences in performance as compared with the conventional methods. c. Evaluate various fermentation conditions such as temperature, pH, and added nutrients for accentuating the desirable performance characteristics of the sequential, semi-continuous process. d. Estimate the potential impact of this development on ethanol cost, using the data generated in the laboratory investigation.

Contractor and Address University of Pennsylvania Department of Biochemistry and Biophysics Philadelphia, Pennsylvania 19104	Title Increasing the Efficiency of Ethanol Fermentation
	Contract No. ET-76-S02-4070
Principal Investigator R.I. Mateles (215) 243-7293	Period of Performance October 1978 to September 1979
	Obligated Fiscal Year 1979 Funding \$59,378
Work Location Philadelphia, Pennsylvania	Cumulative Funding thru Fiscal Year 1979 \$59,378
	Project Summary Ethanol is inhibitory to the yeast that produces it. Commercial ethanol fermentations are terminated when this inhibition causes the production rate to slow too much even though higher ethanol concentrations would lower distillation costs. Removal by solvent extraction of ethanol as it is formed alleviates the inhibition and maintains high production rates. The present investigation will evaluate a method of ethanol removal during its fermentation, by continuously extracting it into a suitable solvent separated from the fermentation broth by a membrane cell in the fermenter or alternatively by circulating the fermentation broth to an extraction cell through which extractant also flows. Specifically, this project will select the best extractants, evaluate them on the basis of distribution co-efficient, toxicity to the fermentation cost, service life and ease of regeneration. Design and cost analysis of a practical system for extraction will be prepared.

Contractor and Address Catalytica Associates, Inc. 3255 Scott Boulevard Suite 7-e Santa Clara, California 95051	Title Catalytic Conversion of Biomass to Fuels Contract No. ET-78-C-03-1883
Principal Investigator Robert L. Garten 408-243-9243	Period of Performance 9/15/78-9/14/79 Obligated Fiscal Year 1979 Funding
Work Location 3255 Scott Boulevard Suite 7-E Santa Clara, California 95051	Cumulative Funding thru Fiscal Year 1979 \$124,850
Project Summary The purpose of this study is to assess the role of catalysis in the thermochemical conversion of biomass into gas and liquid fuels. Key technical limitations in emerging biomass processes are identified, and the potential impact of catalysis for removing the limitations are analyzed. Catalytic conversion concepts currently under development for coal are examined for biomass, taking into account the different physical and chemical properties of these materials. The focus of this study is on the chemistry and reactor engineering aspects of thermochemical conversion processes rather than on total systems and detailed economic analysis. Thus the recommendations concerning technologies for future development are based on an assessment of the most promising catalytic and reactor engineering concepts and a judgement as to their economic feasibility. In gasification, biomass exhibits significant advantages over coal with respect to reaction rate and low char formation. However, differences in the physical and chemical properties of biomass from various sources require sizing, which is a major cost factor in most processes. It would appear prudent to direct attention to the development of a versatile gasification process which would handle a variety of biomass feeds <u>without</u> substantial pretreatment. In this regard, molten salt processes appear promising. In liquefaction, the key problem is to break down the cellulose and lignin polymers into fragments that can be upgraded to liquid fuels. Liquefaction processes utilizing alkali carbonate catalyzed liquefaction with CO and/or H₂ accomplish the depolymerization; however, the product is unstable and corrosive. Catalytic upgrading processes utilizing newly developed shape selective zeolites are discussed with respect to obtaining high quality fuels.	

Element : Conversion Systems
Sub-Element: Thermochemical Gasification

H-2

Contractor and Address Garrett Energy Research & Engineering, Inc. 911 Bryant Place Ojai, California 93023	Title Thermal Conversion of Biomass Materials into Medium Btu Gas
	Contract No. EY-76-C-031241
Principal Investigator Donald E. Garrett 805-646-0159	Period of Performance June 6, 1976-October 1, 1979
	Obligated Fiscal Year 1979 Funding \$220,000
Work Location Hanford, California	Cumulative Funding thru Fiscal Year 1979 \$584,637
	Project Summary Medium Btu gas was produced from biomass (cattle manure and sawdust) in a multiple hearth furnace. Experiments were first run on a bench scale unit to determine the effect of the principal variables, and then similar tests, plus a demonstration run, were conducted in a 6 t/d PDU. The results indicated that a reasonably priced medium Btu gas could be produced in small-scale commercial units.

Contractor and Address Gorham International Inc. PO Box 8 Gorham, ME 04038	Title An Assessment of the Technical and Economic Feasibility of Converting Wood Residues to Liquid and Gaseous Fuel Products Using State-of-the-Art and Advanced Coal Conversion Technology
	Contract No. DE-AC02-78ET20075
Principal Investigator Andrew C. Nyce, Ph.D. 207-892-6761	Period of Performance June 1, 1978 to November 30, 1979
	Obligated Fiscal Year 1979 Funding \$126,428
Work Location Gorham, Maine	Cumulative Funding thru Fiscal Year 1979 \$126,428
Project Summary The objectives of the project are to determine which state-of-the-art and advanced coal gasifiers are technically and economically suitable for gasification of wood feedstocks to produce low, medium, and high Btu gas and synthesis gas and to specify the various modifications necessary to convert these gasifiers for use with wood residues. The primary study tasks are to (1) critically review patents and published literature, (2) conduct on-site interviews with gasifier developers, users, and manufacturers, (3) obtain information on specific gasification technologies, (4) collect prior art and operating data on wood gasification, (5) estimate operating cost, capital equipment costs, gas costs, and gasification rates for coal gasifiers operating on wood feedstocks, (6) identify advantages and disadvantages of using wood feedstocks, (7) evaluate the sensitivity of capital costs and product costs to plant size, (8) determine wood type, size, shape and moisture content most suitable for specific coal gasifiers, (9) identify barriers to implementation of wood gasification plants and (10) develop implementation strategies. A final report will be issued at the end of the project. Issues covered in this report will include (1) application and usage of wood feedstocks in coal gasification, (2) feasibility of converting coal gasifiers for use with wood feedstocks, (3) economics of conversion and various associated costs, (4) recommendations for wood feedstocks and wood feedstock preparation and handling equipment, and (5) wood gasifier implementation plan including a review of various barriers and alternative strategies to overcome these barriers.	

Contractor and Address Wright-Malta Corporation Ballston Spa, NY 12020	Title Steam Gasification of Biomass
	Contract No. DE-AC02-78ET23025.A002
Principal Investigator John A. Coffman 518-899-2227	Period of Performance September 22, 1976 to present
	Obligated Fiscal Year 1979 Funding \$450,000
Work Location Ballston Spa, New York	Cumulative Funding thru Fiscal Year 1979 \$850,000
Project Summary The objective is development of a commercial process and equipment for economical and efficient conversion of biomass into medium Btu fuel gas, useful as a replacement for oil in industry or synthesis of methanol. Process chemistry has been proven in two bench-scale (10 lb/hr) equipments: a batch-type rotary autoclave and a continuous, auger-feed reactor. Optimum conditions were shown to be one hour dwell time, top temperature of 1100-1150° F, and 300 psi, sufficient to effect nearly complete conversion of any biomass to fuel gas. A final research report, C00/4736-12, was submitted on May 25, 1979, and is available from NTIS. Presently, a 6 green ton/day, 2' x 40' auger kiln gasifier PDU is under construction, scheduled to go on stream in May and be fully operational in August. A methanol PDU has been proposed. Process efficiency and economics appear attractive. Gasification efficiency, green wood chips to 450 Btu gas, is estimated to be 90%; projected gas price is \$3.00-3.50/10⁶ Btu. Overall efficiency, green wood chips to fuel grade methanol is estimated to be 73.4%; projected price is 43.5¢/gal. Commercialization of gasification equipment will begin in late 1980, and of methanol plants in mid 1982, if the methanol proposal is accepted.	

Contractor and Address Battelle-Columbus Laboratories 505 King Avenue Columbus, OH 43201	Title Conversion of Forest Residues to a Methane-Rich Gas
	Contract No. N-7405-Eng-92-102
Principal Investigator Herman F. Feldmann 614-424-6424	Period of Performance 8/1/77 to 10/31/80
	Obligated Fiscal Year 1979 Funding \$688,695
Work Location Battelle-Columbus Laboratories 505 King Avenue Columbus, OH 43201	Cumulative Funding thru Fiscal Year 1979 \$1,349,795

Project Summary

The objective of this program is to improve the technology and economics of gasifying wood residue by the use of direct gasification catalysts and the application of a unique gasification reactor system. This will be accomplished by the development of a multi-solid fluidized-bed reactor that allows the production of an intermediate-Btu gas without the use of oxygen and which requires minimal front-end preparation or drying of the biomass feed.

The program scope includes the following tasks:

- Task 1. Experimental Evaluation of Catalytic Effectiveness
- Task 2. Pilot-Plant Evaluation of Multi-Solid Gasification
- Task 3. Revision of Process Flowsheets to Incorporate Continuous Gasification Data

Task 1 has been completed as planned. Study findings demonstrated the effectiveness of catalysts, such as CaO and wood ash, incorporated into the wood feed for enhancing the gasification reactivity. Task 1 also generated extensive data on wood gasification that will provide a significant data base in this area.

Task 2 is currently in progress with construction of the pilot plant. Start-up of the pilot plant is planned in May 1980. Task 2 is scheduled for completion by the end of July 1980, with a demonstration of the technical feasibility of the proposed multi-solid fluidized-bed concept for wood gasification.

Task 3 will be initiated in August following the completion of Task 2 and will assess the economic advantage of the process relative to competing processes.

The contract schedule calls for submission of the final report upon completion of the program by the end of October 1980.

Element : Conversion Systems
Sub-Element: Thermochemical Gasification

H-6

Contractor and Address Gilbert Associates Inc. P.O. Box 1498 Reading, PA 19603	Title Research and Evaluation of Biomass Resources Conversion Utilization Systems (Market/ Experimental Analysis For Development of a Data Base for a Fuels from Biomass Model)
	Contract No. DE-AC02-78ET20611.A000 (CET-78-C-02-50221)
Principal Investigator Dr. Richard P. Stringer 215-775-2600	Period of Performance 9/1/77 through 10/1/80
	Obligated Fiscal Year 1979 Funding \$333,100
Work Location Reading, PA Morgantown, WV	Cumulative Funding thru Fiscal Year 1979 \$333,100
	Project Summary The purpose of this two-year project is two-fold: 1) Development and testing of a tool for energy planners in the form of a computerized biomass allocation model. The model will inform the regional energy planner of the most profitable selection of available biomass resources and the thermochemical conversion processes to satisfy the fuel needs of the residential, transportation, chemicals and electric utility market sectors. The optimization relies on a data base consisting of the selling prices and availabilities of biomass materials, efficiencies and manufacturing costs for thermochemical conversion processes, and the demand and selling prices of the biomass derived fuels in market sectors. 2) Biomass characterization data for a large number of biomass materials in a variety of thermochemical environments. This characterization information if being done in both the laboratory using thermo-gravimetric, pyrogas chromatographic, and effluent gas analysis; and using a versatile pilot plant capable of being operated in the entrained, fluidized, and fixed bed modes. To date (March 21, 1980), the Biomass Allocation Model has been developed and made operational and is being tested. All data required has been obtained; however, the process efficiency, manufacturing cost and selling price data is being updated. Biomass characterization is underway despite some equipment problems in the laboratory phase. Over seventy biomass materials have been collected from around the country. The pilot plant has sucessfully completed runs in all three bed modes.

Contractor and Address Texas Tech University Department of Chemical Engineering Lubbock, Texas 79409	Title Application of SGFM Technology to Other Feedstocks (Phase II)
Principal Investigator Steven R. Beck 806-742-3553	Contract No. EY-76-S-04-3779 Period of Performance 9/1/77-8/31/79
Work Location Lubbock, Texas	Obligated Fiscal Year 1979 Funding \$160,000 Cumulative Funding thru Fiscal Year 1979 \$296,000

Project Summary

Major sources of funding on this project include DOE (approximately \$260,000) and private firms. The major objectives of this project are to produce ammonia synthesis gas, ethylene and/or a low Btu gas (250-350 Btu/scf) using thermochemical reactor (SGFM) technology developed at Texas Tech University. Feedstocks for the thermochemical process include manure, wood, and field waste.

A counter current pyrolysis reactor for biomass has been invented which allows volatile organic compounds to escape from the heating zone very rapidly. This results in a different product mix than has been observed in other pyrolysis research, containing unusually high concentrations of ethylene. Fuel values of gases plus the sparing of petroleum needs by ethylene, if economically feasible, would supplement petroleum supplies. The work includes studies in an existing 1/2 ton/day test reactor to determine the influence of temperature, residence time, pressure, and feedstock materials on the yield and quality of the products of reaction. The scope of work includes economic assessments of the process, utilizing animal manures and other biomass materials as feedstocks. Studies include the effects of reactor geometry and solid/gas contact in cold models. Relationships for the design of a staged reactor will be developed. This work may benefit programs on coal hydrogasification and coal gasification.

Background work costing \$200,000 is presented in several reports, including (1) "Potential for Solid Waste as an Energy Source in Texas," J.E. Halligan, (hereafter "JEH") and W.J. Huffman (hereafter "WJH"), Project N/T-10, Governor's Energy Advisory Council, November 1974; (2) "Synthesis Gas From Manure," WJH, Arizona Cattle Feeders Association, First Annual Seminar, October 18, 1975; (3) "Ammonia Synthesis Gas Generation from Feedlot Wastes: A Pilot Scale Reactor," WJH, R.L. Peterson (hereafter "RLP") and JEH, American Chemical Society, Centennial Meeting, New York, April 4-9, 1976; (4) "Reactor Development on the Conversion of Cattle Feedlot Manure to Ethylene and Ammonia Synthesis Gas," WJH, JEH, and RLP, Final Report, EPA Grant No. S802934-01-4, August 1977; and (5) "Potential Legislative Needs and Animal Residue Conversion Processes," WJH, 1977 (to be published).

