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Programs in Renewable Energy

Biofuels Program Summary

Volume I: Overview

Fiscal Year 1988

On the cover: Scientists are making great advances in biofuels research by applying the new techniques of biotechnology. At Oak Ridge National Laboratory, scientists are using tissue cultures—tiny plantlets grown in test tubes—to study the disease resistance of potential energy crops, improving the efficiency and chance of research success.

This publication is one of a series of documents on the renewable energy programs sponsored by the U.S. Department of Energy. Companion overview and research summaries include the following:

FY 1988 Program Summaries

- Energy Storage and Distribution
- Solar Buildings
- Solar Thermal Energy
- Geothermal Energy
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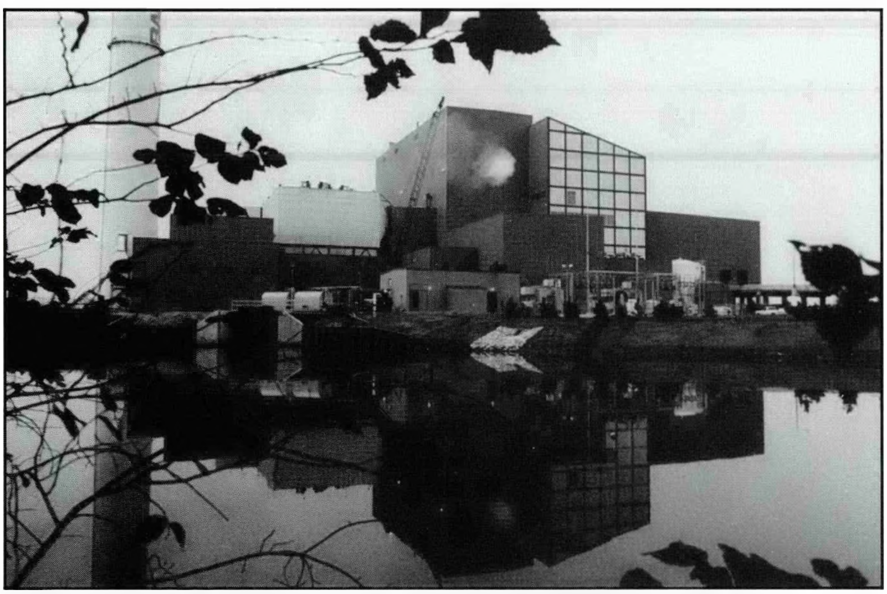
Introduction

Energy from biomass is both a "here and now" technology and a technology for the 21st century. With current technology—mostly direct combustion of wood—the energy contribution from biomass resources is approaching 3 quads, or 4% of our nation's energy use. However, the greatest potential for these resources lies in their conversion to biofuels that can begin replacing and supplementing fossil fuels in the 1990s and mature as major contributors to our energy needs after the turn of the century. By that time, biofuels could supply an additional 10 quads annually, up to 50% of our transportation fuel needs.

The 1980s have seen a doubling in the energy contribution from biomass. Despite a general decrease in conventional fuel prices, there has been an increase in the number of industries, utilities, and municipalities turning to biomass as a source of energy. Today's applications include heat and electricity from municipal waste and industrial wood waste, ethanol from grains, and methane from landfills. The reason for this increase is simple. Even in an era of lower conventional fuel prices, energy from biomass is economically and environmentally competitive in many applications and often replaces a costly waste with a useful product.



The Southwest Resource Recovery Facility in Baltimore, Md., burns municipal solid wastes to produce steam and electricity.

Within the U.S. Department of Energy (DOE), the Biofuels and Municipal Waste Technology Division is working to ensure that the technology for providing economical, plentiful, and renewable supplies of liquid and gaseous fuels will be available when the nation needs them. To this end, research is being pursued on carefully selected pathways leading to the production of renewable gasoline, diesel, and alcohol fuels, as well as pipeline-quality gas.

During fiscal year 1988, the National Biofuels Program continued to make progress in all areas of research, reinforcing the confidence that the research goals necessary to unlock the energy potential of biofuels are both reasonable and achievable.

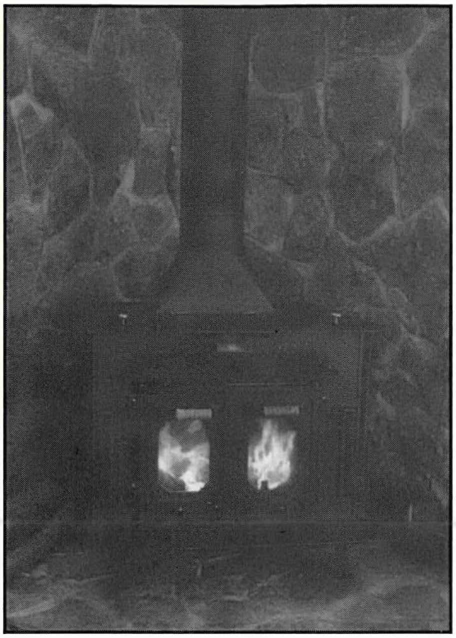
A Short History of Biofuels

Biomass is our oldest fuel. For thousands of years, people have burned wood for cooking, heat, and protection. Until the mid-19th century, wood accounted for virtually all the world's energy supply. At that time, the emergence of the industrial revolution demanded a fuel with greater energy density. As a result, plentiful and convenient fossil fuels such as coal and later oil and natural gas pushed biomass to the "back burner" in the world's developed nations, although wood continued to be the principal fuel in many developing nations.

Biomass was no longer the developed world's primary energy source, but interest in biomass never completely faded. Waste wood continued to be used for energy in the forest products industry, and trees were harvested for residential heating. Innovative uses for biomass were occasionally tried. For example, in the late 1800s methane produced from manure was used for street lighting in England. In the 1930s, a blend of gasoline and alcohol produced from biomass was sold in several midwestern states. During World War II, many Europeans used wood gasifiers to fuel their automobiles when supplies of gasoline ran out. Although biomass was recognized as a potential liquid and gaseous fuel, its use was limited to such short-term, innovative applications. The impetus for the developed world's increased use of biomass—high oil prices and low oil supplies—did not exist.

U.S. industry produces more than 800 million gallons of fuel ethanol each year, primarily from corn.

It was not until the 1970s that biomass began to reemerge as an energy option in the developed nations. The price increases and supply disruptions in petroleum led the world's developed nations to search for alternative fuels. In the United States, the use of biomass once again began to increase. Direct combustion of wood—its oldest application—was suddenly once again in vogue, with utilities and industries turning to wood as a source of electricity and process heat.

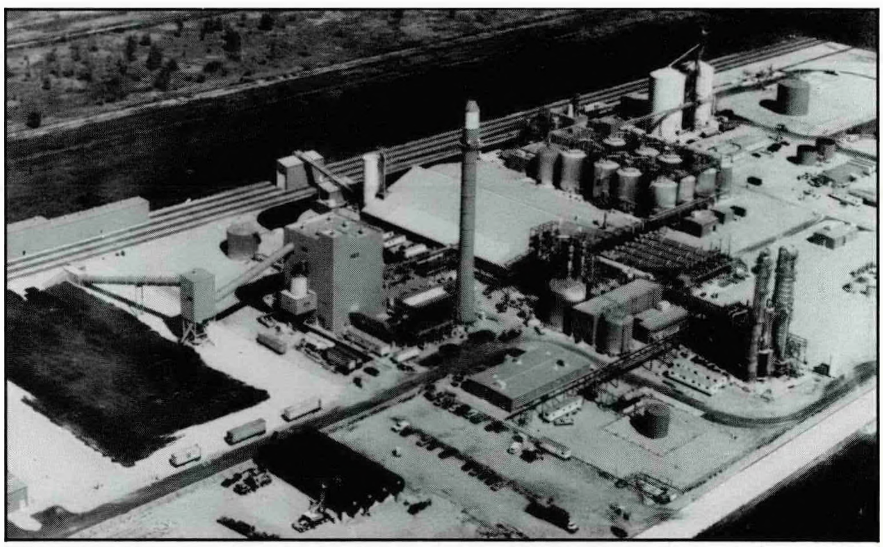


Wood stoves supply heat to 20% of all U.S. homes.

