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RESEARCH, DEVELOPMENT, AND COMMERCIALIZATION ACTIVITIES ON BIOMASS ENERGY IN THE UNITED STATES

by

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RESEARCH, DEVELOPMENT, AND COMMERCIALIZATION ACTIVITIES ON BIOMASS ENERGY IN THE UNITED STATES

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ABSTRACT

Research and development activities in the United States on the production of energy products and synthetic fuels from organic wastes and land- and water-based biomass are growing rapidly. Commercialization of the results of this effort is also progressing but at a lower rate. Commercial plants are currently operating to produce steam and electric power by combustion or co-combustion of municipal solid wastes, agricultural residues, and wood; methane from landfills and cattle manure; and fermentation alcohol for use in gasohol blends. Available fossil fuels are still sufficiently low in cost in the United States to make the economics of producing substitute fuels from biomass borderline or unattractive. Large-scale integrated biomass energy systems are therefore not expected to be constructed and operated until the late 1980's and early 1990's. Nevertheless, about 2.1% of the U.S. total energy supply is now derived from biomass; this corresponds to about 1.7 X 10^{15} Btu.

Introduction

The number of research, development, and commercialization activities underway in the United States on all phases of biomass energy has grown at a phenomenal rate in the last few years. Almost all major universities and research institutes have started programs directed to biomass energy, and industry is getting involved, particularly the larger chemical and petroleum companies. Interestingly, the first commercial systems in the United States were started by small companies. Many state governments have also initiated biomass energy programs. The largest R&D program by far is the Federal Fuels From Biomass Program sponsored by the U.S. Department of Energy. This program has grown from $0.6 million in fiscal 1975, to $12.7 million in fiscal 1977, to $26.9 million in fiscal 1979, and is projected to be $118.9 million in fiscal 1981.* The highlights of current on-going projects in the United States are reviewed in this paper.

Research & Development

Forest Biomass Production

Improved tree growth via short-rotation forestry is under intensive study and investigation by major timber producers. Some projections indicate that yields of dry organic matter can be substantially increased by coppicing techniques and genetic improvements. Advanced designs of whole-tree harvesters, logging residue collection and chipping units, and rapid planting machinery have progressed to the point where prototype units are being evaluated in the field. It is expected that several of these devices will achieve commercial production.

Chemical injections into pine trees have been reported to have stimulatory effects on the natural production of resins and terpenes and may result in high yields of these valuable chemicals. Combined oleoresin-timber production in mixed stands of pine and timber trees is under development, and it appears that when short-rotation forestry is used, the yields of energy products and timber can be substantially higher than the yields from separate operations.

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* These figures do not include DOE project funding on municipal, industrial, or sewage wastes.

Hybridizing techniques seem to be leading to super trees that have short growth cycles and that yield larger quantities of wood biomass. Fast-growing clones of hybrid poplars are being developed for energy farms in which the trees are ready for harvest in as little as 10 years and yield up to 30 m^3/ha-yr. Genetic and environmental manipulation has also led to valuable techniques for the fast growth of saplings in artificial light and controlled atmospheres, humidity, and nutrition. The growth of infant trees in a few months is equivalent to what can be obtained in several years. Miniplantations are being established on several sites to grow hybrids of blue spruce (evergreen) and white spruce (timber tree). Another hybrid which shows promise is the American spruce, a cross between the red, white, and blue spruce.

Test plots aimed at energy applications in the midwestern, northwestern, and southeastern sections of the United States are underway with improved species of Populus and jack pine to obtain optimum spacings, rotations, and culture conditions. Short-rotation intensive culture has already demonstrated improved yields.

A good portion of this effort is expected to advance tree production technology and make it possible to consider energy applications that heretofore were too expensive.

Grass and Cultivated Plant Production

Land-based plant biomass production techniques are being optimized for warm season grasses, sugarcane, sweet sorghum, and other species through in-depth studies in test plots. Improvements in production by way of higher yields and/or lower costs are being developed through closer plant spacing, improved fertilization and irrigation methods, and higher harvesting frequencies. Species improvements via genetic manipulation and nitrogen fixation have not yet been applied to plant biomass species especially chosen for energy applications, but future advancements have been predicted by several specialists in the field.