Contractor and Address Pacific Northwest Laboratory Battelle Memorial Institute P.O. Box 999 Richland, WA 99352	Title Investigation of Gasification of Biomass in the Presence of Catalysts
	Contract No. 80012
Principal Investigator L.K. Mudge L.J. Sealock, Jr. R.T. Robertus 509-375-2268	Period of Performance 10-1-77 to open
	Obligated Fiscal Year 1979 Funding \$560,000
Work Location Richland, WA	Cumulative Funding thru Fiscal Year 1979 \$1,050,000

Project Summary

The purpose of the study is to evaluate the use of single and multiple catalyst systems for gasification of biomass to produce high-valued products. Gasification catalysts, alone or in combination with methanation, cracking and/or reforming catalysts, are used to generate desired product compositions. The major objectives of the study are to determine the technical feasibility of catalytic processes for generation of methane, hydrocarbon and methanol synthesis gases, hydrogen, carbon monoxide, and ammonia synthesis gas and to evaluate the economic feasibility of technically feasible processes.

The work is organized as four tasks: Laboratory Studies (Task 1), Process Development Unit (PDU) Design, Procurement and Installation (Task 2), PDU Operation (Task 3), and Feasibility Studies (Task 4). Task 2 is completed, and the remaining tasks are now being conducted.

Studies completed to date have shown the technical feasibility for generation of methane and methanol from wood. Methanol yield from dry wood is about 60% of the wood weight, or 180 gallons per dry ton, at an energy conversion efficiency of 65%. Methane can be produced from wood at an energy efficiency of about 60%. The processes promise to save about 40% in plant capital investment.

Laboratory studies, PDU studies, and feasibility studies are continuing. Information from these studies will be used to determine economic feasibility. A report on the preliminary feasibility estimate will be submitted by 15 August 1980.

The study is part of the Biomass Energy Systems program on production of gaseous fuels from wood and on indirect production of liquid fuels from wood.

Element : Conversion Systems
Sub-Element: Thermochemical: Liquefaction

I-1

Contractor and Address University of Arizona Department of Chemical Engineering Tucson, Arizona 85721	Title Modified Extruder for Feeding Fine-Ground Cellulosic Slurries to Pressure Systems
	Contract No. DE-AS05-78ET20067
Principal Investigator Don H. White (602) 626-1224	Period of Performance January 1, 1978 to December 31, 1979
	Obligated Fiscal Year 1979 Funding \$109,540
Work Location Tucson, Arizona	Cumulative Funding thru Fiscal Year 1979 \$109,540
	Project Summary The objective of this contract is to evaluate through experimental tests whether a modified screen extruder (as used in food and plastic industries) could be used to feed a finely ground slurry ground sawdust in heavy oils or water into a pressure reactor system. It was shown early in this project that an extruder feeder could pump solid cellulosic slurries up to 70 weight percent, compared with 25 weight percent for existing piston pump systems. This means that an extruder feeder can minimize the quantity of a recycle oil or water. To date, considerable data on the properties of sawdust/oils and sawdust/organic liquid slurries have been determined, involving mainly rheology, compression of the solids in the slurry under pressures up to 10,000 psi, the resistance to flow through said compressed slurries, surface friction of stiff (concentrated) slurries, internal friction of stiff slurries, effect of sawdust particle size and particle size distribution, the effect of void volume and the effect of solids surface wetting. Results of this project should be of direct interest to waste-to-oil projects as well as cellulosic gasification projects.

Element : Conversion Systems
Sub-Element: Thermochemical: Liquefaction

I-2

Contractor and Address University of California Lawrence Berkeley Laboratories (LBL) Cyclotron Road Berkeley, California 94720	Title Catalytic Liquefaction of Biomass
	Contract No. W-7405-ENG-48
Principal Investigator Sabri Ergun (415) 486-6666	Period of Performance October 1, 1977 -- open ended
	Obligated Fiscal Year 1979 Funding \$352,000
Work Location LBL, Berkeley, California 94720	Cumulative Funding thru Fiscal Year 1979 \$562,000
	Project Summary This project has three main objectives. These are (1) to provide continued independent technical evaluation of the progress of the BES liquefaction program; (2) to monitor operations of the biomass liquefaction facility at Albany, Oregon; and (3) to undertake engineering and bench scale experimental studies to enhance the progress of biomass to oil program of DOE. The goal of these objectives is to provide a technical data base for the eventual commercialization of the most economical, efficient and environmentally sound biomass liquefaction (synthetic liquid fuel) facility. Current progress indicates that the construction of the LBL process evaluation unit has been completed, and shakedown tests are nearing completion. At the Albany, Oregon, facility, using the LBL conceived process scheme and technical directives, the unit has successfully produced several barrels of wood oil. Moreover, pumpable water-based slurries containing 33% biomass have been experimentally produced. Several patents have been submitted to cover these achievements. Continued efforts include design, fabrication and operation of a biomass liquefaction process evaluation unit (PEU) at Lawrence Berkeley Laboratory. For the Albany, Oregon, facility, a data base will be developed for the design, fabrication and installation of a commercial tubular reactor. Efforts will also be made to develop a data base for the processing of biomass to highly concentrated liquid and/or solid slurries for high pressure injection into liquefaction reactor systems.

Element : Conversion Systems
Sub-Element: Thermochemical: Liquefaction

I-3

Contractor and Address Wheelabrator Cleanfuel Corporation 2550 "M" St. N.W. Suite 600 Washington, D.C. 20037	Title Operation of the Biomass Liquefaction Facility, Albany, Oregon												
	Contract No. ET-78-C-06-1092												
Principal Investigator W.L. Berry, Jr. Project Manager The Rust Engineering Company (205) 254-4000	Period of Performance July 1, 1978 - June 30, 1980												
	Obligated Fiscal Year 1979 Funding Unknown												
Work Location Albany, Oregon Birmingham, Alabama	Cumulative Funding thru Fiscal Year 1979 Unknown												
	Project Summary The objective is to obtain definitive process information, sufficient for commercial design and economic evaluation purposes, for the conversion of biomass to syncrude. This objective is to be accomplished through the execution of experimental and developmental programs in the Government-owned Process Development Unit (PDU) located adjacent to the Bureau of Mines, Metallurgical Research Center at Albany, Oregon. The Contractor provides all things necessary for the operation of the U.S. Department of Energy PDU and carries out the experimental and developmental operations in the plant as directed by the Government or its Technical Project Officer. Operation is continuous except for directed or emergency shutdown, and consists of the following phases of work: <table><tr><td>Phase I</td><td>Preparatory Work</td></tr><tr><td>Phase II</td><td>Operating Adjustment Period</td></tr><tr><td>Phase III</td><td>Continuation of Process Investigation</td></tr><tr><td>Phase IV</td><td>Modifications of Plant Configuration and/or Process Flowsheets</td></tr><tr><td>Phase V</td><td>Process Development Operations</td></tr><tr><td>Phase VI</td><td>Shutdown and Phaseout</td></tr></table> Phases I, II, and III have been completed. Phases IV and V are underway. A number of test operations have been performed in the Process Development Unit to establish feasibility for two processes: the Pittsburgh Energy Research Center (PERC) process utilizing an organic carrier vehicle for the biomass material; and the Lawrence Berkeley Laboratories (LBL), University of California at Berkeley, process utilizing water for hydrolysis and for the carrier vehicle. A substantial amount of product oil has been produced by the LBL process. This material is being evaluated to determine highest and best use. Economic evaluations of commercial facility capital and operating costs indicate attractive future returns for commercialization.		Phase I	Preparatory Work	Phase II	Operating Adjustment Period	Phase III	Continuation of Process Investigation	Phase IV	Modifications of Plant Configuration and/or Process Flowsheets	Phase V	Process Development Operations	Phase VI
Phase I	Preparatory Work												
Phase II	Operating Adjustment Period												
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Phase IV	Modifications of Plant Configuration and/or Process Flowsheets												
Phase V	Process Development Operations												
Phase VI	Shutdown and Phaseout												

Element : Conversion Systems
Sub-Element: Thermochemical: Liquefaction

I-4

Contractor and Address Battelle-Pacific Northwest Laboratory P.O. Box 999 Richland, Washington 99352	Title Bench Scale Research in Biomass Liquefaction in Support of the Albany, Oregon, Experimental Facility
	Contract No. EY-76-C-06-1830
Principal Investigator Douglas C. Elliott (509) 375-2026	Period of Performance October 1976 - continuing
	Obligated Fiscal Year 1979 Funding \$180,000
Work Location Pacific Northwest Laboratory Richland, Washington	Cumulative Funding thru Fiscal Year 1979 \$370,000

Project Summary

The objective of this project is threefold:

- 1) Facilitate the production of oil from biomass at the Albany Experimental Facility through bench scale process development experimentation.
- 2) Provide analytical support of a routine and specialized nature as needed by the facility operator or determined to be necessary by the technical project monitor.
- 3) Support the development of new biomass liquefaction processes and specifically provide managerial and analytical support for the thermolysis process under development at Wright-Malta Corporation.

RESEARCH AND DEVELOPMENT

Element : Research and Development
Sub-Element: Innovative Conversion

J-1

Contractor and Address Stanford University Civil Engineering Department Stanford, California 94305	Title Heat Treatment of Organics for Increasing Anaerobic Bio- degradability
	Contract No. XR-98174-1
Principal Investigator Dr. Perry L. McCarty (415) 497-2300	Period of Performance June 1, 1979 to May 31, 1980
	Obligated Fiscal Year 1979 Funding \$167,587
Work Location Terman Engineering Center Stanford University Stanford, California 94305	Cumulative Funding thru Fiscal Year 1979 \$164,587

Project Summary

The objective of the study is to evaluate thermochemical pretreatment as a method for increasing the anaerobic biodegradability of organic materials so that they can be more completely fermented to methane gas, a potential source of fuel. The current study has five specific phases: (1) biological conversion of lignocellulose to methane, (2) biodegradation of lignin and lignin fractions, (3) pretreatment of nitrogenous organics for increasing biodegradability, (4) biodegradation of lignin aromatic compounds, and (5) biochemical methane potential and toxicity testing.

The pretreatment process found to have good potential for increasing methane yields from lignocellulose decomposition is termed autohydrolysis. In this process a slurry of lignocellulosic material (currently white fir) receives staged treatment at temperatures varying from 175°C to 225°C. In the absence of chemical additions, this heating results in the production of soluble materials, including organic acids which lower the pH and increase the rate of hydrolysis. The soluble materials are then fermented. Currently, the organic products formed under different treatment temperatures and times are being analyzed in order to better understand this process and work towards its optimization.

In phases 2 through 4, the effect of pretreatment on lignin fractions and nitrogenous materials is being studied. This research complements that from phase 1. The last phase is being conducted to evaluate the potential of pretreatment for a variety of materials.

The aim of this project is to find a means for significantly increasing the methane yield from fermentation of agricultural and forest residues. These are significant potential sources of energy for the future.

Contractor and Address University of California College of Engineering Office of Research Services Berkeley, California 94720	Title Solar Energy Conversion through Biophotolysis
	Contract No. EY-76-S-03-0034-239
Principal Investigator John R. Benemann	Period of Performance April 1, 1977-January 31, 1980
	Obligated Fiscal Year 1979 Funding \$46,310
Work Location Richmond, California	Cumulative Funding thru Fiscal Year 1979 \$221,862
Project Summary This project has for its objective the development of a biological process for using solar energy in the decomposition of water to hydrogen and oxygen. The main system investigated under this project uses nitrogen-fixing blue-green algae. These filamentous algae contain two distinct types of cells--the vegetative cell, capable of nitrogen fixation and, in the absence of nitrogen gas, hydrogen production. These algae can be used to demonstrate simultaneous hydrogen and oxygen production when illuminated under an inert atmosphere. In the laboratory, 3% conversion efficiency of light energy into hydrogen fuel could be demonstrated. However, under outdoor conditions, only about 0.2-0.3% of total solar energy is converted to hydrogen. These conversion rates could be sustained for a period of one month or longer, without need for replacing the cultures. Development of a practical system of biophotolysis will require both improvements in the rate and efficiency of hydrogen production and the design of low-cost converters. During FY 1979, only the former objective was pursued. Immunochemical studies were undertaken to establish the regulatory processes affecting the biosynthesis and activity of the nitrogenase enzyme responsible for most hydrogen production in heterocystous blue-green algae. Also, the localization of the enzyme in heterocysts was studied by specific labeling and electron microscopic observations. The mechanism by which the hydrogen producing system is protected against oxygen inhibition was investigated. These experiments were designed to allow a better understanding of the fundamental mechanisms affecting hydrogen production in these algae. Current progress goals include the design and testing of a prototype converter and study of alternative biophotolysis systems. Preliminary experiments with photosynthetic bacteria have been initiated. Biophotolysis is of significant long-term potential which requires research and exploratory development at this time. Some near-term applications are possible in combination with waste treatment.	

