Photosynthetic Solar Energy: Rediscovering Biomass Fuels

Firewood is still a familiar fuel in much of the United States, but somehow it does not come up in discussions of national energy policy very often. Yet wood was the primary U.S. fuel only a century ago and is still the main source of energy in most of the developing world. As recently as World War II, Sweden, cut off from oil imports, derived virtually all its fuel from wood. Since the Arab oil embargo there has been renewed attention in many countries to the energy potential of diverse forms of biomass—wood, sugarcane, algae, and even material produced by artificial photosynthetic processes.

Wood and dry crop wastes have an energy content of 14 to 18 million Btu per ton, comparable to that of Western coals. Raw biomass contains virtually no sulfur and little ash, however, and except for some difficulties in handling it is as easily burned or gasified as coal. Other chemical and biological conversion techniques exist too, most notably fermentation of sugar and grain crops to ethyl alcohol, and anaerobic digestion of wet biomass wastes to methane. Thus biomass is potentially a renewable source of a full range of storable liquid and gaseous fuels for which domestic sources of their fossil counterparts are increasingly in short supply.

This is the fifth in a series of Research News articles examining recent developments in solar energy research.

Biomass is already the largest source of solar energy in use in the United States. In recent years nearly half a million modern woodburning stoves have been sold—an installed energy capacity that far outstrips all other direct and indirect solar energy devices. The wood products industry now derives an even larger amount, 40 percent of its total energy needs, or about 1 quad (10^{15} Btu) from burning bark and mill wastes. Several recent studies done for the Energy Research and Development Administration (ERDA) suggest that annual production of biomass fuels could conceivably reach 10 quads by the year 2000.

Except for analytical studies, however, the federal energy research program has largely downplayed the biomass option. The ERDA biomass effort initially focused on municipal wastes, a choice that is now generally conceded to have distracted attention from more significant possibilities. The remaining effort has concentrated on the long-range prospects for conversion of biomass to liquid and gaseous fuels and has been meagerly funded—currently \$9.7 million compared to more than \$300 million for coal-based synthetic fuels. Direct combustion of biomass and other near-term applications appear to have been neglected.

State and private efforts have been more aggressive. The California Energy Resources Conservation and Development Commission (ERCDC) has revived a gas producer copied directly from old Swedish designs. According to Robert Hodam of ERCDC, the gasifier is capable of converting nearly any kind of dry agricultural or wood wastes to low-Btu gas with an efficiency of 80 to 85 percent. The gas can be burned in a boiler in place of oil or natural gas. Although ERDA rejected a request to co-fund a demonstration of the device on the grounds that it was not sufficiently novel, ERCDC went ahead. A test unit at a Diamond-Sunsweet walnut factory near Stockton, California, has operated so successfully on walnut shells that the company has decided to build a larger (130 million Btu per hour) gasifier to provide all its energy needs. Based on bids already received, the company expects the gas to cost about \$1 per million Btu, less than half the cost of the natural gas it now burns.

The demonstration has generated considerable interest in dozens of other companies with substantial biomass wastes and a major farm equipment manufacturer is planning to build and market them for farm applications. Hodam estimates that in California alone, where already collected lumber and mill wastes exceed 5.5 million tons per year, the gasifier has an immediate potential for displacing 0.1 quad of oil and natural gas.

The overriding uncertainty about biomass energy is the extent of the resources that are or could be available. Those that can be used immediately are small compared to the 75 quads of energy now consumed by the United States every year, and biomass cultivation for energy on a large scale may not be economic. Moreover, most agricultural scientists believe that energy uses of biomass must coexist with needs for food and fiber, so that very large areas of prime land may not be available exclusively for energy crops in the United States, although they may be in other countries such as Brazil (*Science*, 11 February, 1977, p. 564). Nonetheless, there is increasing optimism among biomass analysts that substantial amounts of energy could be available even in this country from wastes, and from field, tree, and aquatic crops.