An innovative approach to natural hydrocarbon production by plants is being developed (or re-developed depending on one's point of view). The concept was tested in full-scale plantations during the rubber shortage in World War II with the guayule bush; this shrub has the capability of producing polyisoprenes having linear structures and molecular weights similar to those of hevea rubber from the rubber tree (Hevea braziliensis). Other plant species recently found to produce lower molecular weight hydrocarbons capable of being refined into synfuels include the Euphoriba and Avalois sp. which grow well in Southern

California. Equivalent oil yields as high as 10 bbl/acre-year have been projected for these species.

Water-Based Biomass Production

Work on the production of marine biomass has concentrated primarily on California giant brown kelp. A test farm module containing a submerged polypropylene grid to which kelp plants are attached has been designed for deployment in the deep waters of the Pacific Ocean off the California coast. This experiment was initiated late in 1978 to determine whether upwelled deep water containing higher nutrient concentrations than the surface waters will stimulate high kelp growth rates and yields.

Several organizations and local governments in Florida, Louisiana, and the Western States have announced plans to design and build wastewater treatment facilities utilizing the growth of water hyacinth in the sewage influent as the clean-up method. In two of these systems, the water hyacinth will be harvested and anaerobically digested to produce methane. One system will dry the harvested hyacinth in the desert sun and then burn it as fuel in a steam-electric plant. The residual salts may be separated for marketing.

Anaerobic Digestion

Research on anaerobic digestion for the gasification of high-moisture content biomass to form intermediate-Btu gases (19.6 to 31.4 MJ/Nm^3, 500 to 800 Btu/SCF) high in methane has continued with emphasis on feedstock evaluation, the factors that limit fermentation rates and methane yields, and digester designs. Certain biomass such as giant brown kelp, water hyacinth, Coastal Bermuda grass, and other species have been found to have good biodegradabilities, and afford relatively high methane yields under conventional digestion conditions. Species such as peat and woody biomass yield lower quantities of methane, but the pretreatment conditions necessary to improve digestibility have been determined. Overall, conversion efficiencies to methane seem to have plateaued around 50% volatile solids destruction efficiencies and 50% to 60% energy recovery efficiencies as methane. Some of the advanced digestion methods under development are expected to make it possible to reach the next plateau.

Alcoholic Fermentation and Alcohol-Derived Fuels

One research development that some believe is a breakthrough is a pretreatment step that dissolves cellulose thereby eliminating hydrolytic problems due to ligno-cellulose complexes and crystallanity. The treated cellulose can be converted to glucose in high yields (90+%). Practical application of this technique to woody biomass can open routes to many high efficiency biomass applications such as alcohol production. The technique appears to have much greater potential and provide lower cost ethanol than enzyme-catalyzed hydrolysis methods. Enzymic methods usually require a feed particle size of the order of microns to facilitate hydrolysis of the cellulosics.

Gulf Oil is taking a different approach to ethanol from biomass in their combination enzyme-catalyzed hydrolysis-alcoholic fermentation process. The hydrolytic enzyme and yeast for fermentation are present in the same vessel and the reactions occur simultaneously. An 8 000-L/day plant is being built in Kansas to test the process at the pilot scale. Another interesting approach is to convert biomass to ethanol and to use the residue from the fermenters to manufacture hydrogen in a photoelectrolysis plant. This integrated concept for both ethanol and hydrogen production is under development by Battelle.

Although the process is not directly related to alcohol production, Mobil Oil's gasoline-from-methanol process should be mentioned because of its potential for eliminating many of the problems perceived for gasohol fuels. Methanol is converted directly into high-octane gasoline over a synthetic zeolite catalyst at a cost of 5 to 10¢/gal of gasoline produced and no diesel fuel or residue of any kind is formed. Higher alcohols such as ethanol can also be converted to gasoline by this process. The key factor in the commercial use of this process is the cost of the feed alcohol. The current price structure precludes commercialization. The Mobil process is also reported to be suitable for conversion of ethanol to gasoline.