Contractor and Address Dynatech R/D Company 99 Erie Street Cambridge, MA 02139	Title Liquid Hydrocarbon Fuels Production from Biomass
	Contract No. EG-77-C-02-4388-7
Principal Investigator D.L. Wise J.E. Sanderson 617-868-8050	Period of Performance July 1978-June 1980
	Obligated Fiscal Year 1979 Funding \$256,000
Work Location Cambridge, MA	Cumulative Funding thru Fiscal Year 1979 \$320,000
	Project Summary A process is being developed whereby biomass or other forms of organic matter may be converted to liquid hydrocarbon fuels. The process consists of several steps which are: 1. The production of long chain volatile fatty acids (through caproic acid) via methane suppressed non-sterile anaerobic fermentation. 2. Separation and concentration of the long chain volatile fatty acids via liquid-liquid extraction. 3. Electrolytic oxidation of the long chain volatile fatty acids to alkanes via Kolbe electrolysis. Current efforts are concentrated on the operation of this process in a continuous mode on a 300 liter scale. Preliminary economic analyses indicate that this process will be capable of producing liquid fuels from biomass at a cost which compares most favorably with other competitive processes.

Element : Research and Development
 Sub-Element: Innovative Conversion

J-4

Contractor and Address Massachusetts Institute of Technology Department of Nutrition and Food Sciences 77 Massachusetts Ave. Cambridge, Massachusetts 02139	Title Degradation of Cellulosic Biomass and Its Subsequent Utilization for the Production of Chemical Feedstocks Contract No. Original No.: EG-77-S-02-4198 Subcontract No.: XR-9-8109-1
Principal Investigator Daniel I.C. Wang 617-253-2126	Period of Performance Cumulative: 12/1/76-1/31/80 Present: 2/1/79-1/31/80
Work Location Massachusetts Institute of Technology Department of Nutrition and Food Science 77 Massachusetts Avenue Cambridge, MA 02139	Obligated Fiscal Year 1979 Funding \$472,128.61
	Cumulative Funding thru Fiscal Year 1979 \$1,372,157.61
Project Summary This project is a coordinated effort in the biological degradation of cellulosic biomass and the production of useful chemical feedbacks. One of the major objectives is the direct single-step microbiological conversion of celulosic biomass to a liquid fuel, ethanol. This will be achieved using an anaerobic and thermophilic bacterium, <u>Clostridium thermocellum</u>, which is able to degrade biomass with the concurrent production of ethanol. This organism in combination with a second anaerobic and thermophilic bacterium, <u>Clostridium thermosaccharolyticum</u>, can effectively convert both the cellulosic and hemicellulosic fractions in biomass to ethanol. The other major area of study is the production of useful chemical feedstocks. These include the production of acrylic acid by <u>Clostridium propionicum</u>, the production of acetone/butanol by <u>Clostridium acetobutylicum</u> and the production of acetic acid by <u>Clostridium thermoaceticum</u>. Lastly, the microbiological degradation of lignins by mixed cultures is also being examined. The production of a liquid fuel, ethanol, from biomass fits directly into the goals of the Biomass Energy Systems. Some of the milestones which have been achieved during the contract periods on this segment of the project are briefly summarized. Mutation, selection and adaptation programs have been successful with <u>C. thermocellum</u> and <u>C. thermosaccharolyticum</u> where the ethanol tolerance has been increased substantially as well as directing the catabolism of this organism to a single product ethanol. The biomass hydrolysis products (C₆ and C₅ sugars) have been effectively converted by the second anaerobic bacterium, <u>C. thermosaccharolyticum</u>. Mixed culture fermentations on biomass using these two organisms have yielded excellent results; for example, ethanol at 30 g/l (3.8% V/V) has also been characterized. Lastly, increased cellulase production through mutation has also yielded hyperproducing strains.	

The production of other chemicals to spare usage of fossil fuel also falls within the objectives of Biomass Energy Systems. In particular, all of the chemicals (acetic, acetone/butanol, acrylic) being studied are produced in large volume in the U.S.A. The acetic acid fermentation has achieved concentrations of 50 g/l. The production of acetone, butanol has shown increased product concentration through in situ extractive fermentation. Lastly, we have demonstrated for the first time in history the production of acrylic acid through microbial actions.

Contractor and Address Exxon Research and Engineering Company Government Research Laboratories Linden, New Jersey 07036	Title Sensitized Photoelectrolysis of Water with Sunlight Contract No. EG-77-C-02-4271
Principal Investigator Amal K. Ghosh H. Paul Maruska 201-474-3465	Period of Performance June 1, 1977-December 31, 1978 Obligated Fiscal Year 1979 Funding None
Work Location Exxon Research and Engineering Company Government Research Laboratories Linden, New Jersey 07036	Cumulative Funding thru Fiscal Year 1979 \$132,000

Project Summary

A study was made of solar driven water photoelectrolysis cells employing semiconductor electrodes. An extensive review of the literature was undertaken, and the three major problem areas for these devices were identified: corrosion, poor sunlight absorption, and external bias requirement. Although many semiconductors had been tested, none had proven free of all three defects. Two approaches were thus followed for the experimental studies: (1) impurity sensitization of wide band gap stable oxides, and (2) heterostructure formation between unstable sunlight absorbers and corrosion resistant oxides. Water decomposition was achieved with visible light excitation of CR-doped TiO_2 . Transport properties were studied for TiO_2 and $SrTiO_2$ electrodes doped with V, Cr, Mn, Fe, Co and Ni. The correlation between bias requirement and electron affinity of oxides was identified. Performance of heterostructure electrodes was shown to be limited either by pin hole problems or by potential barriers between the valence bands.

Element : Research and Development
Sub-Element: Innovative Conversion

J-6

Contractor and Address Rutgers University Cook College Department of Biochemistry and Microbiology New Brunswick, NJ 08903	Title Producing Mutants of <u>Trichoderma viride</u>
	Contract No. EY-76-G-01-2539
Principal Investigator Douglas Eveleigh 201-932-9829	Period of Performance October 1977 to September 1979
	Obligated Fiscal Year 1979 Funding \$108,835
Work Location New Brunswick, NJ	Cumulative Funding thru Fiscal Year 1979 \$108,835

Project Summary

The objective of this project is to design a series of selective screening techniques for the isolation of high yielding and catabolic repression resistant mutants of Trichoderma viride and T. reesei. Economical production of glucose from cellulosic biomass can provide the basis for industrial fermentation products which substitute for petrochemicals. This project devised a method to obtain catabolite repression-resistant mutants that hydrolyze cellulose in the presence of glycerol. To date, over 10^6 potential mutants have been screened using methods developed for screening total cellulase, endoglucanase, cellobiase, constitutive enzyme and end product resistance. Of these, 500 mutants were isolated and tested further. Three of these mutants are extremely attractive. One is a high yielding cellobiohydrolase mutant and two are catabolite repression resistant, high yielding mutants. One particular mutant has been found to consistently exhibit a productivity of 100 IU/l/hr and thus shows the potential of cutting residence time in a large fermentation facility from 14 days to only 4 days.

Contractor and Address University of Pennsylvania Department of Biochemistry and Biophysics Medical School Philadelphia, PA 19104	Title Biological Production of Liquid Fuels from Cellulosic Residues
Principal Investigator E.K. Pye A.E. Humphrey 215-243-8038	Contract No. EY 76-S-02-4070-AD04 Period of Performance December 1978 to December 1979
Work Location Philadelphia, PA	Obligated Fiscal Year 1979 Funding \$428,080 Cumulative Funding thru Fiscal Year 1979 \$428,080
Project Summary This contract is in its third year and is in collaboration with General Electric (Philadelphia) as subcontractor. The primary thrust of the Penn/GE studies has been the production of ethanol and a lignin/butanol slurry (a pumpable substitute for heating oils and diesel) as major products. The efforts to date, have concentrated on the use of poplar wood as a substrate. Its geographical adaptability and relatively high yields of 10 tons/acre/year make poplar exceptionally attractive for use as a fermentation feedstock. The process emphasizes total biomass utilization, maximizes high value by-products (e.g., polymer grade lignin), operates at elevated temperatures to reduce capital and operating costs, and uses novel low-energy technology for recovery of both ethanol and butanol, The process employs (1) pre-treatment of the biomass with hot butanol, (2) combined high-temperature saccharification and vacuum fermentation for ethanol production, and (3) combined saccharification and extractive fermentation for butanol production. Economic and technical optimization studies are in progress, and recent results conform to the overall concept of the process. Excellent stabilities of <u>Thermoactinomyces</u> cellulase have been demonstrated, making high-temperature operations possible. Several efficient and inexpensive extractants for butanol have been identified and tested. Economics of this process indicate that ethanol production costs range between \$0.70 and \$0.80 per gallon. These costs depend on by-product credits, operating yields, and original biomass costs.	

Element : Research and Development
Sub-Element: Aquatic Systems

L-1

Contractor and Address University of California College of Engineering Office of Research Services Berkeley, California 94720	Title Large-Scale Freshwater Microalgae Biomass Production for Fuel and Fertilizer
	Contract No. DE AS03-76 SF00034
Principal Investigator William J. Oswald 415-642-6000	Period of Performance October 1, 1977-March 31, 1980
	Obligated Fiscal Year 1979 Funding \$194,944
Work Location Richmond, California	Cumulative Funding thru Fiscal Year 1979 \$348,872
	Project Summary This project has for its objective the development of an integrated biomass energy wastewater treatment system based on microalgae. Microalgal ponds are already extensively used in municipal, industrial, and agricultural wastewater treatment; however, a practical low-cost process for harvesting these microscopic plants is lacking. Development of such a process is the principal task of this project. Over the past year a simple flocculation-sedimentation method for algal removal from oxidation ponds has been demonstrated using two 0.25 acre pilot-scale ponds. This harvesting process is based on the use of shallow paddlewheel-mixed algal production ponds operated within seasonally adjusted limits of detention time, depth, and mixing speed. The algal culture discharged from these ponds will flocculate and settle when held in an isolation pond for two days. The supernatant from the ponds would be suitable, after sand filtration, for discharge to surface bodies of water. Productivity of the algal ponds exceeded 50 metric tons/hectare/year of harvestable biomass. The algal sludge derived from the settling ponds was demonstrated to be a suitable substrate for methane production by anaerobic digestion. Thus, the key objectives of this project have been met--development of a low-cost microalgal harvesting process which allows a high biomass productivity and yields a feedstock readily convertible to methane gas. Economics of this process appear very favorable. Objectives for next year are to verify and optimize this process and to develop a detailed economic analysis for applications to local communities. The data collected during this project also has applications to other areas of biomass energy systems, particularly the production of chemical feedstocks from microalgae.

Element : Research and Development
Sub-Element: Aquatic Systems

L-2

Contractor and Address California Institute of Technology Division of Engineering and Applied Sciences 1201 E. California Boulevard Pasadena, California 91125	Title Biological Investigation of Marine Farms
	Contract No. EY-76-C-03-1275
Principal Investigator James J. Morgan Wheeler J. North 213-795-6811	Period of Performance October 1, 1977-September 30, 1979
	Obligated Fiscal Year 1979 Funding \$512,000
Work Location Corona del Mar, California	Cumulative Funding thru Fiscal Year 1979 \$512,000
	Project Summary The main objective is to evaluate the possibility of utilizing kelp as an energy crop. Earlier studies have demonstrated that kelp does not grow well on artificial structures in the ocean without the addition of nutrients. The efforts thus far have concentrated on gathering information which would permit the obtaining of maximal yields. This year, laboratory and field studies will be conducted to: a. Determine the elemental requirements of <u>Macrocystis</u> (Giant Kelp). b. Develop an optimal strategy for fertilizing plants in an oceanic setting. c. Determine harvest yields from a group of adult test plants continually fertilized. Laboratory results indicate that growth-stimulating properties of deep water have been variable. In some cases, changes in availability of trace metals such as Fe and Mn in deep water correlate with changes in ability of the medium to stimulate growth. Mn is clearly a required nutrient. Surface water usually contains adequate supplies of those trace metals lacking in deep water and vice versa. Hence, mixtures of the two can complement each other as growth media. The test farm experiment is in the initial stages, with transplanting in progress. Yield data should become available in 1979.

Element : Research and Development
Sub-Element: Aquatic Systems

L-3

Contractor and Address Woods Hole Oceanographic Institution Woods Hole, MA 02543	Title Cultivation of Macroscopic Marine Algae and Freshwater Aquatic Weeds
	Contract No. XR-9-8133-1
Principal Investigator John H. Ryther	Period of Performance May 1, 1979 - April 30, 1980
	Obligated Fiscal Year 1979 Funding \$252,163
Work Location Harbor Branch Foundation P.O. Box 196 - RFD 1 Ft. Pierce, FL 33450	Cumulative Funding thru Fiscal Year 1979 \$679,830
	Project Summary Research is continuing on the cultivation of the red seaweed <u>Gracilaria tikvahiae</u> , investigating both intensive, suspended culture methods and non-intensive pond-bottom culture. Effects of pulsing air, water, and nutrients for short periods of time are being studied in an attempt to reduce costs and energy inputs. The possibility of simultaneously extracting agar from <u>Gracilaria</u> and fermenting the remaining organic content to methane are also being investigated. Some preliminary studies of ocean-cage culture of <u>Gracilaria</u> and some species of brown seaweeds (<u>Sargassum</u> , <u>Fucus</u> , <u>Ascophyllum</u>) are soon to be initiated. Annual productivity of the freshwater macrophyte <u>Pistia stratiotes</u> (water lettuce) in central Florida is being determined. Water hyacinths are being grown for an entire year in a one-quarter-acre demonstration pond, harvested, processed, anaerobically digested to methane, and the residue, supplemented with secondary sewage effluent, recycled as the nutrient supply for the production unit. A similar experiment with <u>Gracilaria</u> has been initiated. Economic and energy cost-benefit analyses of the aquatic plant systems will be evaluated, considering their use for fuel production, advanced wastewater treatment, chemicals (e.g., agar), feed or fertilizer production, and water reclamation.