Municipalities, faced with waste disposal problems, began to turn to waste-to-energy systems as a way to solve both environmental and energy problems. And homeowners, faced with soaring energy bills, discovered that heating with wood could be both affordable and efficient. At the same time, the potential of biomass to produce liquid and gaseous fuels—biofuels—began to be studied in earnest.

The first biomass-derived liquid fuel to achieve a measure of commercial success has been ethanol from grain crops such as corn. The transportation fuel crises of the 1970s led to the production and use of ethanol as a 10% blend in gasoline. This ethanol-blended gasoline is now 8% of all gasoline produced in the United States. Today, more than 800 million gallons of ethanol are used annually as fuel. Ethanol also makes environmental sense: ethanol has replaced lead as an octane enhancer and is less polluting than conventional fuels. Its main disadvantages are that ethanol fuels from corn and other sugar and starch crops are currently cost-competitive only with federal and state tax credits, and the price of ethanol is dependent on food prices, not fuel prices. The National Biofuels Program is researching technologies to produce cost-competitive ethanol from inexpensive nonfood sources such as wood and grasses rather than food crops.

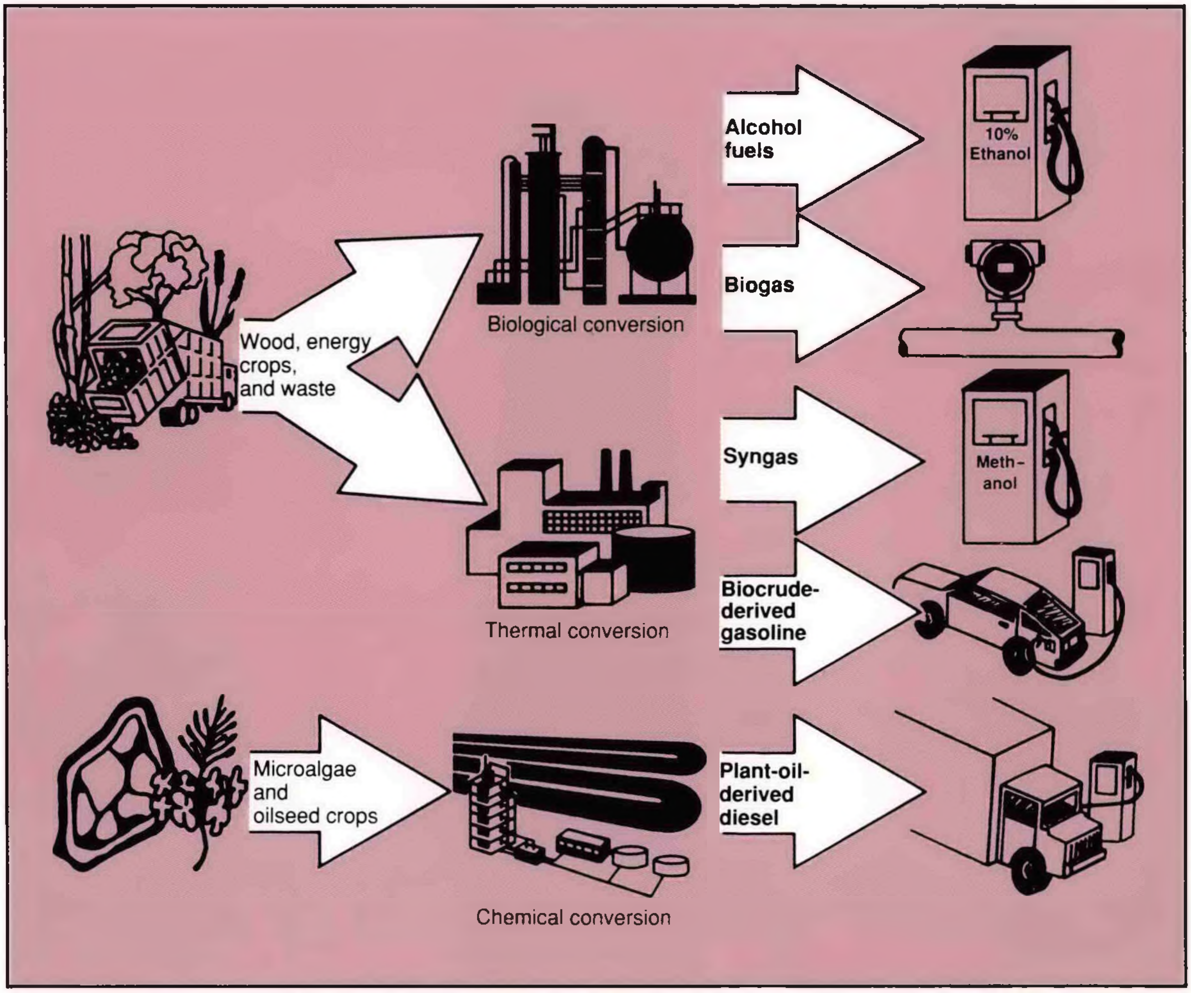
During the 1980s, the National Biofuels Program has focused its research on increasing the availability and quality of biomass as an energy resource and developing conversion processes for making liquid and gaseous biofuels. The most critical area of research centers on the production of transportation fuels—the energy sources our nation needs most. At the same time, growing awareness of the problems associated with fossil fuel use (such as acid rain and the greenhouse effect) has highlighted the fact that biomass systems are environmentally sound alternatives for both energy production and waste disposal.



The New Energy Company of Indiana produces ethanol from grain at this facility in South Bend, Ind.

The Research Program

The goal of the National Biofuels Program is to provide the technology base for the production of cost-competitive liquid and gaseous fuels from biomass resources. During the early stages of biofuels development, DOE provides leadership and serves as a catalyst by sponsoring long-term, high-risk research and development (R&D). As technology is developed, industry's level of cooperation and cost sharing increases. Finally, when the technology is sufficiently advanced and the economics are sufficiently defined, industry assumes responsibility for commercialization.



Research is focused on five pathways that integrate feedstock and conversion research. The pathways result in five specific liquid or gaseous fuels.

Federal research is focused on innovative concepts to produce improved energy crops and convert them to liquid and gaseous fuels. Researchers are applying biotechnology and improved cultivation techniques to improve the growth, productivity, and energy content of the feedstocks. Technical advances in thermochemical (e.g., gasification and pyrolysis) and biochemical (e.g., fermentation and anaerobic digestion) processes will allow improved conversion of these feedstocks to liquid and gaseous fuels. Throughout the biofuels development cycle, interchange with industry is emphasized to ensure that the National Biofuels Program is developing the necessary research data and that results of federal research are transferred to industry.

As a result of a careful screening and evaluation process, the National Biofuels Program has established specific fuel pathways and research priorities. These integrated fuel pathways have the greatest potential to produce renewable, economical liquid and gaseous fuels. Integration allows for specific feedstocks to be tailored to specific conversion processes, and vice versa, thus enhancing fuel production from each of the pathways. Cost goals have also been established for each pathway and are shown in the table below. For comparison, gasoline currently costs $8.00 per million Btu and natural gas $3.00 per million Btu.

Biofuels Cost Goals

Biofuels	Current Production Cost* ($ per million Btu)	Cost Goal at Introduction* ($ per million Btu)	Projected Year of Market Introduction
Liquid Fuels			
Ethanol (nonfood)	24.50	10.00	2000
Gasoline	—	10.00	2010
Diesel	58.00	10.00	2020
Methanol	14.00	10.00	1995
Gaseous Fuels			
Syngas	8.00	3.50	1992
Biogas	5.00	3.50	1996*

*Includes feedstock costs (currently $3.25 per million Btu for terrestrial energy crops, with a goal of $2.00 per million Btu by 1996).