An application of ethanol that is often overshadowed by the fuel applications is the use of ethanol as a raw material for the manufacture of chemicals. An ethanol-based organic chemicals industry in which the primary derivatives of ethanol (ethylene, acetaldehyde, and acetic acid) are converted to other organic chemicals by established routes is under serious study by several chemical companies.

Combustion

Research on biomass combustion systems has concentrated on the use of oxygen-enriched air for increasing the flame temperature of high-moisture content biomass, particulate emissions associated with biomass combustion, co-firing systems in which biomass is combusted with a fossil fuel, and the combustion characteristics of wood-derived chars alone and in combination with oil or coal.

Pyrolysis and Other Thermochemical Processes

Thermochemical gasification research is being developed by many research groups. Partial oxidation, steam reforming, steam-oxygen reforming, hydrogasification, and pyrolysis reactions are all under active research with a wide range of biomass. Most of this work is aimed at maximizing the production of synthesis gas. No one method seems to be preeminent as far as having a clear technical superiority over other methods. A few systems studied at the laboratory scale have produced significant quantities of olefins which have a higher intrinsic value than synthesis gas. As the product compositions are related more quantitively to reaction conditions, better control of product selectivity is expected. Some reports indicate that those thermochemical gasification methods which can convert the moist feed without drying operate at higher efficiencies, as might be expected, and also provide higher synthesis gas yields. Considerable effort is in progress to develop better catalysts for thermochemical gasification. Alkaline salts, lime, and wood ash mixed directly with the biomass feed have been reported to be effective catalysts. It should be noted that most thermochemical gasification systems do not yield gaseous products only; char and liquid products form as well. The quantity of each depends on the reaction conditions and the feed characteristics.

Research has emphasized the design of fluidized bed gasifiers, multiple hearth gasifiers for high-moisture-content biomass, hydrogasification units, and small-scale producer gasifiers. Test programs are in progress to evaluate these units at the process development unit (PDU) and pilot plant scales. A wide range of reactor designs and conversion chemistries is being studied, especially for the production of low-Btu gas having heating values of 100 to 450 Btu/ft^3. The processes that yield gases with heating values near the high end of this range can generally be categorized as systems that use pure oxygen in partial oxidation systems, two-bed systems that keep the nitrogen in air separated from the product gas, pure pyrolysis systems, or hydrogasification systems. The producer gasifiers usually employ partial oxidation with air and yield product gases with heating values from 100 to 200 Btu/ft^3. Such units were in commercial use for the gasification of wood, agricultural residues, and municipal wastes many years ago and recently have been considered again for low-Btu gas manufacture. Retrofitting of an automated producer gasifier to a gas-fired boiler offers a potentially low-cost fuel supply. Test programs are currently being conducted by several firms.

Thermochemical liquefaction is much more limited in scope than gasification. Currently, there are only two direct liquefaction processes under development in the United States at the pilot plant scale on which information has been reported. One is flash pyrolysis (Occidental Research Corp.) and the other is the PERC process in which carbon monoxide is reacted with biomass slurries in an aqueous carbonate solution (Albany, Oregon). Both processes yield heavy fuel oils. It is interesting to note that no hydroliquefaction research seems to be in progress.

Analysis of Large Areas

Many studies have been performed to assess the potential of biomass energy for specific regions of the country, such as an individual state, and a particular biomass industry within an area. One of the more interesting studies was a comprehensive analysis of biomass energy possibilities for the State of Hawaii. The principle objective of this study was to determine the energy potential of Hawaii's biomass resources and to propose how they could be effectively tapped in the 1980's to provide the state with a viable alternative to current fuel sources. The situation in Hawaii is ideal for this study because there are no indigenous petroleum resources. In 1977, about 92% of Hawaii's energy came from imported petroleum, 7% from burning bagasse, and 1% from hydroelectric facilities. The study resulted in recommendations for improved usage of bagasse, energy recovery from municipal solid wastes (MSW), establishment of short-rotation eucalyptus energy farms and wood-powered electric plants, and marine energy farms for the kelp Sargassum, five species of which are native to Hawaii. Implementation of these recommendations and others on renewable resources is now getting started through the state Senate's Committee of Energy and Natural Resources.