Contractor and Address Woods Hole Oceanographic Institution Woods Hole, MA 02543	Title Bioengineering Aspects of Inorganic Carbon Supply and Light Effects in Mass Algal Cultures Contract No. SERI XR-9-8144-1 DOE Prime--EG-77-C-01-4042
Principal Investigator Dr. Joel C. Goldman 617-548-1400	Period of Performance June 1, 1979-May 31, 1979
Work Location Woods Hole, MA	Obligated Fiscal Year 1979 Funding \$95,645 Cumulative Funding thru Fiscal Year 1979 \$180,554
Project Summary The study involves a thorough investigation of the inorganic carbon requirements of algae under mass culture conditions. The major research topics considered include: (1) the growth kinetics of various freshwater and marine algae under inorganic limitation at different pH levels; (2) comparisons of growth with bubbled CO₂ and HCO₃ alkalinity as inorganic carbon sources at varying pH levels; (3) effects of pH on algal growth under non-carbon limiting conditions; and (4) effects of mixing in inorganic carbon limiting and non-limiting situations on algal growth. The studies are being carried out under laboratory conditions with continuous algal cultures and controlled temperature and light intensity. Algae are grown in a defined medium with pH control using non-carbon buffers. A variety of algal species that typically have been identified as being dominant in outdoor mass cultures are being examined under the above conditions. Results to date include: (1) With proper non-carbon pH control, bicarbonate is an adequate inorganic carbon source only up to a relatively low input flux of inorganic carbon. Chemical precipitation prevents further bicarbonate addition; (2) for yield optimization, some form of bubbled CO₂-enriched gas is required; (3) for CO₂-air mixtures up to at least P_{CO₂} < 0.17%, algal production at a fixed growth rate is linearly proportional to the total input flux of bubbled CO₂ (P_{CO₂} x bubble rate); (4) with small bubbles, about 50% efficiency of carbon use is achieved whereas with large bubbles, the efficiency is reduced to <20%. For P_{CO₂} ≥ 1% bubble size is unimportant, and light limitation is achieved at low bubble rates. Experiments to test the effect of pH on the above processes are in progress. The major goal is to isolate the effects of inorganic carbon limitation, pH, and mixing on algal growth under mass culture conditions. With this knowledge it may be possible to estimate the actual quantities of inorganic carbon necessary to force light to be limiting under mass culture conditions so that rational decisions can be made regarding the engineering design and economics of carbon supply for very large algal bioconversion schemes.	

Element : Research and Development
Sub-Element: Aquatic Systems

L-5

Contractor and Address Columbia University School of Engineering and Applied Science New York, New York 10027	Title Algal Concentration by Ultrafiltration
	Contract No. EY-76-S-02-4076
Principal Investigator Harry Gregor S. Mizvahi 212-280-4716	Period of Performance August 2, 1976-July 31, 1979
	Obligated Fiscal Year 1979 Funding \$269,000
Work Location New York, New York	Cumulative Funding thru Fiscal Year 1979 \$269,000
	Project Summary Twenty-four different algal cultures were grown, representing freshwater species grown under different conditions. A few marine algae were also treated. Ultrafiltration (F) studies were carried out at varying flux rates and constant pressure. The experiments run in the laboratory concentration cells have yielded up to 500-fold concentrations, exceeding initial estimates. Pilot plants having an effective membrane area of 5 ft ² are being built and will be tested on different algal species, using membranes of different porosities with different inter-membrane spacings to avoid mechanical blockage and achieve maximal convention across the membrane surfaces. Tests will first be carried out on both fresh and marine algae to investigate flux-pressure characteristics and ascertain the degree of concentration achievable. Then, three optimized devices will be made for field use in other laboratories.

Element : Research and Development
Sub-Element: Aquatic Systems

L-6

Contractor and Address Columbia University School of Engineering and Applied Science New York, NY 10027	Title Permselective Membrane Control of Algal and Wood Digesters for Increased Production and Chemical Recovery
	Contract No. EG-77-S-02-4292
Principal Investigator Harry P. Gregor 212-280-4716	Period of Performance July 1977 to January 1979
	Obligated Fiscal Year 1979 Funding \$82,682
Work Location New York, New York	Cumulative Funding thru Fiscal Year 1979 \$82,682
	Project Summary The objective of this project is to investigate permselective membrane control of algal and wood fermenters. In this study, various forest product pulps and algal species are fermented using two- to four-liter capacity vessels under conventional or high-rate organic loadings. The steady-state process is seeded by an anaerobic sludge and operated with a two- to four-week hydraulic detention time. Project tasks include monitoring gas production, solids, percent volatiles, and chemical oxygen demand. The contents of the vessel are then circulated through the appropriate membranes to remove various end-products, especially ammonia, methane, and short chain fatty acids such as acetic acid, propionic acid, butyric acid, valeric acid, and isovaleric acid. The project will also monitor separation processes such as ultrafiltration using non-fouling membranes, electrodialysis, reverse osmosis, water-splitting membranes, solvent extraction, and enzyme-coupled membranes. These permselective membranes not only allow practical separation, but control the operations of fermenters. The algae being evaluated include the following: <u>Anabaena</u> , <u>Chlorella</u> , <u>Chlorococcus</u> , <u>Gleotrichia</u> , <u>Microcystis</u> , <u>Phormidium</u> , and <u>Selenastrum</u> .

SUPPORT AND OTHERS

Element : Support and Others
Sub-Element: Analysis

M-1

Contractor and Address SRI International 333 Ravenswood Avenue Menlo Park, California 94025	Title Mission Analysis for the Federal Fuels from Biomass Energy Program
	Contract No. EY-76-C-03-0115
Principal Investigator Fred A. Schooley 415-326-6200	Period of Performance January 1, 1978 to January 30, 1979
	Obligated Fiscal Year 1979 Funding \$250,000
Work Location Menlo Park California and 10 U.S. areas	Cumulative Funding thru Fiscal Year 1979 \$250,000
	Project Summary SRI International (formerly Stanford Research Institute) has been assisting DOE in determining which fuels from biomass missions (conversion routes) are most likely to lead to economically viable market penetration within the competitive fuels environment. The overall objective of this study is to perform a mission analysis of the Federal Biomass Energy Systems Program and, based on the results, develop program recommendations. To accomplish this objective, SRI has undertaken the following activities: a. Energy flow diagrams showing all possible paths of the biomass production/resource base, potential conversion technologies, alternative products, and end-use consumption markets have been developed. b. Forecasts of biomass availability as a function of price through the year 2020 for alternatives including organic residues, terrestrial energy crops, and marine energy crops have been developed. c. Potential biomass conversion technologies including current status of development have been described. Considered in the evaluation of selected options were feedstock requirements, storage and preparation requirements, process efficiency (detailed schematic flow diagrams were developed including energy and material balances), and process economics (including capital and operating costs, and required selling prices of products). d. Program recommendations for the Federal Biomass Energy Systems Program have been developed.

Contractor and Address SRI International 333 Ravenswood Avenue Menlo Park, California 94025	Title Preparation of a Cost Data Bank for DOE/Biomass Energy Systems Branch
	Contract No. EY-76-C-03-0115/PA141
Principal Investigator Dr. A.Y. Kam Mr. R.L. Dickenson (415) 326-6200	Period of Performance October 1, 1978 to December 31, 1979 (Extension to 9/30/80 has been requested)
	Obligated Fiscal Year 1979 Funding \$185,307
Work Location 333 Ravenswood Avenue Menlo Park, CA 94025	Cumulative Funding thru Fiscal Year 1979 \$340,007
	Project Summary This study deals with the preparation of a broad-based biomass energy systems technology and cost data bank for the Biomass Energy Systems (BES) Branch of the Department of Energy. The major effort involves a critical economic and technical analysis of a wide spectrum of technology options (thermochemical and biochemical) for processing various biomass materials into energy and solid fuels from biomass. When completed, the data bank will provide a comprehensive and consistent data base for workers in the field. Twenty-two BES technology options have been selected for inclusion in the Data Bank. The selection consists of fourteen thermochemical conversion options and eight biochemical options. The majority of the options are believed to be available now or in the near-term. A consistent methodology has been developed to permit a systematic analysis of the technology options. At present, all the analyses are near completion. Results indicate that the major factors contributing to cost uncertainties for biomass energy products are quite diverse in nature. For processes in early developmental stages, process know-how in terms of conversion, product yields and selectivity and thermal efficiency are major factors. For a number of conversion options, the by-product value will strongly influence the fuel product cost. For well established technologies such as power and steam generation, feed and equipment costs constitute the major uncertainties. A report is being prepared on this task. The data bank will be used as the basis for studies on the likely future market penetration of biomass energy products and the probable influence of available Federal options on the commercialization of Biomass Energy System technologies. The SRI Biomass Market Penetration Model has been refined and updated. Results from the data bank are being integrated with the existing data base. Test runs of the model are underway.

Contractor and Address Intertechnology/Solar Corporation 100 Main Street Warrenton, Virginia 22186	Title Follow-on Studies of the Photosynthesis Energy Factory
	Contract No. ET-78-C-01-3024
Principal Investigator Dr. Malcolm D. Fraser (703) 347-7900	Period of Performance 7 July 1978 to 7 October 1979
Work Location Warrenton, Virginia	Obligated Fiscal Year 1979 Funding
	Cumulative Funding thru Fiscal Year 1979 \$208,796
Project Summary A Photosynthesis Energy Factory (PEF) is an integrated bioconversion system consisting of a dry-land Energy Plantation, wood-fired power plant, and wetlands biological waste-water treatment system, such as an algae pond. Products of a PEF are electricity from the powerplant, synthetic natural gas from digestion of the wetlands biomass, and reclaimed wastewater. Effluents and by-products from one system part can be used beneficially by other parts, leading to increased energy conversion and resource recovery at lower costs. An initial project was undertaken to study the concept of the PEF and its characteristics and apparent benefits. The project was divided into three parts or tasks. The objective of one task was to analyze the concept of the PEF, with particular emphasis on the complementary and synergistic aspects of the system. A second task was concerned with the analysis and selection of potential sites. The final task was to develop preliminary designs and associated cost estimates for potential demonstration systems at the best sites. The analysis which was performed in this initial project indicated that some interactions between the PEF subsystems are generally cost-effective while others are probably site-specific or can be improved upon. However, it was also concluded that various improvements should be made in the model to reflect different modes of operating the PEF to make it a more flexible concept. From the results of the initial project, it was concluded that certain refinements in the design of a PEF should be analyzed to give the PEF greater applicability as well as to improve its economics. Thus, it was decided to investigate in more detail certain aspects of the design and operation of the dry-land Energy Plantation subsystem. The PEF model has been expanded and generalized by analyzing possible improvements in the areas of materials transportation, water and nutrient balances, other types of wetlands biological systems, and improvements in wood-fired combustion systems. Direct application of municipal wastewater to a dry-land Energy Plantation has been analyzed, also. Potential sites for PEF systems will be evaluated with the improved technoeconomic model.	

Work remaining to complete the project includes gathering data for a few additional sites and running the model program to analyze and compare the different mode of designing and operating the PEF. The work product will be a comprehensive analysis of the economic viability of the PEF.

Contractor and Address Pacific Northwest Laboratory Battelle Memorial Institute P.O. Box 999 Richland, Washington 99352	Title Biomass Energy Systems Program Management Assistance
	Contract No. 80213
Principal Investigator G.F. Schiefelbein L.J. Sealock, Jr.	Period of Performance February 20, 1979 - open
	Obligated Fiscal Year 1979 Funding \$350,000
Work Location Richland, Washington	Cumulative Funding thru Fiscal Year 1979 \$350,000
	Project Summary Diminishing United States supplies of low-cost petroleum fuels and chemical feedstocks has prompted government and industry to pursue the development of renewable domestic energy resources. One such activity is the Biomass Energy Systems (BES) program. The BES program encompasses the production, harvest and conversion of all forms of biomass to clean fuels, petrochemical substitutes and other energy intensive products. Biomass comprises all organisms, both terrestrial and aquatic. The BES program is unique among solar technologies-terrestrial and aquatic, because it represents the most direct route of converting solar energy into the liquid and gaseous fuels, petrochemical feedstocks and other energy forms in common use today. The purpose of this program is to provide management support to the BES program office in the areas of indirect liquefaction (via synthesis gas), direct combustion and thermochemical conversion by gasification. This management support effort will enable the BES program office to ensure that development activities in these specific areas are carried out in an integrated, well-planned manner with timely completion of goals within budget. The management support to be provided will include: (1) project monitoring and evaluation, (2) program planning and assistance, (3) miscellaneous support activities, (4) in-house program support activities, and (5) reporting.

BIBLIOGRAPHY

This bibliography consists of two sections. The first section lists reports, technical papers, and articles which have resulted from, or are related to, research projects described in this Program Summary. The second section lists general bibliographic references related to biomass technology.

Most of the technical journals/publications containing listed papers can be obtained through technical libraries. The addresses of various journals/publications have been included in the citation. Unless otherwise specified, most of the reports can be obtained from:

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, Virginia 22161
Telephone No. (703) 557-4650

To facilitate receipt of a report from NTIS, provide as much relevant information as possible (title, author, report number, date of publication, etc.). The NTIS is required by its enabling legislation to recover the costs incurred for printing and distributing copies of reports to the public. To comply with this legislation, NTIS imposes a cost for each service provided. The following methods of payment may be used:

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- Establish a NTIS deposit account. Information can be obtained directly from NTIS at the Springfield, Virginia, address.

A. Direct Combustion

The following articles/publications are related to the project described in summary A-2.

"Development of Wood as an Alternative for Large Power Generating Systems," August 1978

Authors: J.T. Hamrick
Aerospace Research Corp.
4 Jae Valley Road, S.E.
Roanoke, Virginia 24014
Published by: Oak Ridge National Laboratory
Oak Ridge, Tennessee
Report No: OR05682-8 (NTIS)

The following articles/publications are related to the project described in summary B-1.