Research Progress and Challenges

Successful development of biofuels technologies depends on research advances both in energy crops and their conversion to liquid fuels. Feedstock research will help ensure that there are plentiful supplies of low-cost biomass available for conversion. Conversion research will ensure that biomass feedstocks will be converted to high-value liquid and gaseous fuels at competitive prices. The following pages summarize the DOE program and future R&D directions for developing fully the energy potential of biofuels.

Technology Overview

The two basic elements to biofuels pathways, a feedstock and a conversion process, are interdependent and must be combined into a productive biofuels system.

Feedstock. A small fraction of the solar energy reaching the earth is used by plants via photosynthesis, which is essential to all life on earth. In this process, plants combine sunlight with carbon dioxide, water, and nutrients to produce organic materials, or biomass, and expel oxygen. Biomass is energy stored in the various types of carbohydrates, ranging from sugars to cellulose. This energy is released when the plant is burned or, if converted to a fuel, when the fuel is consumed. Currently available biomass feedstocks include wood from conventional forestry operations, wood wastes, municipal wastes, and agricultural products and residues. Research is under way to produce improved feedstocks better suited for conversion to fuels: fast-growing tree species that are up to 10 times more productive than conventional forests, high-yielding herbaceous energy crops, and aquatic crops that produce fuel oils directly.

Conversion. Biomass is converted to energy via two processes. Thermochemical conversion uses high temperatures to convert biomass directly to energy, or to a liquid or gaseous fuel. Direct combustion randomly breaks down the structure of biomass to produce heat. However, to produce high-value liquid and gaseous fuels, the thermochemical process must be much more controlled. When heated with reduced oxygen, the long chains of molecules in biomass are broken down into simpler molecules that are useful directly as gaseous fuels or can be converted to liquid fuels such as gasoline and methanol. Biochemical conversion uses living organisms (bacteria, fungi) to produce enzymes (biological catalysts) that promote specific chemical reactions to produce liquid and gaseous fuels. The two biochemical conversion processes under investigation are fermentation and anaerobic digestion. Fermentation uses yeasts or other microorganisms to produce alcohol fuels. Anaerobic digestion uses bacteria in the absence of oxygen to produce methane.

Feedstock Research

The key to realizing the full potential of biofuels is to ensure the availability of feedstocks that can be converted to high-value liquid and gaseous fuels. At present, existing resources —wood and wood wastes, agricultural residues, and municipal wastes—are the feedstocks that contribute to the 3 quads of annual biofuels use. However, providing the resource base for the full potential of biofuels will require the development of feedstocks that are more productive and tailored specifically for energy.

Energy Crops

The National Biofuels Program has been investigating the development of energy crops and has focused on short-rotation hardwood trees and herbaceous crops. These energy crops can yield an average of more than 10 dry tons per acre per year, compared with 1-2 dry tons per acre per year found in nature. Wood energy research focuses on hardwoods, which have the ability to regrow from the stump after harvest, facilitating multiple harvests from a single planting. Fast-growing hardwood trees are harvested in 2-8 years, rather than in the 30-60 years common in conventional forestry.

During the past decade, results of short-rotation research have been impressive. Of 140 candidate species, researchers have selected five of the most suitable species for further research. Yields have averaged 3-4 times those of conventional forestry practices, with additional gains likely through increased use of genetic improvement techniques. Many of the large forestry industry companies are becoming more involved in short-rotation wood research; several companies have provided land, labor, and materials for planting. Others are initiating their own test plots.

During FY 1988, research focused on the lead model specie, *Populus*. Experimental *Populus* plots of 20-80 acres were established to improve the

Test plots of sycamore trees provide researchers at Oak Ridge National Laboratory with information on the effects of culturing practices and environmental factors.

Switchgrass, a traditional forage crop, is highly productive and can be grown as an energy crop with conventional farming techniques.

understanding of disease and pest risks from managing larger, single-specie sites, and to provide realistic cost figures and operating data. Industry continues to share the costs of this research. In addition, laboratory and field tests were conducted to identify the most promising nitrogen-fixing species. Nitrogen fixation eliminates or decreases the need for expensive fertilizer, reducing overall costs of short rotation systems. FY 1988 also saw the beginning of efforts to identify desirable energy characteristics of short-rotation trees for future tailoring via biotechnology to match the requirements of specific fuel conversion processes.

Herbaceous energy crops offer the advantages of high yields and frequent harvests during the growing season. Together with short-rotation wood, herbaceous feedstocks provide a continuous supply of biomass throughout the year. Current research is focusing on grasses and oilseed crops. Since its inception in 1984, herbaceous energy crop research has concentrated on evaluating and selecting promising species for further development. Of 300 species screened, 25 with the most potential have been identified.

During FY 1988, screening continued to define the most promising species for the Great Plains, Midwest, and Southeast; and agronomic, energy, and nutrient requirements were defined for the best of these species. In addition, efforts continued to evaluate desirable traits for tailoring to specific conversion processes.

Municipal Wastes

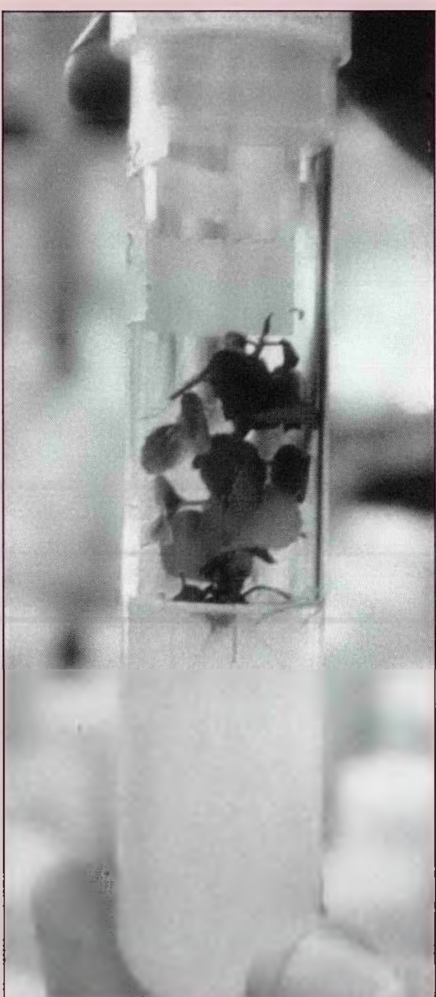
Each year, the United States produces nearly 240 million tons of solid wastes, or about one ton of solid waste per person. Traditional methods of disposing of this enormous burden—landfilling and incineration (burning to reduce volume)—are expensive and pose serious environmental problems. Furthermore, local governments report that wastewater treatment is their single largest energy consumer, accounting for over 40% of their annual energy budgets.

Municipal solid waste—garbage—is a growing problem in many U.S. cities. It can be converted to heat, electricity, or fuels, changing a disposal problem to an energy resource.

The solution is to turn the potential headache of waste disposal into a benefit by converting the wastes into energy, and to recycle valuable materials such as aluminum, newsprint, and glass. Current technology is available to convert municipal waste to steam and electricity while producing less pollution than the fossil fuel displaced and eliminating the groundwater pollution of landfills.

During the previous decade, federal efforts have assisted in moving a number of waste-related technologies into the marketplace: combustion to produce steam, heat, and electricity; recycling of materials to conserve energy; production of refuse-derived fuel as a substitute for coal; and recovery of gas produced from landfills. In addition, pioneering research sponsored by the National Biofuels Program in the understanding and control of dioxins produced by the combustion of wastes has made municipal waste a more attractive energy option.

The National Biofuels Program is continuing its research efforts in municipal waste technology. Research is continuing to process the wide variety of



Tissue culturing—growing tiny plantlets in test tubes—is an example of how biotechnology techniques can help improve the efficiency of research.