Commercialization

Integrated Biomass Energy Systems

Although several small- and moderate-scale biomass production projects are in the field-test stage, integrated biomass production-conversion systems in which biomass is grown specifically for energy production or synfuels manufacture have not yet reached the field in the U.S.A.; this is expected to begin in the 1980's. But as alluded to in the previous sections of this paper, many types of processes are being developed that utilize biomass as primary energy sources. Some of these projects have reached the commercial stage.

Combustion

A recent survey of waste and biomass energy pilot, demonstration, and commercialization projects in the United States indicates that many are aimed at recovery of recyclables and energy from waste materials. (1) The most direct approaches to energy from municipal wastes — direct combustion or separation of recyclables and a refuse-derived fuel (RDF) for burning — have been emphasized in many of these projects. This survey indicates that waste gasification to produce low-Btu gas for steam and electric generation via thermochemical processing and intermediate-Btu gas for the same applications via anaerobic digestion were established technologies several years ago. Much of the current process development work is therefore aimed at improvements in operating conditions, product yields, and overall system efficiencies of processes that have been known for many years.

Combined waste disposal and steam-electric production by combustion of MSW is a proven and established technology in the United States. Operating problems have occurred in many of the plants that are currently on-line, but in the main, these problems have not resulted in permanent shut-downs. Emissions requirements have probably been the source of the most difficulty. Retrofitting of control systems on existing plants has eliminated many of these problems and new plants coming on-line are expected to meet or exceed environmental requirements.

Many wood combustion facilities are in commercial use in the United States for the production of heat, steam, and the cogeneration of steam and electric power. Plans have been announced by a number of companies including public utilities to build new wood-powered generation plants. Some of these plants are scheduled for construction and operation in the Midwest, the West Coast, and the New England area. Burlington, Vermont, for example, is proceeding with a

50-MW plant scheduled for completion in 1982. A larger 100-MW wood-powered steam-electric plant in Maine is also in the design stage under sponsorship of the U.S. Department of Energy. At the present time, major users of wood and other biomass combustion systems for power generation are the sugar, pulp and paper, and wood products industries. But small-scale units operated by home owners, farmers, and small businesses are receiving renewed interest.

Steam-electric production from agricultural and forest biomass such as bagasse and hogged wood is thus established commercial technology in the United States. Many of the existing plants are designed to burn fossil and nonfossil fuels either simultaneously or separately. According to a recent survey of installations that generate their own power, pulp and paper mills burn 46% wood-derived fuels and 54% fossil fuels while forest product mills burn 98% wood fuels and 2% fossil fuels.

Fabricated fuel pellets made from a variety of cellulosics are now commercially available. User costs for these solid fuels, which have heating values in the 18.6 to 20.9-MJ/kg (8 000 to 9 000 Btu/lb) range, are reported to be about the same as 29.1-MJ/kg coal (12 500 Btu/lb) on an equivalent energy content basis. One of the products utilizes a thermoplastic binder which gives improved mechanical and combustion properties to the pelletized fuel.

Thermochemical Conversion

Interestingly, large-scale thermochemical processes to manufacture low-Btu gas and liquid fuels from non-fossil feeds do not seem to be faring too well in the United States. Of those processes that have been under development for several years and then scaled-up to either full-size or large demonstration plants (Baltimore, Md.; El Cajon, Calif.), start-up and technical problems have delayed continuous operation of the plants. In other cases where the technology for conversion of a municipal waste to low-Btu gas was seemingly established several years ago in demonstration plants (Buffalo, N.Y.; South Charleston, W. Va.), commercial development in the United States has been slow. In one case (Andco-Torrax Process), two plants have already been built and two are under construction in Europe, but none has been announced for the U.S.A.

Anaerobic Digestion

Recently, the collection and upgrading of landfill gas to substitute natural gas (SNG) was commercialized by distribution in a gas utility system (Palos Verdes, Calif.). Several months were required to solve start-up problems, but now it is expected that many similar systems will be built and operated on existing landfills.