"Fuel Gas from Environmental Feedlot--Quarterly Progress Report," April 4, 1980

Authors: Solar Energy Research Institute
Golden, Colorado 80401
Published by: NTIS

B. On-Farm Systems

The following articles/publications are related to the project described in summary B-2.

"A Generalized Model for Substrate Utilization Kinetics" (1978)

Authors: Y.R. Chen and A.G. Hashimoto
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Published by: Environmental Engineering Division
American Society of Civil Engineers
345 E. 47th Street
New York, NY 10017

"Chemical Composition and Nutritional Value of Anaerobically Fermented Beef Cattle Residues" (Abstracts)

Authors: R.L. Prior, R.V. Mlejnek, and A.G. Hashimoto
P.O. Box 166, USDA, Clay Center,
Nebraska 68933
Presented at: Joint Meeting of American Dairy Science Association
(ADSA) and American Society of Animal Science, Michigan
State University, East Lansing, MI July 9-13, 1978
ADSA
113 N. Neil Street
Champaign, Ill 61820; and
American Society of Animal Science

c/o David C. England
Department of Animal Science
Oregon State University
Corvallis, Oregon 97331

"Methane Fermentation Kinetics" (1978)

Authors: Y.R. Chen and A.G. Hashimoto
P.O. Box 166,
USDA, Clay Center, Nebraska 69833
Accepted by: Biotechnology and Bioengineering, 1978
John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

"Anaerobic Fermentation of Animal Manure"

Authors: A.G. Hashimoto, R.A. Rhodes, Y.R. Chen
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Publication: Transactions of American Society of Agricultural Engineers (ASAE), June 1979
2950 Niles Road
St. Joseph, MI 49085
ASAE Paper No. 79-4066

"Methane and Protein Production from Animal Feedlot Wastes"

Authors: A.G. Hashimoto, Y.R. Chen, and R.L. Prior
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Presented at: 33rd Annual Meeting of the Soil Conservation Society of America (SCA), Denver, Colorado July 30-August 2, 1978
SCA
7515 N.E. Ankeny Road
Ankeny, IA 50021

"Thermophilic, Anaerobic Fermentation of Beef Cattle Residue"

Authors: A.G. Hashimoto, Y.R. Chen, and R.L. Prior
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Publication: Proceedings, Institute of Gas Technology's Conference on Energy from Wastes and Biomass
Washington, D.C., August 1978
Institute of Gas Technology
3423 S. State Street
Chicago, Ill 60610

"Capillary Tube Viscometer for Animal Waste Slurries"

Authors: A.G. Hashimoto, Y.R. Chen
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Publication: Agriculture Engineering
September 1975, Page 25

"Rheological Properties of Aerated Poultry Waste Slurries:

Authors: Y.R. Chen and A.G. Hashimoto
Publication: Transactions of American Society of Agricultural Engineers (ASAE)
19:(1):128-133, 1976
Available from the authors

"Energy Requirements for Anaerobic Fermentation of Livestock Waste"

Authors: Y.R. Chen, A.G. Hashimoto,
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Publications: Proceedings of 4th International Symposium on Livestock
Wastes, May 1979
Amarillo, Texas 79101
Available from the authors

"Methane and Biomass Production Systems for Beef Cattle Manure"

Authors: A.G. Hashimoto, R.L. Prior, and Y.R. Chen,
P.O. Box 166, USDA, Clay Center
Nebraska 68933
Publication: Proceedings, Great Plains Extension Seminar on Methane
Production from Livestock Manure, 1978
Available from the authors

"Methane Fermentation Kinetics" (Abstracts)

Authors: Y.R. Chen, A.G. Hashimoto,
P.O. Box 166, USDA, Clay Center,
Nebraska 68933
Publication: Symposium No. 8 of Biotechnology in Energy Production
and Conservation, Gatlinburg, TN, May 10-12, 1978
Published by: John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

The following articles/publications are related to the project described in summary B-4.

"Design and Operation of a 50,000 Gallon Anaerobic Digester at the State Honor Dairy Farm, Monroe, Washington," 1979

Authors: Elizabeth Coppinger, et al.
Ecotope Group, 747 - 16th East
Seattle, Washington 98112
Publication: Solar Energy Research Institute
1536 Cole Boulevard
Golden, Colorado 80401 (NTIS)

The following articles/publications are related to the project described in summary B-5.

"Evaluation of Systems for Purification of Fuel Gas from Anaerobic Digestion" (1979)

Authors: E. Ashare, D. Augenstein, J.C. Yueng, J. Hossan and L. Duret
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139
Available from NTIS

"Fuel Gas Production from Animal and Agriculture Residues and Biomass" (1979)

Authors: D.L. Wise and R.L. Wentworth
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139
Publication: NTIS, Report No: C00-2991-28 (154 pages) (\$8.00)

"Anaerobic Digestion Technology," Progress Report (June 1977)

Authors: Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139
Publication: NTIS, Report No: C00-2991-19 (\$7.25)

"Evaluation of Systems for Purification of Fuel Gas from Anaerobic Digestion" (July 30, 1978)

Authors: E. Ashare, D.C. Augenstein, J.C. Young, J. Hassan, and L. Duret
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139
Publication: NTIS Report No: C00-2991-19 (244 pages) (\$10.75)

"Fuel Gas Production from Animal and Agricultural Residues and Biomass,"

Authors: D.L. Wise and R.L. Wentworth
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139
Presented at: Anaerobic Digestion Contractors Coordination Meeting (Report), Fort Lauderdale (May 30, 1978)
Publication: NTIS, Report No: C00-2991-34 (208 pages) (\$9.25)

"Fuel Gas Production from Animal Residue" (November 15, 1976)

Authors: E. Ashare, L. Wise, and R.L. Wentworth
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139
Publication: NTIS Report No: C00-2991-10 (141 pages) (\$7.25)

"Fuel Gas Production from Animal Waste" (February 1, 1977)

Authors: E. Ashare, R.L. Wentworth, D.L. Wise
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139

Publication: NTIS, Report No: C00-2991-11 (\$4.50)

"Fuel Gas Production from Residues and Biomass," Coordination Meeting Report, Hastings, (October 28, 1977)

Authors: R.L. Wentworth and D.L. Wise
Dynatech R/D Company
99 Erie Street
Cambridge, Mass 02139

Publication: NTIS, Report No: C00-2991-25 (91 pages) (\$6.00)

C. Alcohol Production Systems

The following articles/publications are related to the project described in summary C-2.

"Evaluation of the State of the Art of Biomass Based Methanol Process"

Author: Edward Wan
Science Applications, Inc.
McLean, Virginia 22101

Published by: NTIS, Progress Report No: 1, August 14, 1978

"Development of Biomass to Methanol Systems Algorithms and Models" (1978)

Author: Edward Wan
Science Applications, Inc.
McLean, Virginia 22101

Submitted to: Department of Energy (Draft)
Available from the author

"Technical and Economic Assessment of the Production of Methanol from Biomass" (1978)

Author: Edward Wan
Science Applications, Inc.
McLean, Virginia 22101

Published by: NTIS

The following articles/publications are related to the project described in summaries C-5, C-6 and C-8.

"Biomass Conversion--Recent Developments"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Presented at: Interciencia Association, Guaruja, Brazil, March 15, 1978
Available from the author

"What Roles for Fuels from Biomass"

Author: E.S. Lipinsky
Publication: Energy Digest, 2(12), June 15, 1977, page 4
Published by: Technical Insights, Inc.
158 Linwood Plaza
P.O. Box 1304
Ft. Lee, New Jersey 07024

"Can Sucrose Compete with Hydrocarbons as a Chemical Feedstock?"

Authors: E.S. Lipinsky and W. Sheppard
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Publication: Sucrochemistry, American Chemical Society (ACS) Symposium Series No. 41. 1977, pages 336-350
ACS
1155 16th Street, N.W.
Washington, D.C. 20036

"Conversion of Sugar Cane Products into Fuels and Chemicals Feedstock"

Author: E.S. Lipinsky
Battelle Columbus Laboratories,
505 King Avenue
Columbus, Ohio 43201
Publication: Sugar Journal, 39, August 1976, pages 27-30
Available from the author

"Energy: New Crop Sources"

Authors: T.A. McClure and D.A. Scantland
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Publication: Agricultural Engineering, September 1977
Available from the author

"Field Crops as a Future Source of Fuels and Chemicals Feedstocks"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Publication: Agricultural, Biomass, Wind, New Developments, 7, August 1976, pages 105-107
Available from the author

"Fuels from Biomass: Integration with Food and Materials Systems"

Author: E.S. Lipinsky
Battelle Columbus Laboratories

505 King Avenue
Columbus, Ohio 43201
Publication: Science, 199 (4329), February 10, 1978, pages 644-651
American Association for the Advancement of Science
1515 Massachusetts Avenue
Washington, D.C. 10005

"Fuels from Biomass Systems for Arid Land Environments"

Authors: E.S. Lipinsky and S. Kresovich
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Presented at: The International Arid Lands Conference on Plant Resources, October 19, 1978
Proceedings of the Arid Land Plant Resources Conference
Aridland Plant Resources Laboratory
Texas Tech. University
Lubbock, Texas 79409

"Fuels from Sugarcane and Corn"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Presented at: Power Engineering Society, January 10, 1978, Available from Institute of Electrical and Electronics Engineers
345 E. 7th Street
New York, NY 10017

"Fuels from Sugar Crops," First Quarterly Report, (July 19, 1977)

Authors: E.S. Lipinsky et al.
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Published by: NTIS Report No: TID-27834 (\$8.00)

"Fuels from Sugar Crops: Status and Prospects"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Presented at: The American Society of Sugarcane Technologists (ASST) Conference at Orlando, FL, June 22, 1978
ASST
P.O. Box 1546
Fort Collins, Colorado 80522

"Growing Sugar Crops for Fuel"

Author: E.S. Lipinsky
Battelle Columbus Laboratories

505 King Avenue
Columbus, Ohio 43201
Presented at: The Second Annual Fuels from Biomass Symposium, Troy,
NY, June 20-22, 1978. Available from the author or Dr.
H.R. Bungay, Rensselaer Polytechnic Institute, Troy, New
York 12181

"Perspectives on Preparation of Cellulose for Hydrolysis"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Publication: American Chemical Society Monograph, October 1978
American Chemical Society (ACS)
1155 16th Street, N.W.
Washington, D.C. 10036

"Sugarcane Versus Corn Versus Ethylene as Sources of Ethanol for Motor Fuels and Chemicals"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Presented at: The American Society of Sugarcane Technologists (ASST)
Meeting in Fort Walton Beach, FL, June 23, 1977
ASST
P.O. Box 1546
Fort Collins, Colorado 80522

"Sugar Crops as a Source of Fuel"

Authors: E.S. Lipinsky, S. Kresovich, T. McClure and W. Lawhon
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Volume I - Agricultural Research, June 31, 1978
Volume II - Processing and Conversion Research, August
31, 1978

"Systems Analysis of Fuels from Biomass"

Author: E.S. Lipinsky
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Presented at: The American Physical Society (APS) Conference
Washington, D.C., March 29, 1978
APS
335 E. 4th Street
New York, NY 10017

"Systems Study for Fuels from Sugarcane, Sweet Sorghum, and Sugar Beets"
(Multi-volume report), Battelle Columbus Laboratories, 505 King Avenue, Col-
umbus, Ohio 43201, Available from NTIS

Authors: E.S. Lipinsky, et al.
 Volume I - Comprehensive Evaluation, 1976
 Report No: BMI-1957-VI/LL (\$8.00)
 Volume II - Agricultural Consideration, 1976
 Report No: BMI-1957-V2/LL (\$10.75)
 Volume III - Conversion of Fuels and Chemical Feed-
 stocks, 1976
 Report No: BMI-1957-V3/LL (\$9.25)
 Volume IV - Corn Agriculture, 1977
 Report No: BMI-1957-V4/LL (\$9.25)
 Volume V - Comprehensive Evaluation of Corn, 1977
 Report No: BMI-1957 A-V5/LL (\$9.00)

"Systems Study of Sugarcane, Sweet Sorghum, Sugar Beets and Corn for Fuels and Chemical Feedstocks"

Author: E.S. Lipinsky
 Battelle Columbus Laboratories
 505 King Avenue
 Columbus, Ohio 43201
 Publication: Proceedings of Fuels from Biomass Symposium
 University of Illinois, April 18-19, 1977
 Available from the author

"The Prospects for Fuels from Biomass"

Author: E.S. Lipinsky
 Battelle Columbus Laboratories
 505 King Avenue
 Columbus, Ohio 43201
 Publication: Proceedings of the 12th Intersociety Energy Conversion
 Engineering Conference, Volume I, Washington, D.C.
 August 28 to September 2, 1977
 Available from the author

"Using Sugar Crops to Capture Solar Energy"

Author: E.S. Lipinsky
 Battelle Columbus Laboratories
 505 King Avenue
 Columbus, Ohio 43201
 Publication: "Biological Solar Energy Conversion," Academic Press,
 1977, pages 397-410
 111 5th Avenue
 New York, NY 10003

"Economics of Manufacturing Liquid Fuels from Corn Stover"

Authors: D.M. Jenkins, et al.
 Battelle Columbus Laboratories
 505 King Avenue
 Columbus, Ohio 43201
 Available from: NTIS (TID-29-419 (\$5.00, outside U.S. \$10.00))

The following articles/publications are related to the project described in summary C-9.