The Role of Biotechnology

Scientists believe that the most significant advances in biofuels research are likely to come from the application of biotechnology. Broadly defined, biotechnology involves the use of biological systems to amplify, modify, or transfer genetic material to achieve a specific purpose. Biotechnology is fast becoming a key to the success of a number of biofuels pathways. In feedstock research, biotechnology is key not only to higher yields, but also to feedstocks with specific energy characteristics. For example, the development of energy crops with higher energy densities and less ash will greatly improve thermochemical conversion technologies. Likewise, feedstocks with more cellulose and less lignin are desirable for biochemical conversion.

The innovative techniques used in biotechnology are extremely powerful because they allow a large amount of control over biological systems. For example, recombinant DNA, one of the newer techniques, allows direct manipulation of the genetic material in individual cells. This technique can be used to develop woody and herbaceous plants that are disease or drought resistant, or to develop improved organisms for more efficient ethanol production. Another technique, cell fusion, combines the desirable characteristics of different types of cells into a single cell. This technique can be used to develop a herbaceous energy crop with resistance to herbicides or produce a biogas-producing organism that can tolerate high concentrations of damaging organic acids. Bioprocess engineering allows the adaptation of biological methods for large-scale use. Improvements in techniques for immobilizing cells or enzymes in bioreactor design can, for example, help increase production and facilitate recovery of fuel products. In the next decade, the competitive advantage in areas related to biotechnology may depend in large part on maximizing bioprocess engineering.

The science of biotechnology is in its infancy, but advances are occurring at a whirlwind pace. The rapid advances happening now—and likely to continue—in biotechnology have the potential to radically alter the economics of biofuel production to the degree that biofuels may replace petroleum-based options soon after the turn of the century.

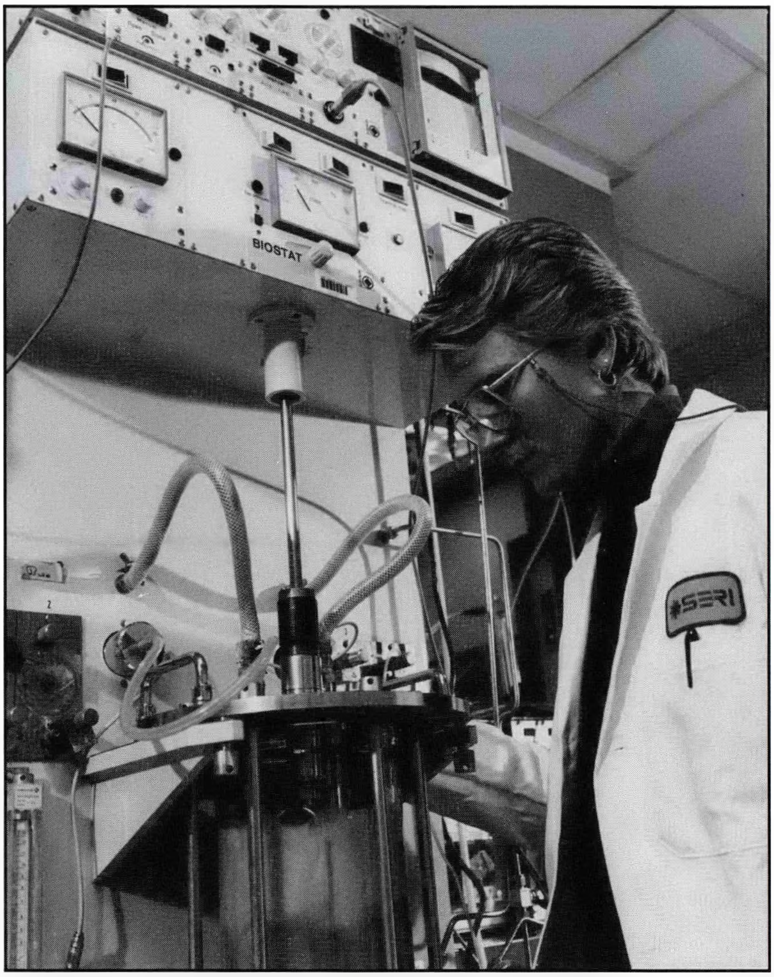
wastes into a refuse-derived fuel that is more suitable for conversion. This research led to a successful large-scale test burn of refuse-derived fuel pellets. In other research, a model was developed for the chemical degradation of municipal solid waste, an important step toward producing gasoline from municipal wastes.

Conversion Research

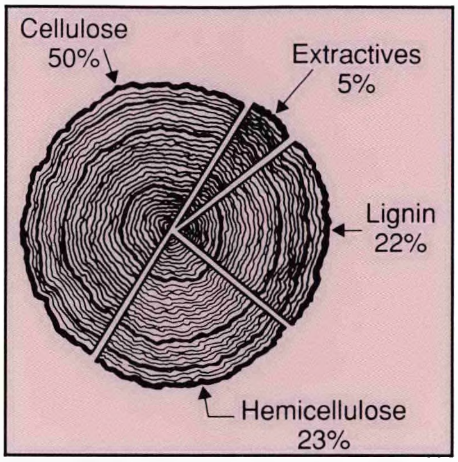
Biofuels conversion technologies under investigation can be divided into thermochemical and biochemical processes. However, because of the National Biofuel Program's focus on pathways to produce liquid and gaseous fuels, conversion research has been organized into selected pathways for liquid fuels (ethanol, gasoline, diesel, and methanol) and gaseous fuels (syngas and biogas).

Ethanol

Today, ethanol is produced commercially from starch and sugar crops. These crops are used primarily as food, which sets their value. At current prices, ethanol from these feedstocks is competitive only with government support in the form of tax credits for ethanol producers.



Simultaneous saccharification and fermentation converts wood to ethanol in one reactor. The cost of ethanol from this process has dropped from about $4.00 per gallon to around $1.80 per gallon over the last ten years.



Typical composition of hardwood feedstock.

The National Biofuels Program is investigating biological systems that convert inexpensive cellulose and hemicellulose, the two principal components of wood and grasses, to sugars that are then fermented to ethanol. Cellulose is difficult to convert to glucose sugars, but the glucose is easily converted to ethanol. Hemicellulose is easily converted to the sugar xylose, which is difficult to convert to ethanol. The key research steps include using biotechnology and genetic engineering to develop improved organisms for better conversion of cellulose to sugar and hemicellulose sugars to ethanol. Together, these steps will substantially reduce the cost of ethanol from biomass.

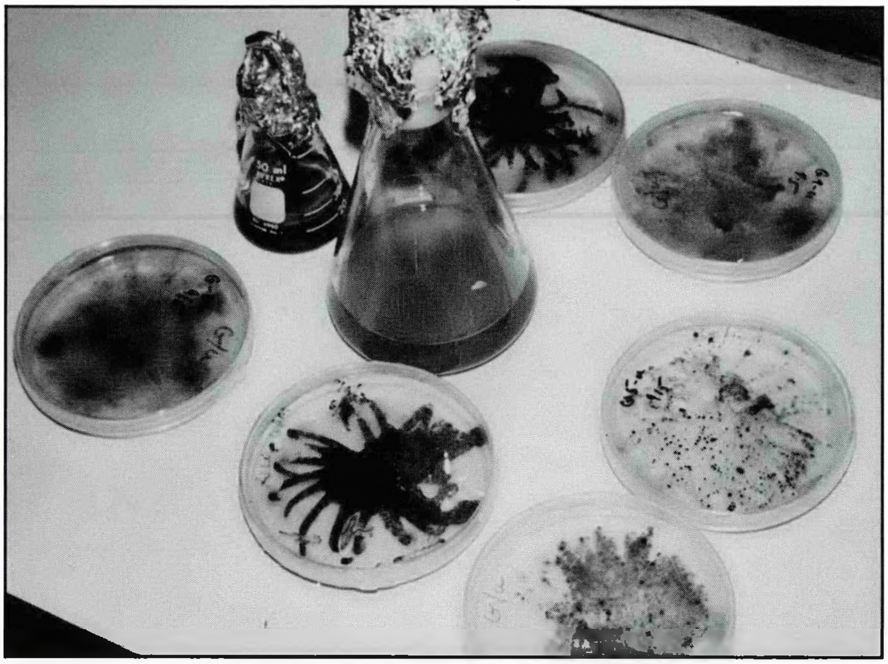
DOE-sponsored researchers have already noted significant progress in producing ethanol from nonfood sources. Research has focused on enzymatic hydrolysis, a process in which enzymes selectively convert cellulose to sugar. Only a few years ago, enzymatic systems converted 60%-70% of cellulose to sugar. During FY 1988, yields in experimental systems approached 90%. During the same period, ethanol concentrations from fermentations increased from 2% to nearly 5%, reducing the cost and energy associated with distillation.