According to a study done for ERDA by the Stanford Research Institute, 277 million tons of U.S. agricultural residues are potentially collectable per year; an additional 26 million tons of manure could be collected from feedlots. Corn stalks, husks, and cobs in particular are regarded as readily available in quantities that could produce as much as 1 quad of energy in corn belt states that now consume large quantitites of propane and liquefied petroleum gases (LPG) to fire crop dryers and other farm equipment.

Sugarcane and sweet sorghum, as well as corn itself, might prove to be good energy crops. A study by Battelle Memorial Institute concluded that there might be a substantial near-term market for industrial alcohol (ethanol) fermented from these materials. About 300 million gallons a year of industrial alcohol are now made from ethylene, which in turn is made from natural gas or petroleum. Battelle's estimates are that biomass ethanol from a full-scale plant could sell for \$1 to \$1.25 per gallon, compared to about \$1.15 per gallon for ethanol from ethylene. According to Edward Lipinski of Battelle, the study director, further cost reductions in biomass ethanol are possible if the processing equipment could be operated year-round and not just during the sugarcane harvest; for example, a mill could stockpile molasses, a sugar by-product, and ferment it when the cane harvest was over, or use sweet sorghum, a high-yield tropical grass that can be grown as a second crop in sugarcane areas. There is also growing interest in the idea that a second, energy-related market could help stabilize U.S. sugar and grain prices in years of plenty—a concept that has worked well in Brazil.

Some investigators have proposed that biomass ethanol can already be made cheaply enough to compete with gasoline as a motor fuel in some parts of the United States. Large commercial facilities to produce ethanol for blending with gasoline are under consideration in Nebraska, where there is an excess of spoiled or poor-quality corn, and in Hawaii, where fuel prices are high and sugarcane is abundant.

Forest wastes in the United States are nearly as large as those from agriculture. They total about 24 million tons per year in unused mill wastes and 83 million tons left on the ground in the forests with current harvesting methods, according to a recent report by the Mitre Corporation. This report concludes that as much as 4.5 quads of energy per year could be produced on just 10 percent of now-idle forest and pasture land with wood grown in close-spaced, short-rotation tree farms using poplars, eucalyptus, or other high-yield species.

The forest products industry does not yet think of itself as a potential energy producer and some industry spokesmen are skeptical that biomass in the quantity proposed in the Mitre report can be produced without cutting into the timber and paper markets. But a feasibility study done by the Forest Products Laboratory in Madison, Wisconsin, points out that the Swedish forest industry is already producing 60 percent of its own energy needs and concludes that the U.S. forest industry could come close to being self-sufficient in energy by 1990 using wastes alone—a development that would expand present production from 1 to almost 3 quads of biomass energy.

Experiments by Claud Brown at the University of Georgia forestry school show that sycamore planted in rows and harvested at 5 years of age yield 10 to 16 tons of biomass per acre per year, three times the yield of traditional long-rotation silviculture. The younger trees prove easier to harvest with mechanical equipment and are of suitable quality for either energy or pulp production. Brown also points out that the breeding and genetic manipulation techniques which led to modern high-yield grains are only just beginning to be applied to forestry, so that substantial improvements, perhaps more than a doubling in yield, can be expected. Other investigators point to a huge unused reserve of wood—exceeding 10 quads—that is contained in stagnant stands of noncommercial species or diseased trees; if harvested, this biomass could have a major near-term local impact on energy supplies in New England or the Great Lakes region.

A third major category of potential biomass resources is aquatic plants. William Oswald of the University of California at Berkeley has proposed growing blue-green algae on sewage wastes and has obtained yields of 16 to 32 tons of dry biomass per acre per year. Algae are readily converted to methane by anaerobic digestion, but they also are rich in protein and may lend themselves to the joint production of energy and food. Water hyacinth, a rapidly growing plant that now clogs many inland waterways, has also been proposed as a potential feedstock for methane production.