"Biomass Based Alcohol Fuels"

Authors: W. Park, G. Price and D. Salo
Mitre Corporation, McLean, Virginia 22101
Available from: NTIS

"Comparative Economic Assessment of Ethanol from Biomass"

Author: D. Medville, J. Rosenberg, D. Salo and M. Schauffler
Mitre Corporation, McLean, Virginia 22101
Available from: NTIS

D. Silviculture

The following articles/publications are related to the project described in summary D-4.

"Water and Land Availability for Energy Farming"

Authors: Fred Schooley, et al.
Stanford Research Institute
Menlo Park, California 94025
Published by: NTIS

The following articles/publications are related to the project described in summary D-5.

"Energy in Forestry-Production & Use," Resource Report No. 5

Author: W.H. Smith, et al.
University of Florida
Gainesville, Florida 32601
Presented at: 10th Spring Symposium
Florida Section, Society of American Foresters
May 30-31, 1978
Available from the authors

The following articles/publications are related to the project described in summary D-7.

"Screening of Non-Commercial Woody Plants as Biomass Fuel Producers"

Authors: H.L. Ragsdale
Biology Department, Emory University
Atlanta, Georgia 30322
Published by: Oak Ridge National Laboratory
Oak Ridge, Tennessee
Available from NTIS
Presented at: The Third Annual Biomass Energy Systems Proceedings
SERI
Golden, Colorado 80401
SERI/TI-33-285, Available from the author

The following publications are related to the project described in D-12.

"Reclaiming Surface Mines with Black Locust Energy Plantations"

Authors: S.B. Carpenter, D.H. Groves, and R.A. Eigel
University of Kentucky, Lexington, Kentucky 40506
Publication: Kentucky Farmer, January 1979
Kentucky Farmer
P.O. Box 645
Bowling Green, KY 42101

"UK Foresters Study Black Locust on Strip-mining Land"

Author: S.B. Carpenter
University of Kentucky
Lexington, Kentucky 40506
Publication: Co-operative Extension Service News, July 28, 1978, p.7
University of Kentucky
Lexington, Kentucky 40506

The following articles/publications are related to the project described in summary D-13.

"Machine for Row-Mulching Logging Slash to Enhance Site--A Concept"

Authors: P. Koch and D.W. McKenzie
U.S. Forest Service
2500 Shreveport Highway, Pineville, Louisiana 71360
Publication: Transactions of the American Society of Agricultural Engineers (ASAE), 20(1), 1977, pages 13 to 17
2950 Niles Road
St. Joseph, MI 49085

"Machine to Harvest Slash, Brush, and Thinnings for Fuel and Fiber--A Concept"

Authors: P.Koch and D.W. McKenzie, U.S. Forest Service
2500 Shreveport Highway, Pineville, Louisiana 71360
Publication: Journal of Forestry, 74, 1976, pages 809-812. Available from the author

"Utilization of Southern Hardwoods"

Author: P. Koch, U.S. Forestry Service
2500 Shreveport Highway, Pineville, Louisiana 71360
Publication: Proceedings, Second Symposium on Southeastern Hardwoods
Dothan, Alabama, 1977, pages 17 to 39
Available from the author

The following articles/publications are related to the project described in summary D-16.

"Forest Irrigation: A Review"

Author: E.A. Hansen
North Central Forest Experiment Station

- 1992 Folwell Avenue
St. Paul, Minnesota 55108
- Publication:** Proceedings, Soil Moisture...Site Productivity Symposium, Myrtle Beach, SC, 1977, pages 126-137
Available from the author
- "Harvesting and Benefication of Whole Tree Chips from Three Short Rotation Intensively Cultured Species" (Abstracts)**
Authors: J.A. Sturos, J.B. Crist, J.G. Isebrands, and N.D. Nelson
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
- Publication:** Proceedings, Annual Meeting for Prod. Res. Doc., Atlanta, Georgia, June 25-29, 1978, page 5
Available from authors
- "Intensively Cultured Plantations--Structure and Biomass Production of 1- to 7-Year Old Tamarack in Wisconsin"**
Authors: J. Zavitkovski and D.H. Dawson
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
- Publication:** Technical Association of Pulp & Paper Industry (TAPPI) 61(6):68-70, 1978
TAPPI
1 Dunwoody Park
Atlanta, Georgia 30338
- "Propagating Cuttings of Some Populus Clones for Tree Plantations"**
Authors: H.M. Phipps, D. Benton, and D. Netzer
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
- Publication:** Plant Propagator 24(2):11-13, 1977
International Plant Propagator
P.O. Box 3131
Boulder, Colorado 80307
Available from the author
- "Rooting Populus Cuttings in Various Media Bound with a Liquid Polymer"**
Author: H.M. Phipps
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
- Publication:** Plant Propagator 24(2):11-13, 1978
Available from the author
- "Short Rotation Silviculture as an Energy Source" (Abstract)**
Author: J.G. Isebrands, North Central Forest Experiment Station

1992 Folwell Avenue
St. Paul, Minnesota 55108
Publication: Proceedings, National Conference on Forest Product
Utilization Research, Madison, Wisconsin
October 25-27, 1977, page 18
Available from the author

"Structure and Biomass Production of 1- to 7-Year-Old Intensively Cultured Jack Pine Plantations in Wisconsin"

Authors: J. Zavitovski and D.H. Dawson
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
Publication: USDA, Forest Service Research Paper, NC-157, page 15
Available from the authors

"Structure and Biomass Production of 1- to 7-Year-Old Intensively Cultured Tamarack Plantations in Wisconsin"

Authors: J. Zavitovski and D.H. Dawson
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
Publication: 1978 Technical Association of Pulp & Paper Industry Annual Meeting, Chicago, Illinois, 1978, p.29-35
TAPPI
1 Dunwoody Park
Atlanta, Georgia 30330

"Vegetative Propagation of Populus for Intensively Cultured Plantations"

Authors: D.H. Dawson and H.M. Phipps
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
Publication: Proceedings, Fourth North American Biological Workshop
August 9-11, 1976, pages 8-22
State University of New York, Syracuse, NY
Available from the author

The following articles/publications are related to the project described in summary D-17.

"Improved Poplars for Michigan Through the Michigan State Co-operative Tree Improvement Program"

Authors: James W. Hanover
Department of Forestry
Michigan State University
East Lansing, Michigan 48823
Presented at: The Proceedings of North American Poplar Council

July 1979, pp. 115-122
Available from the author

The following articles/publications are related to the project described in summary D-21.

"Development of a Handbook on 'Wood As a Fuel for Non-Wood Product Industries and Institutions'" (1979)

Author: M.D. Levi
School of Forest Resources
North Carolina State University
Raleigh, North Carolina 27607
Available from the author

The following articles/publications are related to the project described in summary D-22.

"The Use and Selection of Trees for Energy and Chemicals"

Authors: M. Williford, R.C. Kellison, D.J. Frederick and W.E. Gardner
School of Forest Resources
North Carolina State University
Raleigh, N.C. 27650

Published by: The Proceedings of the 15th Southern Forestry Improvement Conference, July 1979
Mississippi State University
Starkesville, Mississippi
Available from the authors

"Species Selection and Silvicultural Systems for Producing Fuels from Woody Biomass in Southern United States"

Authors: D.J. Frederick, R.C. Kellison, W.E. Gardner, M. Williford and P.K. Slichter
School of Forest Resources
Hardwood Research Co-operative
North Carolina State University
Raleigh, N.C. 27650

Presented at: The Proceedings of the Third Annual Conference on Biomass, 1978
Energy Systems
Solar Energy Research Institute
Golden, Colorado 80401
Available from the authors and NTIS

The following publications are related to the project described in D-23.

Note: All publications listed below are available from Southeastern Forest Experiment Station, P.O. Box 2570, Asheville, N.C. 28802

"Attempt to Induce Lightwood in Balsam Fir and Tamarack by Treating with Paraquat"

Authors: P. Kiatgrajai, et al.
Publication: Wood Science 9(1), 1976, pages 31-36

"Attempt to Induce Lightwood in Eastern Hemlock by Treating with Paraquat"

Authors: P. Kiatgrajai, et al.
Publication: Wood Science 8(3), 1976, pages 170-173

"Capturing Solar Energy in Pine Oleoresin"

Author: D. Roberts
Publication: Capturing the Sun through Bioconversion, Washington Center for Metropolitan Studies Proceedings, Workshop No. 9 Long Range Concepts, 1976, pages 673-674

"Chemical Stimulation of Wood Oleoresin Production in Pine Trees"

Author: D. Roberts
Publication: The 1977 McGraw-Hill Yearbook of Science and Technology, pages 230-231
McGraw Hill, Inc.
1221 Avenue of America
New York, New York 10018

"Chemically Inducing Lightwood Formation in Southern Pines"

Authors: D. Roberts and W. Peters
Publication: Forest Products Journal 27(6), 1977, pages 28-30

"Lightwood Formation in Red Pine Treated with Paraquat"

Authors: H. Wroblewska, A. Connor, and J. Rowe
Publications: Wood Science 10(1), 1977, pages 1-5

"Lightwood Research Coordinating Council, Proceedings of Annual Meeting, 1975"

"Lightwood Research Coordinating Council, Proceedings of Annual Meeting, 1976"

"Lightwood Research Coordinating Council, Proceedings of Annual Meeting, 1977"

"Lightwood Research Coordinating Council, Proceedings of Annual Meeting, 1978"

"Paraquat-Induced Lightwood in Two European Conifers--Scotch Pine and Norway Spruce"

Authors: H. Wroblewska, A. Conner, J. Rowe, W. Peters, and D. Roberts
Publication: Wood Science 10(4), 1978, pages 181-186

"Status of Lightwood Induction Technology"

Authors: D. Roberts and W. Peters
Publications: Naval Stores Review, January - February 1978, pages 4-5

The following articles/publications are related to the project described in summary D-24.

"Increased Woody Biomass Production and Land Treatment of Wastewater--An Economic Symbiotic Relationship" (1979)

Author: W.E. Sopper
Land & Water Research Building
The Pennsylvania State University
University Park, Pennsylvania 16802

Available from: Technology for Energy Conservation Information Transfer, Inc.
Silver Spring, Maryland 20910

"Maximizing Forest Biomass Energy Production by Municipal Wastewater Irrigation"

Authors: W.E. Sopper and S.N. Kerr
Land & Water Research Building
The Pennsylvania State University
University Park, Pennsylvania 16802

Proceeding of: Energy from Waste, April 1980
Institute of Gas Technology (IGT)
IIT Center
3424 S. State Street
Chicago, Illinois 60616

Available from: IGT

The following articles/publications are related to the project described in summary D-29.

"Energy Biomass from High-Producing Rangeland Shrubs of the Inter-Mountain United States," March 1980.

Authors: C.M. McKell and Gordon Van Eppes
Institute of Land Rehabilitation,
Utah State University
Logan, Utah 84322
Available from the authors

The following articles/publications are related to the project described in summary D-31.

"Near Term Potential of Wood as a Fuel" (1979)

Authors: D. Salo, L. Gisselman, D. Medville, & G. Price
The Mitre Corporation
McLean, Virginia 22101

Published by: NTIS

E. Herbaceous

The following articles/publications are related to the project described in summary E-1. All are available free of charge from:

The American Experiment Station
P.O. Box H
University of Puerto Rico
Rio Piedras, PR 00928

"Agricultural and Wild Plants as Renewable Energy Sources for Puerto Rico"
(Abstract)

Author: A.G. Alexander
Publication: Proceedings SOPCA (October 1978)

"Biomass as a Renewable Energy Source"

Author: A.G. Alexander
Presented at: Biomass Workshop, INTERCIENCA/SBPC Symposium, "Energy and Development in the Americas," Santos, Brazil, March 1978

"Production of Sugar Cane as an Alternate Source of Fuels and Chemical Feedstocks for Puerto Rico"

Author: A.G. Alexander
Publication: Proceedings of the Puerto Rico Sugar Technology Association, November 1977

"Production of Sugar Cane and Tropical Grasses as a Renewable Energy Source"
(Technical Quarterly Reports I, II and III, June 1, 1977 to February 28, 1978)

Authors: A.G. Alexander, C. Gonzalez-Milina, J. Ortiz-Velez

"Sugar Cane as a Source of Fiber, Fuels, and Chemical Feedstocks for Puerto Rico"

Author: A.G. Alexander
Publication: Proceedings, Puerto Rico Sugar Technology Association, November 1978

"Solar Energy Storage by Tropical Grasses and Their Potential as Sources of Biomass"

Author: A.G. Alexander
Publication: Proceedings of Caribbean Studies Association, January 1978

The following articles/publications are related to the project described in summary E-2.

"Herbaceous Species Screening Program--Phase I" (1979)

Authors: K.A. Saterson, M.K. Luppold, K.M. Scow and R.E. Lee
Arthur D. Little (ADL-Case No. 82412)
35 Acorn Park
Cambridge, Massachusetts 02140

Available from: NTIS

F. Anaerobic Digestion

The following articles/publications are related to the project described in summary F-1.