Only a decade ago, there were no systems to convert hemicellulose sugars to ethanol. Today, researchers have methods to produce enzymes that will convert these sugars to a similar fermentable sugar. During FY 1988, researchers increased production of enzymes by genetically altered organisms and developed a reactor system that offers the potential for reducing ethanol costs by 40%.

With continued improvements, the cost of ethanol, which has decreased from $4.00 per gallon in 1980 to $1.80 per gallon today, can reach its program goal of $0.80 per gallon—without tax credits—by the turn of the century.

Diesel

Certain aquatic and terrestrial plants possess a unique quality: the ability to produce oils that can be extracted and upgraded to diesel fuel. In particular, aquatic plants are fast-growing and high-yielding, and their ability to be harvested frequently gives them the potential to be a reliable energy supplier. During the past decade, researchers have screened thousands of species of microalgae to identify individual species that have high yields or high oil content. Researchers are evaluating the performance of these high-yield species in an outdoor test facility to determine their ability to sustain growth and measure their response to varied environmental conditions. Meanwhile, researchers are using genetic engineering to combine high growth and high oil yield in a single organism, and to modify the chemical composition of oils to require less upgrading.



Several species of microalgae—single-celled aquatic plants—produce oils that can be extracted and upgraded to diesel fuel. Scientists are improving the productivity and yield of the process through genetic improvement.

Producing diesel fuel from microalgae is a long-term option; the technology is not expected to reach the marketplace until 2020. However, the high productivity of microalgae—potentially as high as 250 barrels per acre per year—combined with the potential for dramatic improvements via genetic engineering justify the commitment in microalgae as a source of fuel.

During FY 1988, continuous operation of the outdoor microalgae test facility in the Southwest provided long-term productivity, performance, and cost data that can provide a basis for future pond design requirements. Physiological and oil characterization studies of 500 selected strains resulted in the identification of 25 strains, which form the basis for mass culture systems and provide the gene pool for genetic improvement. In addition, oil biosynthesis research and advanced genetic techniques were initiated on selected species to permit cultural and genetic manipulations for increased oil production and improved fuel quality.

Gasoline

Gasoline is made from petroleum by breaking the long, naturally occurring hydrocarbon chains apart and reassembling them into shorter chains. Even though organic materials such as wood or municipal waste are solids, they can be converted to gasoline through a thermal process known as pyrolysis.

As recently as the early 1970s, the technology for effectively producing gasoline from biomass did not exist. Federally sponsored research over the past decade has resulted in dramatic advances in this technology. For example, conversion yields of 20% for gasoline from dry biomass were once the maximum achievable; today, yields of 60% are obtained in the laboratory. Scientists have produced gasoline with an octane rating of 76, which is comparable to straight-run gasoline from petroleum.

Scientists are studying two different processes for making gasoline from biomass. In the first, biomass is converted to biocrude, an oil, in a high-pressure pyrolysis process. The biocrude is then upgraded by treating it

Engineers at the Solar Energy Research Institute have developed a fast-pyrolysis process to convert wood and municipal solid wastes to gasoline and other valuable chemicals.

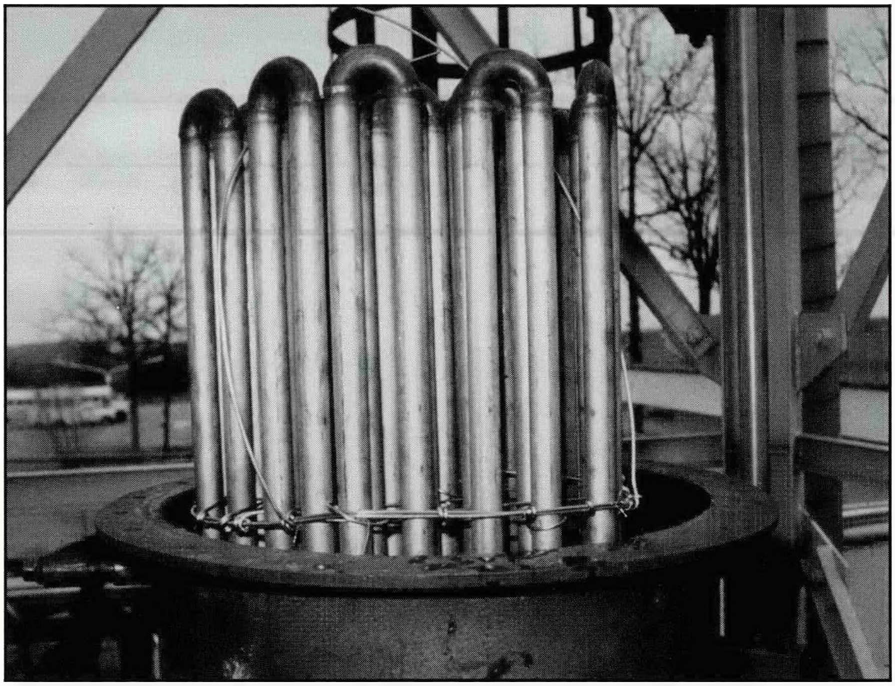
with hydrogen in the presence of catalysts. This process selectively breaks apart the molecules in the biocrude, removing oxygen and adding hydrogen, resulting in gasoline. In the second process, vapors produced by a low-pressure pyrolysis process are reacted over zeolite catalysts, eliminating the need for hydrogen. The hydrogen-based process is more efficient, while the catalytic process is simpler and operates at milder conditions. Industry is involved in research on both processes.

During FY 1988 scientists made significant progress in selecting zeolite catalysts. Twenty catalysts were screened, and three were chosen for further testing. In addition, coking in this process was reduced from 8% to 4%. Advances in research should reduce the projected cost of biomass-derived gasoline from $3.00 per gallon with today's technology to about $1.00 per gallon soon after the turn of the century.

Methanol

Methanol (wood alcohol) was originally made as a by-product in the production of charcoal. Today, methanol is made primarily from natural gas. It is sold mainly as a chemical feedstock and, to a lesser extent, as a fuel. Although 5% methanol blends can be used interchangeably with gasoline, several automobile manufacturers are interested in using methanol at much higher concentrations in new multifuel engines. Methanol has great appeal as a fuel because it is very clean-burning. It can also be processed to produce an octane enhancer or reacted with zeolite catalysts to produce gasoline.

The technology for producing methanol from natural gas is well developed. Natural gas is reformed to produce hydrogen and carbon monoxide. These gases are reacted further to produce methanol.



A gasifier developed at the University of Missouri in Rolla, Mo., converts wood to syngas, a feedstock for methanol. The exchanger tube bundle shown supplies heat to the process.

Methanol can also be made from biomass in a process very similar to that used with natural gas. First, the biomass is converted to synthesis gas (syngas) in a thermochemical process known as gasification. Syngas is a mixture of carbon monoxide, hydrogen, carbon dioxide, and other gases such as methane and ethane. This syngas is then reacted catalytically at elevated temperature and pressure to combine the carbon monoxide and hydrogen, forming methanol.

The remaining research barriers to producing methanol from biomass involve the production of syngas — gas ratio optimization, gas cleanup, and gas compression. Optimizing the gas ratio of hydrogen to carbon monoxide to 2:1 can be accomplished by using external sources of hydrogen during gasification or potentially through improved gasifier design. Clean gas, which is critical to the operation of the methanol production unit, is a function of gasifier design and requires the elimination of tars and particulates. Gas compression is important because today's methanol production units operate under pressure. Capital costs increase significantly if the gasifier uses a low-pressure feed.