An even more ambitious proposal, by Howard Wilcox of the Naval Undersea Center in La Jolla, California, is to grow huge rafts of kelp in the open ocean as sources of methane, animal feeds, and chemicals. To feed the kelp, nutrient-rich water would be pumped up from the lower levels of the ocean. The proposal has attracted the interest of the gas pipeline industry, which is helping fund preliminary research. The project may face environmental objections, however, because deep-ocean water is also rich in carbon dioxide, so that the artificial upwelling would by one estimate release three times as much carbon dioxide to the atmosphere per unit of energy gained as would the burning of a comparable amount of coal or oil.

An alternative approach to biomass energy is to try to improve on the efficiency of plants as photosynthetic solar energy collectors. The highest sustained yields reported for any plant approach 50 tons per acre per year for sugarcane—which Melvin Calvin of the University of California at Berkeley describes as "the best, most efficient solar energy device we have today on a large scale." Quanta of visible light converted photosynthetically to chemical bonds represent 50 to 90 kilocalories per mole of captured energy, whereas the same quanta captured as heat at 700°C represents only about 2 kcal/mole. But only about 4 percent of the light reaching the cane is used in photosynthesis. To overcome this limitation, Calvin is working on the construction of an artificial membrane system that could produce hydrogen from water by simulating the photosynthetic process. He believes that efficiencies as high as 75 percent should be ultimately attainable and that artificial photosynthetic membranes may be achieveable within 15 years.

Despite innovative ideas and claims of feasibility for a wide range of proposals, the economics of most biomass energy systems are still uncertain. Relatively few experimental efforts or field trials have been conducted, especially with crops grown for energy production, and most cost estimates are based on analytical studies or are extrapolated from outmoded equipment. These preliminary estimates are encouraging, however, and the competitiveness of biomass fuels seems certain to increase as supplies of oil and gas dwindle and costs rise. Synthetic fuels from coal now appear likely to cost between \$4 and \$5 per million Btu, a target that many investigators believe can also be met with biomass systems capable of large energy yields.

One aspect of the ERDA program for synthetic fuels from biomass that concerns many biomass specialists is, paradoxically, its focus solely on energy. They point out that in the United States biomass production is so embedded in the food and fiber industries as to make multiple use of biomass resources the most economical approach. Lipinski, for example, points to the potential of using corn as a feedstock for alcohol production, corn husks and stalks as fiber for paper production or fuel for grain drying, and the protein-rich stillage left over from alcohol fermentation as an animal feed—all of which are already being pursued separately. There is as yet no experience with and no funding for integrated processing facilities—biomass refineries—and some critics doubt that ERDA or its successor, the new Department of Energy (DOE), is institutionally capable of such an integrated approach. They note that DOE does not have a network of field stations capable of testing and tailoring multiple-use biomass processes to meet the various needs of farmers and foresters in different regions and that the Department of Agriculture, which does have such a network, has no charter in the energy field.

One novel idea for a biomass refinery is that proposed by Michael J. Antal, Jr., of Princeton University. He suggests producing hydrogen from organic wastes with steam generated by solar heat concentrated on a boiler. According to his calculations, such a refinery might process crop residues gathered from a "wasteshed" of 70 square miles, about 100 tons per day; the hydrogen that results would have an energy content 36 percent greater than that of the raw biomass and cost less than hydrogen made from natural gas. The efficiency of the combined solar-thermal and biomass process is estimated to be higher than 70 percent, in part because steam reforming makes use of the moisture contained in most biomass rather than using a portion of the energy to drive it off first.

Biomass is such an obvious and ubiquitous resource that its energy potential has been largely overlooked. New ideas for how to tap this potential are appearing at a rapid rate and many of them may be applicable in the near term. Before the United States is faced with the necessity of committing hundreds of billions of dollars to a fossil-based synthetic fuel industry, it would be advantageous to explore much more thoroughly whether biomass fuels can also play a major role.

—Allen L. Hammond