"Biological Conversion of Organic Refuse to Methane, Annual Progress Report"
(July 1974)

Authors: C. Liebman and J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: PB-235 468/6GI (184 pages) (NTIS)

"Biological Conversion of Organic Refuse to Methane--Annual Progress Report"
(August 1975)

Authors: C. Liebman and J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: PB-247 751/IGI (160 pages) (NTIS)

"Biological Conversion of Biomass to Methane" (September 1976)

Author: J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Publication: (NTIS)

"Biological Conversion of Organic Refuse to Methane, Quarterly Progress Report" (December 1976)

Author: J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Publication: Available from the author

"Biological Conversion of Organic Refuse to Methane, Final Report, Volume I"
(1976)

Author: J.T. Pfeffer, J.C. Liebman, J.W. Brown, and G.E. Quindry
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: C00-2917-3-VI (\$9.00) (NTIS)

"Biological Conversion of Organic Refuse to Methane, Final Report, Volume 2"
(1976)

Author: J.T. Pfeffer, J.C. Liebman, J.W. Brown, and G.E. Quindry
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: C00-2917-3-V2 (\$6.50) (NTIS)

"Biological Conversion of Organic Refuse to Methane, Quarterly Progress Report" (April 1977)

Author: C. Liebman
Department of Civil Engineering

University of Illinois
Urbana, Illinois 61801
Report No.: C00-2917-5 (NTIS)

"Biological Conversion of Biomass to Methane, The Effect of Reactor Design on Kinetic" (December 1977)

Authors: R.H. Geissers and J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: C00/2917-8 (59 pages) (NTIS)

"Biological Conversion of Biomass to Methane" Quarterly Progress Report (May 1978)

Author: J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: C00-2917-10 (NTIS)

"Biological Conversion of Biomass to Methane, Beef Lot Manure Studies" (July 1978)

Author: J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: C00-2917-9 (NTIS)

"Production of Panel Board from Residue Left from the Fermentation of Organic Wastes to Methane"

Authors: C.S. Walters, J.T. Pfeffer, and P. Chaw
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Publication: Forest Products Journal, Volume 27(9), 1977, pages 12-20
Available from the authors

"Reclamation of Energy from Organic Wastes" (1974)

Author: J.T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801
Report No.: PB 231 196/9G1 (132 pages) (\$6.50), (NTIS)

The following articles/publications are related to the project described in summary F-2.

"Feasibility study of Anaerobic Digestion of Agriculture Crop Residues" 1979

Author: D.L. Wise & E. Ashore
Dynatech R/D Co.

99 Erie Street, Cambridge, Massachusetts 02178
Published by: NTIS

The following articles/publications are related to the project described in summary G-1.

"Selective Hydrolysis of Hardwood Hemicellulose by Acids"

Authors: Y.Y. Lee, C.M. Lin, T. Johnson & P.P. Chambers
Auburn University, Auburn, Alabama 36830
Presented at: Fifth Enzyme Engineering Conference, Hennikar, New Hampshire, July 1979, Available from the authors

"Sugar Recovery & Fermentation from Wood Hemicellulose"

Authors: M.L. Limbaugh, S. Verraghvan, Y.Y. Lee, & R.P. Chambers
Auburn University, Auburn, Alabama 36830
Presented at: The International Solar Engineering Conference, Atlanta, Georgia, May 1979, Available from the authors

G. Fermentation

The following articles/publications are related to the project described in summary G-2.

"Computation of the Fraction of Induced Cells in Enzyme Induction Systems"

Authors: C.R. Wilke, U. Von Stockol, and R.D. Yang
University of California, Lawrence Berkeley Labs.,
Berkeley, California 94720
Publication: Biotechnology and Bioengineering 19, 1977, pages 445-458
John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

"Continuous Cellulase Production"

Authors: C.R. Wilke and G. Mitra
University of California, Lawrence Berkeley Labs.,
Berkeley, California 94720
Publication: Biotechnology and Bioengineering 17, 1975, page 1
John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

"Ethanol Effects on the Kinetics of Continuous Fermentation with Saccharomyces cerevisiae"

Authors: C.R. Wilke and C.D. Bazua
University of California, Lawrence Berkeley Labs.,
Berkeley, California 94720
Publication: Biotechnology and Bioengineering 7, 1977, pages 105-118
John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

"Exponential Growth Kinetics for Polyporus versicolor and Pleurotus ostreatus in Submerged Culture"

Authors: C.R. Wilke and P.A. Carroad
University of California, Lawrence Berkeley Labs.,
Berkeley, California 94720
Publication: Applied and Environmental Microbiology 33, 1977, page
871, Available from author

"Rapid Ethanol Fermentation Using Vacuum and Cell Recycle"

Authors: C.R. Wilke and G.R. Cysewski
University of California, Lawrence Berkeley Labs.,
Berkeley, California 94720
Publication: Biotechnology and Bioengineering 19, 1977, pages 1125
John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

"Utilization of Cellulose Materials Through Enzymatic Hydrolysis, I. Fermentation of Hydrolysate to Ethanol and Single Protein"

Authors: C.R. Wilke and G.R. Cysewski
University of California, Lawrence Berkeley Labs.,
Berkeley, California 94720
Publication: Biotechnology and Bioengineering 18, 1976, pages 1315-
1323
John Wiley & Sons, Inc.
605 Third Avenue
New York, NY 10016

The following articles/publications are related to the projects described in summary G-5.

"Preliminary Engineering and Cost Analysis of Purdue/Tsao Cellulose Hydrolysis (Solvent) Process" (1978)

Authors: George T. Tsao
Laboratory of Renewable Resources Engineering
Purdue University
West Lafayette, Indiana 47907
Published by: NTIS

The following articles/publications are related to the projects described in summary G-7.

"Fuels from Biomass--Newsletter"

Issues published prior to March 1979 available through:
Dr. Henry Bungay
Rensselaer Polytechnic Institute
Dept. of Chemical and Environmental Engineering
Troy, New York 12181
Issues published after March 1979 available through:
Dr. Larry Douglas

Solar Energy Research Institute
1536 Cole Boulevard
Golden, Colorado 80401

H. Thermochemical Conversion Gasification

The following articles/publications are related to the projects described in summary H-2.

"Conversion of Biomass Materials into Gaseous Products" (1978)

Author: D.E. Garrett
Garrett Energy Research & Engineering Inc.
911 Bryant Place
Ojai, California 93023
Published by: NTIS, Report No. SAN/1241-71/1 (\$6.80)

"Environmental Considerations in Forest Residue Energy Production"

Author: D.E. Garrett
Garrett Energy Research & Engineering Inc.
911 Bryant Place
Ojai, California 93023
Published by: AIChE Symposium Series, 177, 74, 1978, pages 87-91
Available from: AIChE
345 E 47th St.
New York, NY 10017

"Thermal Processing of Biomass Materials: Technological and Economic Considerations" (1979)

Author: D.E. Garrett
Garrett Energy Research & Engineering Inc.
911 Bryant Place
Ojai, California 93023
Published in: Proceedings for the 5th National Conference on the Interagency Energy/Environment R&D Program, EPA Decision Series, NTIS

"The Garrett Energy Research Gasification Process"

Authors: R. Mikesell, Dinh Hang and D.E. Garrett
Garrett Energy Research & Engineering Inc.
911 Bryant Place
Ojai, California 93023
Presented at: Symposium--Energy from Biomass and Wastes, August 14, 1978, p. 749-768
Available from: Institute of Gas Technology
IIT Center
3424 S. State Street
Chicago, Illinois 60616

The following articles/publications are related to the project described in summary H-7.

"A Review of Heat/Mass Balances and Product Data During Partial Oxidation of Cattle Feedlot Manure"

Authors: W.J. Huffman, S.R. Beck, J.E. Halligan, and B.C. Landeene
Texas Tech University
Lubbock, Texas 79409

Presented at: The 84th National American Institute of Chemical Engineers (AIChE) Meeting, Atlanta, GA
February 26-March 1, 1978
AIChE
345 E 47th Street
New York, NY 10017

"Ammonia Synthesis Gas from Manure" (1978)

Authors: W.J. Huffman, R.L. Peterson, and J.E. Halligan
Texas Tech University
Lubbock, Texas 79409

Available from: NTIS

"Fluidized Bed Gasification of Cattle Feedlot Manure"

Author: S.R. Beck
Texas Tech University
Lubbock, Texas 79409

Presented at: Institute of Gas Technology (IGT), 2nd Symposium, Clean Fuels from Biomass and Waste, January 1977
IGT
3424 State Street
Chicago, Ill. 60616

"Synthesis Gas from Bovine Wastes"

Authors: J.E. Halligan, K.L. Herzong, and H.W. Parker
Texas Tech University
Lubbock, Texas 79409

Publication: Industrial Engineering Chemistry, Process Design Development, 14, 1975, pages 64-69
Available from the author

"Thermochemical Evaluation of Animal Waste Conversion Processes"

Authors: J.E. Halligan, and R.M. Sweezy
Texas Tech University
Lubbock, Texas 79409

Presented at: The 72nd National American Institute of Chemical Engineers (AIChE) Meeting
St. Louis, MO, May 21-24, 1972
AIChE
345 E 47th Street
New York, NY 10017

"Variable Velocity Fluidized Bed for Pyrolysis of Biomass"

Authors: S.R. Beck, W.J. Huffman, U. Mann, and H.D. Wong

Texas Tech University
Lubbock, Texas 79409
Publication: American Chemical Society (ACS), Symposium Series No.
76, 1978, pages 307-322
ACS
1155 16th Street, S.W.
Washington, D.C. 10036

The following articles/publications are related to the project described in summary H-8.

"Catalyzed Gasification of Biomass"

Authors: J.L. Cox, D.H. Mitchell, L.K. Mudge, R.J. Robertus, L.J. Sealock, Jr., and P.C. Walkup
Battelle Pacific North West Labs
Richland, Washington 99352
Presented at: First World Conference on Future Sources of Organic Raw Materials, July 10-13, 1978
Toronto, Ontario
PNL-SA-6689, Available from the authors

"Investigation of the Gasification of Biomass in the Presence of Catalysts"

Authors: D.H. Mitchell, L.K. Mudge, R.J. Robertus, and L.J. Sealock, Jr.,
Battelle Pacific North West Labs
Richland, Washington 99352
Presented at: Fourth Biomass Thermochemical Conversion Coordination Meeting: Fuels from Biomass Program, April 26-27, 1978

"Investigation of the Gasification of Biomass in the Presence of Catalysts"

Authors: J.L. Cox, L.K. Mudge, R.J. Robertus, L.J. Sealock, Jr., and P.C. Walkup
Battelle Pacific North West Labs
Richland, Washington 99352
Presented at: Fifth Biomass Thermochemical Conversion Coordination Meeting: Fuels from Biomass Program, September 19-20, 1978

"Investigation of the Gasification of Biomass in the Presence of Multiple Catalysts"

Authors: J.L. Cox, L.K. Mudge, R.J. Robertus, L.J. Sealock, Jr., and P.C. Walkup
Battelle Pacific North West Labs
Richland, Washington 99352
Presented at: Second Annual Fuels from Biomass Symposium, June 20-22, 1978
Rensselaer Polytechnic Institute
Troy, New York
(NTIS)

I. Liquefaction

The following articles/publications are related to the project described in summary I-1.

"Bench-Scale Research in Thermochemical Conversion of Biomass to Liquids in Support of the Albany, Oregon, Experimental Facility" (October 26, 1977)

Authors: D.C. Elliott and P.C. Walkup
Battelle Pacific North West Labs
Richland, Washington 99352

Published by: NTIS, Report No. TID-28415

J. Research and Development--Innovative Conversion

The following articles/publications are related to the project described in summary J-1.

"Thermochemical Pretreatment of Nitrogenous Materials to Increase Methane Yield"

Authors: D.C. Stuckey & P.L. McCarty
Stanford University
Civil Engineering Department
Stanford, California 94305

Published by: Biotechnology in Energy Production & Conservation Proceedings of the First Symposium, pp.219-221, May 10-12, 1978
Oak Ridge National Laboratory
Oak Ridge, Tennessee (NTIS)

The following articles/publications are related to the project described in summary J-3.

"Acetic Acid Production from Marine Algae" (October 14, 1977)

Authors: J.E. Sanderson, D.C. Augenstein, & D.L. Wise
Dynatech R/D Co.
99 Erie Street, Cambridge, Mass. 02139

Published by: NTIS, Report No. COO/4388-1

The following articles/publications are related to the project described in summary J-4.

"A Novel Route to the Production of Acetic Acid by Fermentation"

Authors: D. Wang, R. Fleischaker, and G. Wang
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Publication: Biochemical Engineering: Renewable Resources of Energy and Chemical Feedstocks, American Institute of Chemical Engineers (AIChE) Symposium Series 181, Volume 74, 1978, page 105
AIChE

345 E 47th Street
New York, NY 10017

"Anaerobic Biomass Degradation to Produce Sugars, Fuels, and Chemicals"

Authors: D. Wang, C. Cooney, S. Wang, J. Gordon and G. Wang
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Publication: Proceedings of the Second Annual Fuels from Biomass Conference, Volume 1, Troy, NY., 1978, page 537 (NTIS)

"Degradation of Cellulosic Biomass and its Subsequent Utilization for the Production of Chemical Feedstocks"-Progress Reports

Authors: D. Wang, C. Cooney, A. Demain, R. Gomez and A. Sinskey
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Report No: C00-4198-1 (May 1977) 96 pages
C00-4198-2 (June 1977) 80 pages
C00-4198-3 (September 1977) 112 pages
C00-4198-4 (November 1977) 231 pages
C00-4198-5 (February 1978) 163 pages
C00-4198-6 (May 1978) 202 pages
C00-4198-7 (August 1978) 205 pages
C00-4198-8 (November 1978) 139 pages
(NTIS)

"Sugar Accumulation During Enzyme Hydrolysis and Fermentation of Cellulose"

Authors: J. Gordon, M. Jiminez, C. Cooney, and D. Wang
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Publication: Biochemical Engineering: Renewable Resources of Energy and Chemical Feedstocks, American Institute of Chemical Engineers (AIChE) Symposium Series 181, Volume 74, 1978, page 91
AIChE
345 E 47th Street
New York, NY 10017

The following articles/publications are related to the project described in summary J-5.