During FY 1988, a catalytic process was developed that destroys 99% of large-molecule tars produced in biomass gasification. In addition, researchers demonstrated the feasibility of converting high-moisture feedstocks to gaseous fuels in a continuous-feed reactor.

Hydrogen

The advantages of hydrogen as a fuel have been recognized for a long time. It produces only water when burned. It has the highest energy-to-weight ratio of any fuel (although its energy-to-volume ratio is low). It is extremely abundant in the form of water. However, several disadvantages exist as well: there are no natural sources of pure hydrogen, it is difficult to store, and current commercial production techniques are expensive and rely on fossil fuels.

Today hydrogen is produced mainly from natural gas by reformation to hydrogen and carbon monoxide. The process is similar to that used for making methanol. The hydrogen is recovered and the carbon monoxide is reacted with steam to produce more hydrogen and carbon dioxide.

Hydrogen can be made from biomass instead of natural gas, and the National Biofuels Program is pursuing this option. This work is associated with the research on methanol production. In fact, some researchers consider methanol to be a hydrogen storage medium.

Hydrogen can also be obtained by electrolysis, in which water molecules are split into hydrogen and oxygen by an electric current. However, since electricity is made primarily from nonrenewable fossil fuels, scientists are pursuing two new methods for making hydrogen from renewable resources. One method uses a photochemical process with special membranes to separate hydrogen and oxygen from water. The second method uses a photoelectrochemical process involving semiconductors to generate electricity, which in turn splits water. Both of these represent long-term options.

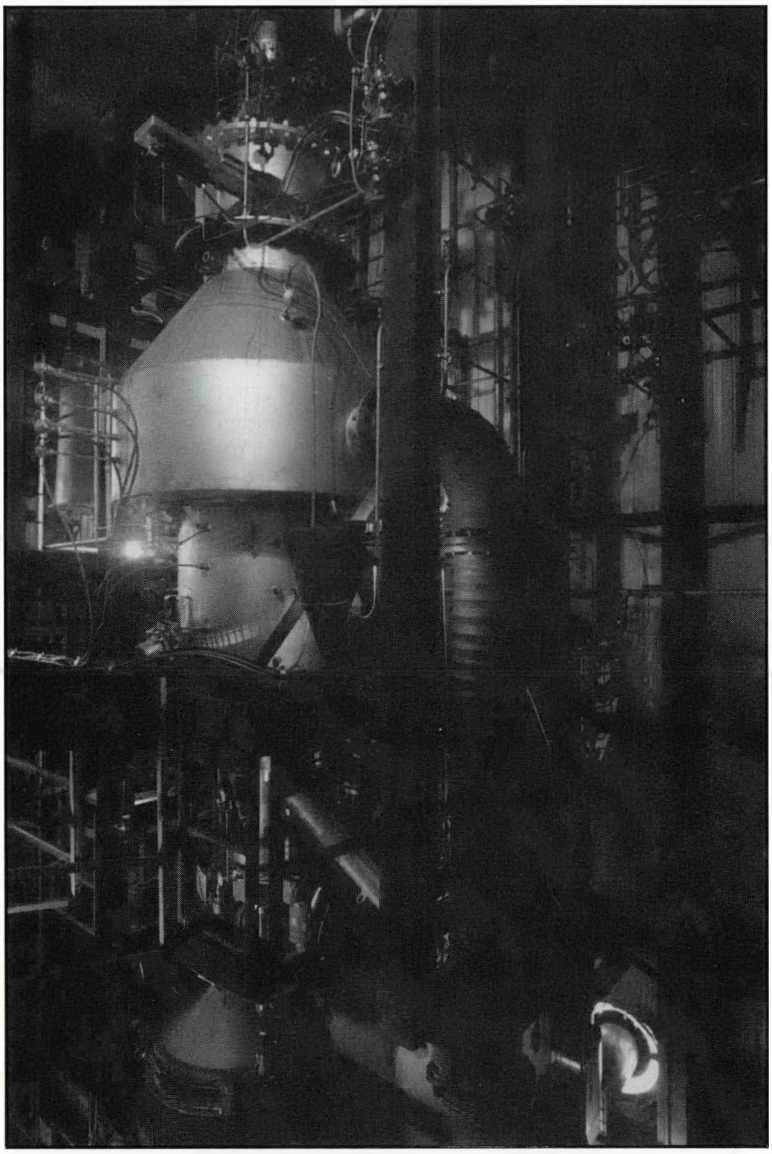
Another key activity is the development of hydrogen storage and transport methods. Storage research is focused on the use of activated carbon at low temperatures. Transport research is addressing metal embrittlement, because hydrogen might be transported through existing natural gas pipelines.

During FY 1988, experiments in high-temperature steam electrolysis achieved conversion efficiencies 30%-50% above those of conventional electrolysis processes. In addition, a twofold improvement in hydrogen storage capacity was achieved using modified activated carbon. Photoconversion research resulted in a conceptual water-splitting system. Finally, a technical assessment underscored the value of hydrogen as a feedstock for methanol production from biomass.

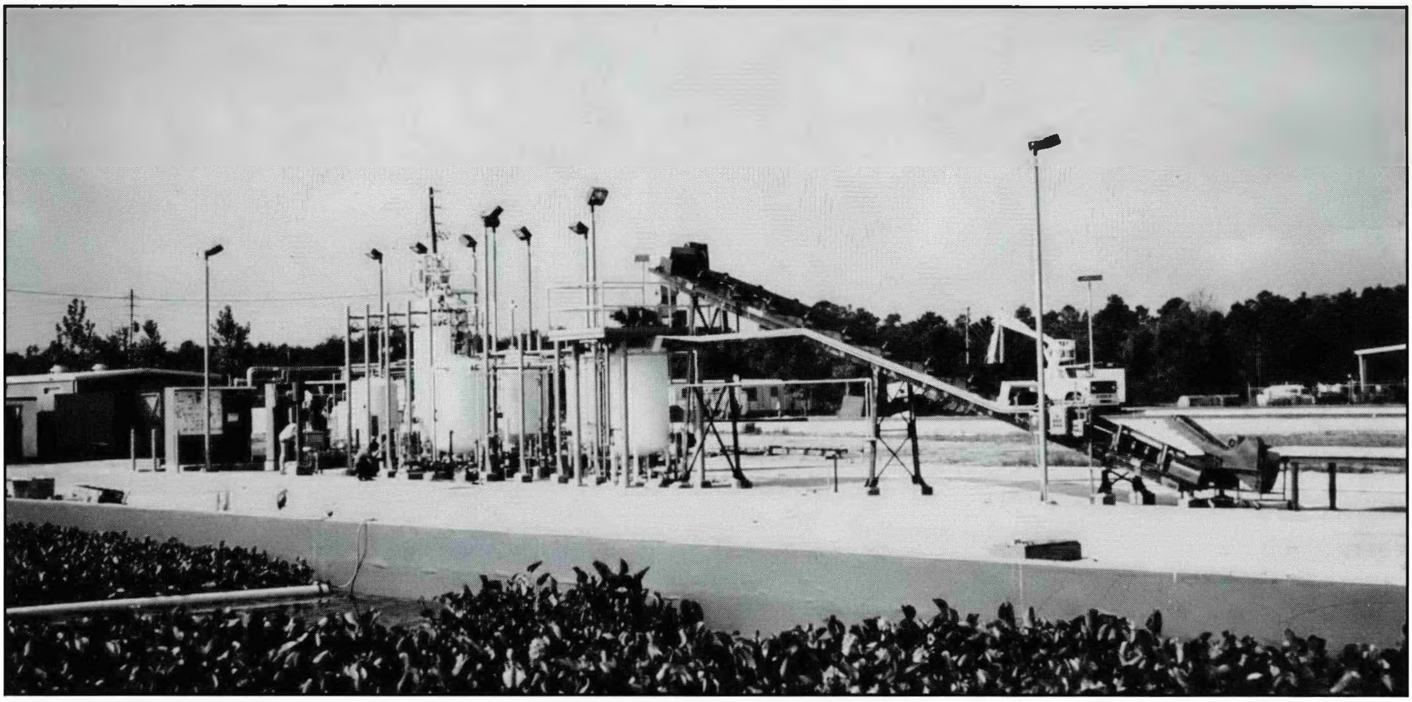
Syngas

In addition to serving as a feedstock for methanol production, syngas can be used as an industrial fuel. Syngas is suitable for use as a boiler fuel, an engine fuel, or pipeline-quality gas, depending on its quality. The exact proportions of the component gases of syngas dictate its quality. These vary depending on the feedstock, the gasifier design, and the gasifier operating conditions. The heating value for syngas can range from 200 to 500 Btu per standard cubic foot.