Commercial production of SNG has also been started by anaerobic digestion of cattle manure collected from dirt feedlots (Guymon, Okla.). Several months were also required to solve start-up problems, but this pioneering project, the first of its type to apply and receive authorization from the then Federal Power Commission, attained commercial status on April 1, 1978, when the gas was injected into the pipeline for transmission to Chicago, Illinois. The plant operator, Calorific Recovery Anaerobic Processes, Inc. has a 20-year contract with Peoples Gas Company for delivery of SNG at a rate of about 600 million cubic feet per year. Other projects of a similar scale are expected to be started in the West and Southwest. Several smaller scale methane-from-manure projects are also underway. The projects include research studies in confined feedlots and farms, as well as small-scale commercial systems for farms.

Alcohol Fuels

More interest and activity has probably been generated over the last year or so on the use of methyl and ethyl alcohols and alcohol-gasoline blends as motor fuels in the U.S.A. than ever before. The pro- and anti-fuel alcohol forces are choosing sides at all levels of Federal and state governments as well as in the petroleum and automotive industries. The publicity on the subject has generally left the average citizen with the feeling that if the politics could be solved, our energy problems would be at least partially eliminated by the manufacture of alcohol fuels. In view of the potential large-scale usage that may eventually occur in the United States, the subject is an important one.

From an applications standpoint, there are differences of opinion in the U.S.A. regarding the suitability of alcohol fuels for motor vehicles. Examination of the properties of pure methanol, pure ethanol, and gasoline shows that there are major differences in vaporization characteristics, flammability limits, energy contents, and octane numbers between the alcohols and gasoline. Some of these differences would be expected to be beneficial in motor fuel application while others might not. Currently, the American Petroleum Institute has taken the position that methanol-gasoline and ethanol-gasoline blends are not desirable motor fuels because of the handling problems associated with them and because the potential advantages of pure alcohols are lost and not realized in blends. In the longer term when synfuels from such materials as agricultural products become economically competitive with petroleum, the API proposes that the use of alcohols as fuels should be reexamined. The most attractive of such uses would be in stationary gas turbines, or as straight fuel in specially designed automobile engines.

Gasohol containing up to about 10 vol % ethanol in unleaded gasoline is commercially available in the corn belt of the Midwest. States such as Nebraska, Iowa, and Illinois have reasonably large gasohol marketing programs underway and despite the higher cost of gasohol (about 5¢ to 10¢/gal), sales are brisk. With momentum in favor of the pro-gasohol forces building up and the simultaneous gasoline shortages, it appears that gasohol will ultimately become a major commodity in the United States. In contrast, methanol seems to have been forgotten as a fuel blending component.

Economics of Commercial Processes

The economics of technically feasible, demonstrated biomass energy resources and processes will ultimately determine when and how a particular process is commercialized. Available fossil fuels are still sufficiently low in cost in the United States to make the economics of producing subsitute fuels from wastes borderline or unattractive if the process is viewed specifically as an energy-producing system. The increasing cost of waste disposal by conventional methods and the related environmental factors, however, when considered together with the credits for the energy products tend to make combination disposal-energy recovery processes more competitive with both conventional waste disposal and energy costs. The large number of new projects, especially in the separation and combustion categories, in the United States support this contention. In Western Europe where fuel costs are high and landfilling sites are scarce, there are, for example, 243 municipal waste-to-energy combustion plants in operation. (1) When the same kinds of conditions begin to prevail in the United States, waste-to-energy projects will be commercialized at a much higher rate.

The same economic conditions currently exist for manure gasification processes; methane revenues alone do not justify the process and in fact provide a lower return than the by-product animal feeds. In cases where a large renewable energy resource is generated on-site and there is a need for fuel, such as in a lumber mill or a sugarcane processing plant, the economics are often favorable for direct processing such as via bagasse or wood combustion to steam and electric power.

Summary

Many research and development projects aimed at the production of synthetic fuels and energy products from biomass are underway in the United States, and new waste-to-energy plants are coming on-line to add to those in commercial use. However, available fossil fuels are still sufficiently low in cost to make the economics of producing substitute fuels from biomass borderline or unattractive if the system is used only as an energy source. Large-scale integrated biomass synfuel systems are therefore not expected to be constructed and operated until the late 1980's and early 1990's.

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