"Photocatalytic Decomposition of Water at Semiconductor Electrodes"

Authors: H.P. Maruska and A.K. Ghosh,
Exxon Research and Engineering Co.
Linden, New Jersey 07036

Publication: Journal of Solar Energy, Volume 20, 1978, pages 443-458
Available from: Authors, Exxon Research and Engineering Company,
Linden, New Jersey 07036

"Sensitized Photoelectrolysis of Water by Sunlight"

Authors: A.K. Ghosh and H.P. Maruska

Exxon Research and Engineering Co.
Linden, New Jersey 07036

Report No: C00-4271-1 September 1977, 64 pages
C00-4271-2 December 1977, 25 pages
C00-4271-3 March 1978, 16 pages
C00-4271-4 June 1978, 35 pages
C00-4271-5 September 1978, 22 pages
C00-4271-6 December 1978, 163 pages

Available from: Authors, Exxon Research and Engineering Company
Linden, New Jersey 07036

The following articles/publications are related to the project described in summary J-6.

"Semiquantitative Plate Assay for Determination of Cellulose Production by Trichoderma Viride"

Authors: B.S. Montecourt and D.E. Eveleigh
Cook College, Rutgers University
New Brunswick, New Jersey 08903

Published by: Applied Environmental Microbiology, 33, 1977, pages 179-183

Available from the authors

The following articles/publications are related to the project described in summary J-7.

"Background Information for the Economic Assessment of Solvent Fermentation Processes," January 1977

Authors: E.K. Pye
Medical School, University of Pennsylvania
Philadelphia, PA 19104

Published by: NTIS, Report No. C00/4070-4

L. Research and Development--Aquatic Systems

The following articles/publications are related to the project described in summary L-1.

"Cultivation on Sewage of Microalgae Harvestable by Microstrainers--Progress Report" (April 1977)

Authors: J.R. Benemann, B.L. Loopman, J.C. Weissman, D.M. Eisenberg, and W.J. Oswald
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Report No: TID-277702 NTIS (\$9.25)

"A Critical Analysis of Bioconversion with Microalgae" (1977)

Authors: W.J. Oswald and J.R. Benemann
Lawrence Berkeley Laboratory

University of California
Berkeley, California 94720
Publication: Biological Solar Energy Conversion, 1977, pages 379-396,
Academic Press, New York, NY 10003

"Cost Analysis of Microalgae Biomass Systems," Final Report (1979)

Authors: W.J. Oswald, et al.
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Report No: HCP/T1605-01 (NTIS)

"Cultivation on Sewage of Microalgae Harvestable by Microstrainers," Progress Report (1978)

Authors: R.J. Benemann, et al.
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Report No: NTIS TID-27702 (\$9.25)

"Energy Production with Microalgae"

Authors: R.J. Benemann, et al.
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Publication: Nature, 268, 1977, pages 19-23, Available from the authors

"Species Control in Large-Scale Algal Biomass Production" (November 1977)

Authors: R.J. Benemann, et al.
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Report No: NTIS SAN/7405-77/1

The following articles/publications are related to the project described in summary L-2.

"Adverse Factors Affecting Giant Kelp and Associated Seaweeds"

Authors: W.J. North
California Institute of Technology
Pasadena, California 91125
Publication: Proc. Symp. Pathogens of Marine Algae, Experientia, 1978
Available from the author

"Algae Nutrition in the Sea--Some Thoughts about Management Possibilities"

Authors: W.J. North
California Institute of Technology
Pasadena, California 91125
Publication: The Marine Plant Biomass of the Pacific Northwest Coast,
Oregon State University (OSU) Press, Corvallis, Oregon,
1977, pages 215-230, Available from OSU

"Concerning the Selection of Seaweeds Suitable for Mass Cultivation in Number of Large Open-Ocean, Solar Energy Facilities (Marine Farms) in Order to Provide a Source of Organic Matter for Conversion to Food, Synthetic Fuels, and Electrical Energy"

Authors: G.A. Jackson and W.J. North
California Institute of Technology
Pasadena, California 91125
Contract No: N60530-73-MV176 (135 pages)
Available from: U.S. Naval Weapons Center
China Lake, California

"Evaluating Oceanic Farming of Seaweeds," Semi-Annual Progress Report (June 1 to November 30, 1974)

Authors: W.J. North
California Institute of Technology
Pasadena, California 91125
Report No: NSF/RANN/SE/GI-43881/PR/74/2 (53 pages)
National Science Foundation (NSF)
1800 G Street, N.W.
Washington, D.C. 20550

"Evaluating Oceanic Farming of Seaweeds as Sources of Organics and Energy," Semi-Annual Progress Report (December 1 to December 31, 1974)

Authors: B.N. Anderson and W.J. North
California Institute of Technology
Pasadena, California 91125
Report No: NSF/RANN/SE/GI-43881/PR/75/4 (210 pages)
National Science Foundation (NSF)
1800 G Street, N.W.
Washington, D.C. 20550

"Growth Factors in the Production of Giant Kelp"

Authors: W.J. North
California Institute of Technology
Pasadena, California 91125
Publication: Symposium Papers, Clean Fuels from Biomass and Wastes, 1977, pages 128-140
Available from: Institute of Gas Technology
Chicago, Ill. 60616

"Nutritional Requirements of Macrocytics"

Authors: W.J. North and P.A. Wheeler
California Institute of Technology
Pasadena, California 91125
Publication: Proceedings, 9th International Seaweed Symposium, 1978
Santa Barbara California
Available from the authors

"Possibilities of Biomass from the Ocean: the Marine Farm Project"

Authors: W.J. North

- California Institute of Technology
Pasadena, California 91125
- Publication: Biological Solar Energy Conversion, November 1976, pages 347-361, Academic Press, New York, NY 10003
- "Ocean Food and Energy Farm Project, Subtasks 1 and 2: Biological Studies of Macrocystis pyrifera Growth in Upwelled Oceanic Water, Final Report" (November 1976)
- Authors: W.J. North, et al.
California Institute of Technology
Pasadena, California 91125
- Report No: ERDA/USN/1027/76/4 (259 pages) (NTIS)
- "Progress in Studies of Oceanic Production of Biomass" (1977)
- Authors: W.J. North
California Institute of Technology
Pasadena, California 91125
- Publication: Proceedings, Second Annual Symposium on Fuels from Biomass
Rensselaer Institute
Troy, New York
(NTIS)
- "The Oceanic Setting as a Site for Biomass Production"
- Authors: W.J. North
California Institute of Technology
Pasadena, California 91125
- Publication: Proceedings, Fuel from Biomass Symposium, April 18-19, 1977, pages 99-114
University of Illinois,
Urbana, Ill.
(NTIS)

The following articles/publications are related to the project described in summary L-3.

- "Biomass Production by some Marine and Freshwater Plants"
- Authors: T.A. DeBask, M.D. Hanisak, J.H. Ryther, R.W. Stenberg, and L.D. Williams
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
- Presented at: Second Annual Fuels from Biomass Conference
Rensselaer Polytechnic Institute
Troy, New York
June 20-22, 1978
(NTIS)
- "Cultivation of Macroscopic Marine Algae and Freshwater Aquatic Weeds," Progress Report (December 1976)

Author: J.H. Ryther
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
Report No: C00/2948-2
(NTIS)

"Growth Patterns of Codium fragile Subsp. Tomentosoides in Response to Temperature, Irradiance, Salinity, and Nitrogen Source"

Author: M.D. Hanisak
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
Publication: Marine Biology, May 1978
Available from the author

"Some Aspects of the Growth and Yield of Gracilaria foliifera in Culture"

Authors: B.E. Lapointe and J.H. Ryther
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
Publication: Aquaculture, 1978
Available from the authors

"Uptake of Inorganic Nitrogen by Codium fragile Subsp. Tormentosoides (Chloophyta)

Authors: M.D. Hanisak and M.M. Harlin
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
Publication: Journal of Psychology, May 1978
Journal Press
2 Commercial Street
Provincetown, MA 02657

The following articles/publications are related to the project described in summary L-4.

"Mass Production of Algae-Bioengineering Aspects"

Authors: J.C. Goldman and J.H. Ryther
Woods Hole Oceanographic Institute
Woods Hole, Mass. 02543
Publication: Biological Solar Energy Conversion, 1977, Academic Press, New York, NY 10077, pages 367-368

The following articles/publications are related to the project described in summary M-1.

"Mission Analyses for the Federal Fuels from Biomass Program"

Authors: F.A. Schooley, et al.
SRI International
Menlo Park, California 94025
Volume I - summary and Conclusions, December 1978
Volume II - Mission Selection, Market Penetration Modeling, and Economic Evaluation, December 1978 TID-29091
(NTIS)

Volume III - Feedstock Availability (NTIS) (1979)
Volume IV - Thermochemical Conversion of Biomass to
Fuels and Chemicals, January 1979 (NTIS)
Volume V - Biochemical Conversion of Biomass to Fuels
and Chemicals (1979)
TID-29093 (NTIS)

Report No:

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Mitre Corporation, McLean, Virginia 22102

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Vol. 2: The Biomass Potential of Short-Rotation Farms, 1977, K. Howlett, A. Gamache, Report No. TR-7347-V2/LL (\$8.00) (NTIS)

Vol. 3: Land Suitability & Availability, 1977
D. Salo, R. Inman, B. McGurk, J. Verhoeff
Report No. Mitre-TR-7347-V3/LL (\$9.00) (NTIS)

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R. Inman, D. Salo, B. McGurk
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C. Bliss, D.O. Blake
Report No. Mitre-TR-7347-V6/LL (\$7.25) (NTIS)

Vol. 6: Forest & Mill Residues as Potential Sources of Biomass, 1977
K. Howlett, A. Gamache
Report No. Mitre-TR-7347-V5/LL (\$11.00) (NTIS)

Silvicultural Biomass Farms -- A Recommended Research, Development and Demonstration Plan

2. "Design of a Pilot Silvicultural Biomass Farm at the Savannah River Plant," March 1977

Authors: D.J. Salo, J.F. Henry, R.E. Inman
Mitre Corporation, McLean, Virginia 22102

Published: NTIS

3. "Near term Potential of Wood As a Fuel"

Author: Mitre Corporation
McLean, Virginia 22102

Available from: NTIS

4. "Crop, Forestry and Manure Residue Inventory - Continental U.S.," 1976, Stanford Research Institute, Menlo Park, California 94025

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Vol. 2: East North-Central Including Illinois, Indiana, Michigan, Ohio, Wisconsin

Vol. 3: West North-Central Including Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota

Vol. 4: South Atlantic Including Delaware, Florida, Georgia, Maryland, North Carolina, Virginia, West Virginia

Vol. 5: East South-Central Including Alabama, Kentucky, Mississippi, Tennessee

Vol. 6: West South-Central Including Arkansas, Louisiana, Oklahoma,
Texas
Vol. 7: Mountain Including Arizona, Colorado, Idaho, Montana, Nevada,
New Mexico, Utah, Wyoming
Vol. 8: Pacific Including California, Oregon, Washington
Available from: NTIS

5. "Energy in Forestry Production and Use" (August 1978)
Author: A.F. Jensen
University of Florida
Gainesville, FL 32601
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6. "The Eucalyptus Energy Farm: Feasibility Study and Demonstration Phase I,
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Author: E. Mariani, et al.
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P.O. Box 5084
Alexandria, Virginia, 22305
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Final Report, November 1978
Author: Inter/Technology Corporation
Box 340
Warrenton, Virginia 22186
Available from: NTIS
8. "Cultural Treatment of Selected Species for Woody Biomass Fuel Production in
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Authors: Linda Sutliff Dolan
City of Seattle
Department of Lighting
1015 Third Avenue
Seattle, WA 98104
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Authors: D.L. Dawson
Institute of Forest Genetics
Box 898
Rhineland, WI 54501
Available from: USDA Forest Service
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
10. "Species Control in Large-Scale Algal Biomass Production" (1978)
Authors: W.J. Oswald & John R. Beneman
University of California

College of Engineering
Sanitary Engineering Research Laboratory
Richmond, CA 94804

Published by: NTIS

11. "Kelp Bed Mariculture & Resource Management" (July 1978)
Authors: M. Neushal et al.
University of California
Department of Biological Sciences
Santa Barbara, California 93106
Available from: NTIS
12. "Biomass from Florida Sugarcane as an Energy Source"
Authors: Gary J. Gascho, S.F. Shih & G. Kidder
University of Florida
Belle Glade, Florida 33430
Published by: Sugar Y Azucar, 73(6):46, 1978
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13. "Biomass--A Cash Crop for the Future"
A Conference on the Production of Biomass from Grains, Crop Residue, Forages &
Grasses for Conversion to Fuels & Chemicals (1978)
Author: Midwest Research Institute
Kansas City, MO
Available from: NTIS (\$12.50)
14. "The Feasibility of Growing Cassava As An Energy Crop" (1979)
Author: Calvin C. Sherman
Florida Solar Energy Center
300 State Road
Cape Canaveral, Florida 32920
Available from the author

B. Biomass Conversion

15. "Biological Conversion of Biomass to Methane" (December 1977)
Author: John T. Pfeffer
University of Illinois,
Department of Civil Engineering
Urbana, Illinois 61801
Available from: NTIS
16. "Methane Production by Anaerobic Digestion of Biomass" (1978)
Author: Vincent G. Murphy
Solar Energy Applications Laboratory
Colorado State University
Fort Collins, Colorado 80523
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17. "Bio-Gas in India--Retrospects of Prospects"
Author: Devinder Sood
PRC Energy Analysis Co.
McLean, Virginia 22102
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Sao. Paulo, Brazil
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Authors: Tom Reed & Becky Bryant
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Authors: Donald W. Pingrey and N. E. Waggoner
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Authors: Leo A. Spano, et al.
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Virginia Polytechnic Institute & State University

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Authors: W.J. Jewell
Cornell University
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