The National Biofuels Program has successfully completed research on a number of promising syngas concepts, with industry playing a large role. The technology has now advanced to the point where industry has expressed interest in assuming a larger burden in bringing the technology to the marketplace. The Department of Energy is planning a 50/50 cost-shared facility with industry to obtain necessary data on larger-scale syngas systems, a necessary step before industry application of the technology will occur. Researchers are optimistic that syngas systems can become a commercial reality by 1992.



A downdraft gasifier developed at the Solar Energy Research Institute is being tested at the pilot scale by SynGas, Inc.



This experimental test unit in Orlando, Fla., converts liquid and solid wastes to methane in anaerobic digesters. The project is supported jointly by the Gas Research Institute and the Solar Energy Research Institute.

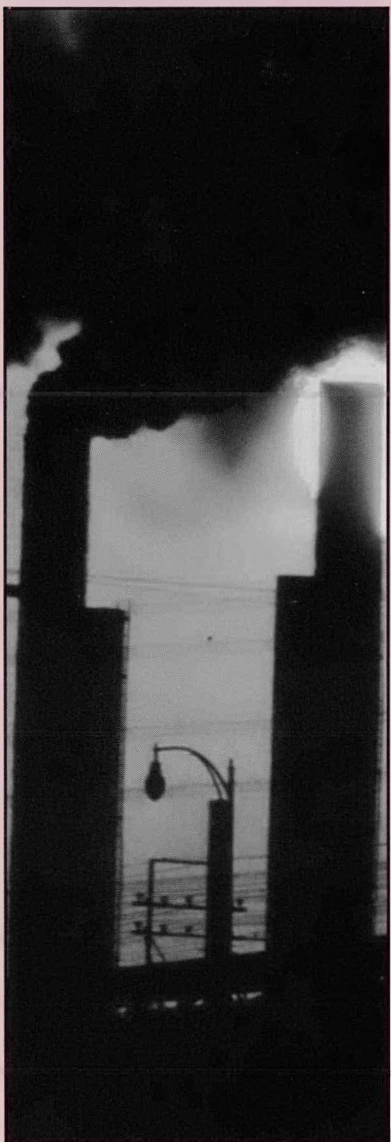
Biogas

Biogas, a mixture of methane and carbon dioxide, is the product of a biological process called anaerobic digestion, in which organic compounds are decomposed by microorganisms. The heating value of biogas is about 500 Btu per standard cubic foot, about one-half that of natural gas. The National Biofuels Program has sponsored research on the anaerobic digestion of various feedstocks. A recently completed project successfully showed that municipal waste and sewage sludge can be converted to biogas.

One key to improving anaerobic digestion technology is understanding the basic biochemistry, physiology, and genetics of the microorganisms. Once these are understood, genetic improvements can be undertaken to improve efficiencies. Another key is reducing capital costs. A third key area is increasing the volume of feedstock in the digester and decreasing the time to convert the feedstock to biogas. Research is currently addressing these issues and, with continued advances, should result in cost-competitive biogas production by 1996.

During FY 1988, significant advances were noted in biogas research. Research to understand the basic biochemistry and physiology of anaerobic organisms advanced to the point that a small-scale outdoor test facility for photoenhancing biogas production is planned in 1990. Solids residence time was reduced from 25 to 20 days. Research continued on digester tank designs to increase feedstock concentration from 6%-10% to 20%.

Biofuels and the Greenhouse Effect



Gases such as carbon dioxide from combustion of fossil fuels are accumulating and trapping heat, which may cause global warming.

As the use of fossil fuels has grown over the past 100 years, so have the levels of carbon dioxide (CO_2) in the atmosphere. The buildup in the atmosphere of CO_2 and other gases such as methane tends to trap and reflect heat back to the earth's surface. There is a widespread concern in the scientific community that this is causing the earth's temperature to rise, which in turn could cause severe disruption to our environment.

CO_2 is a by-product of the use of all conventional fuels. Biomass produces 180 pounds of CO_2 per million Btu. Coal produces slightly more (200 pounds); petroleum slightly less (160 pounds). Biomass contributes to the CO_2 problem only when it is used as a nonrenewable resource and is not replanted. Unfortunately, this is how biomass is used in many applications, especially in the Third World. However, when biomass is treated as a renewable energy crop and the supply of biomass is continuously replenished, its role in stemming increased CO_2 emissions becomes clear.

All plants have the ability to absorb and thus reduce atmospheric levels of CO_2. When a tree is used for energy, the CO_2 stored in the tree is released into the atmosphere, increasing CO_2 levels. However, if a new tree is planted to replace the one used, it will absorb CO_2 in amounts roughly equal to the CO_2 emitted from the tree used for energy. As a result, the net overall change in CO_2 levels is zero—as long as trees used for energy are continuously replaced.

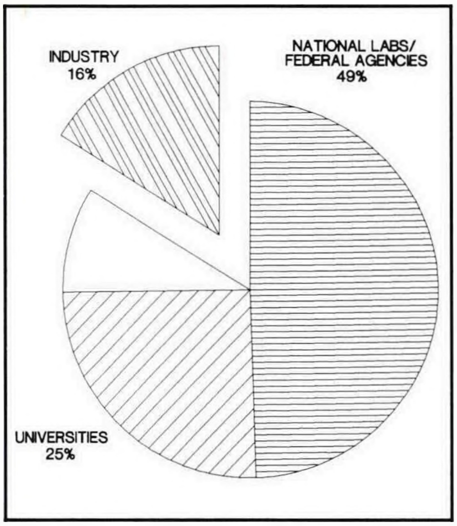
When conventionally grown biomass is replaced by fast-growing species with more than 10 times the productivity of natural species, additional carbon is captured from the atmosphere. When fast growing trees are harvested, up to 33% of the carbon remains in the living root mass.

Further, the carbon in biomass is destined to be released into the atmosphere in the long term. To the extent that all living matter decays to CO_2 and methane over time, the use of biomass (decaying wood, municipal and other wastes) for energy not only represents CO_2 that would occur naturally in any event, but it also displaces CO_2 and methane that would be released by fossil fuel. In this sense, biomass can actually result in a net decrease in CO_2 levels when used wisely.

The National Biofuels Program stresses a balance between growing new feedstocks for energy and converting those feedstocks to energy. By maintaining a rough equilibrium between using feedstocks for energy and replacing them with new feedstocks, biofuels systems represent at worst a recycling of carbon with no net CO_2 increase, and at best a recapture of additional CO_2 from the atmosphere. In either event, biofuels have a positive role to play in reducing levels of CO_2 in the atmosphere.

Program Management

Organization



The National Biofuels Program supports research at national laboratories, at universities, and in industry.

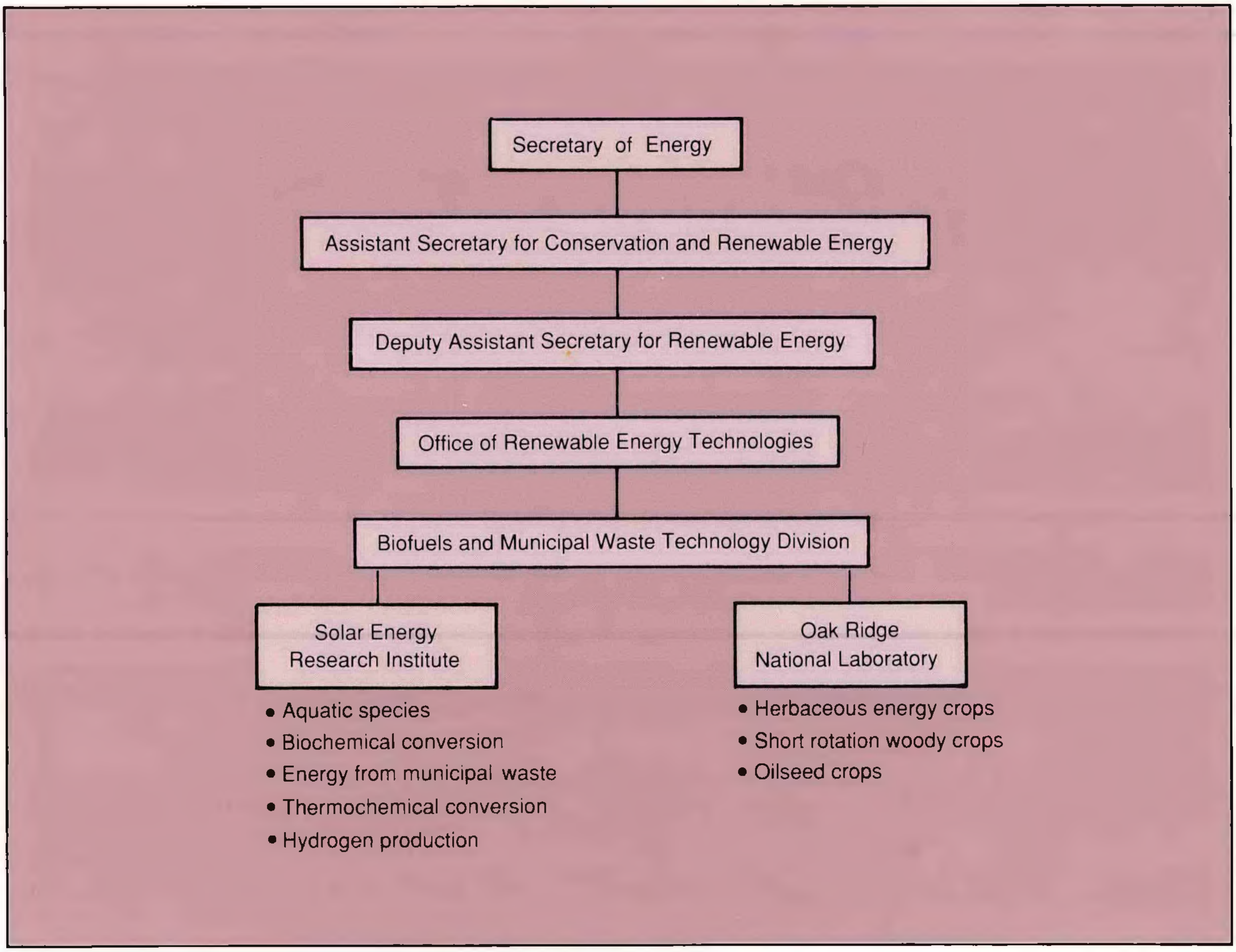
The Biofuels Program is managed by the Director of The Biofuels and Municipal Waste Technology Division (BMWT) at DOE Headquarters, Washington, D.C. BMWT is responsible to the DOE Assistant Secretary for Conservation and Renewable Energy, through the Director, Office of Renewable Technologies, and the Deputy Assistant Secretary for Renewable Energy.

The headquarters organization provides the centralized leadership necessary to ensure that the Biofuels Program activities are consistent with national energy policy, priorities, and directives. Management of technical acitivities is decentralized among national laboratories to ensure that specialized technical expertise is available to supervise the research.

To ensure the continuing exchange of technical and programmatic concerns, the division sponsors an annual program review during which the national laboratories and federal contractors provide updates on their activities. Reviews of each research area are also held annually. All of these reviews are open, and the public is encouraged to attend. At headquarters, the director holds monthly informal conferences in which program managers report on current technical and programmatic issues and problems in their respective areas.

Fiscal Year 1988 Funding

Research Area	Budget ($ in thousands)
Terrestrial Energy Crops	$3700
Aquatic Energy Crops	810
Thermochemical Conversion	3960
Biochemical Conversion	2725
Hydrogen Production	2200
Regional Biomass Program	3660
Total	$17055



Biofuels and Municipal Waste Program Participants

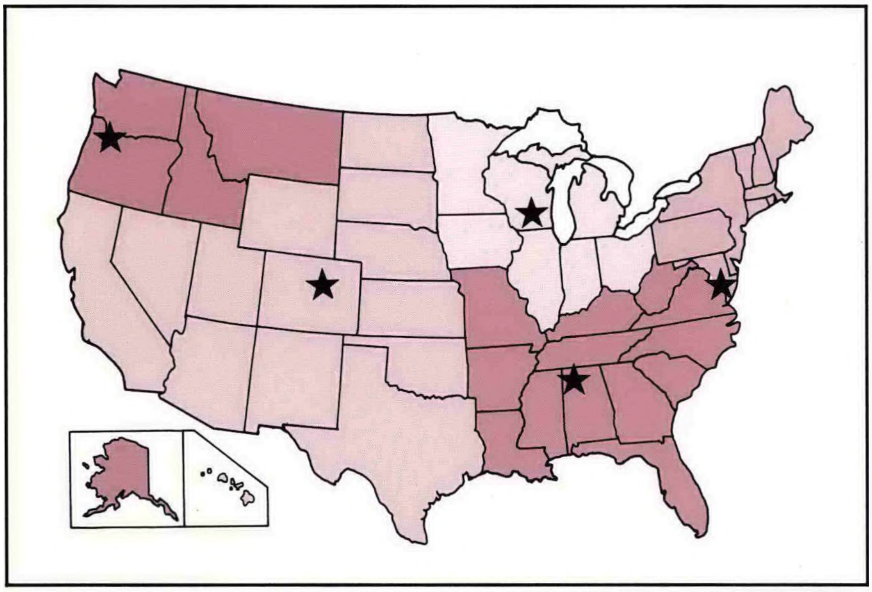
Technology Transfer

A central strategy of the National Biofuels Program is developing mechanisms for cooperation with industry in all phases of biofuels development. In the early stages, government takes a lead role, and prospective industrial users are encouraged to participate in project development, on review panels, and in cooperative research including cost sharing. In the later stages, responsibility for demonstration and commercialization shifts to the private sector, with federal researchers in a support or consultant role.

The National Biofuels Program is already working closely with a number of participants in the emerging biofuels industry, ranging from small businesses to large energy companies. Industry is kept informed about progress in research through technical meetings and conferences, publication of research advances in technical journals, and discussions with industry representatives and trade groups.

The Regional Biomass Energy Program

The Regional Biomass Energy Program carries out activities directed toward technology transfer, industry support, resource assessment, and programs designed to match local resources to conversion technologies. A key part of the Regional Program's mission is to encourage cooperation between industry and government through cost-shared projects that build private sector confidence in biofuels technologies. The development of individual state bioenergy programs to leverage efforts on the national level is an important element of the Regional Program.



Five Regional Biomass Energy Programs work closely with local governments and industry to encourage use of the biomass resource through cost-shared demonstration projects and resource assessments.

In recent years, the Regional Program has helped increase the use of biomass energy as an alternative to conventional fuels. For example, the conversion of an Alabama prison facility to wood energy resulted in an annual fuel savings of $200,000. Industry cost-sharing continues to grow, with one region leveraging $220,000 of federal funding to attract $740,000 in industry support. This close government/industry cooperation is expected to continue into the 1990s and serves as a model for other efforts in technology transfer.

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