undermined by other groups who have not yet adopted the techniques.

Few people in this day and age question the environmental wisdom of diminished reliance on chemical insecticides. In addition, most insecticides are petrochemicals, and in the winter of 1977 no one needs to be reminded about what is happening to the cost of oil products. Research such as that in the Huffaker project is demonstrating that integrated pest management is also economically attractive. If the costs of insecticides continue to escalate, it should become even more so.—JEAN L. MARX

Unconventional Energy Sources: Brazil Looks for Applications

Campinas. The existence at the university here of a large and, for Brazil, novel research group devoted to solar energy would seem to contradict the oft-repeated saying about everything taking longer in a developing country. During the time that a solar energy institute has been under study in the United States, the Campinas solar energy group was conceived of, assembled, and funded, and it has been in operation for nearly 2 years. The project is part of a larger national research program on unconventional energy sources to which the Brazilian government has committed about $15 million, a substantial sum here, in its first 2 years. The emphasis of the research is decidedly practical—"low-profile science" one of the principal investigators proudly calls it—but the results are already attracting industrial interest for such applications as drying crops with solar heaters to prevent spoilage. In addition, investigations are getting under way here and at other research centers to explore a hydrogen economy, conversion of biomass to fuels, conservation, and even ways to use coal, which in Brazil is an unconventional energy source.

The solar energy research program is motivated by the realization that Brazil's more than 8 million square kilometers lie almost totally between the equator and the Tropic of Capricorn. Except for parts of the Amazon Basin that are often obscured by clouds, intense sunlight is readily available in all parts of the country. Yet except for burning wood, which is still a major source of energy in rural areas, solar energy has never been exploited in Brazil. Even the architecture of most houses reflects the influence of imported designs rather than of the tropical climate.

The goal of the national research program on unconventional energy sources is to remedy this situation and to lay a technical base for tapping what is certainly an enormous long-range potential. The program is the brainchild of the Financiadora de Estudos e Projetos (Finep), a science-oriented funding agency attached to the Ministry of Planning. The program is the agency's first venture into the energy field, but as the guardian of the national fund for science and technology and the major source of support for graduate education in the sciences in Brazil, Finep is no stranger to research.

Most of the research is being done at universities such as the State University of São Paulo at Campinas, a suburb of São Paulo. Finep officials say that the Campinas group has been the national program's pioneering effort and so far its most successful one. One American energy researcher who has visited Campinas, Robert Williams of Princeton, says there is "a great deal of intelligence in the design of the research." He is impressed with how much they have achieved with relatively little money, which he describes as a "refreshing contrast" to solar energy research in the United States. The Campinas research group is headed by João Meyer, a particle physicist who until recently was senior physicist at CERN, the European high-energy research center in Geneva, but who came back to Brazil for that purpose. Meyer also helped plan the national program.

The Campinas energy research program is in many ways not typical of university research in Brazil, which is far more often basic than applied and is usually organized along strict disciplinary or departmental lines. At Campinas, for example, the physics department is dominated by a large, sophisticated solid-state laboratory that thinks of itself as the Bell Labs of Brazil and works on such things as semiconductor lasers. The energy research group, however, has a very different orientation, more applied and directed toward Brazil's immediate problems. Meyer says, "We are consciously doing development science," rather than trying to compete in the international arena. The group now comprises 70 people, including more than a dozen young, U.S.-trained Ph.D.'s, and is interdisciplinary in composition—physicists, chemical and mechanical engineers, architects, and agronomists. The energy research effort is also institutionally independent of the regular university departments, an arrangement for which Meyer credits the flexibility of the university administration and which has helped get things off to a quick start.

A major focus of research has been to see if solar energy can be used to reduce crop spoilage. Brazil produced about 40 million tons of corn, coffee, soybeans, rice, and wheat in 1976. But rainfall and fungus infections damaged as much as an additional 50 percent—the exact amount is not really known and varies greatly from year to year, according to Gonzalo Roa of the Campinas group. Much of this damage arises because crops have traditionally been left to dry either in the field or on open floors. To reduce spoilage, the Brazilian government has begun to help farmers use more mechanized techniques, particularly drying bins through which hot air is forced continuously; the air is usually heated by burning oil, however, which exacerbates the country's energy problems because oil is an expensive and largely imported fuel. Roa believes that a scheme in which solar energy is used to heat the air in the drying bins would be cheaper and more efficient, in addition to saving petroleum.

The Campinas group has developed mathematical models of the drying process, building on U.S. work along similar lines. They have also built drying bins equipped with simple and very inexpensive solar collectors, which were made from galvanized iron sheets in a frame covered with polyethylene. Measurements of incident solar radiation, inlet and outlet air temperatures, humidities, and other variables in experiments with these bins have shown that low-temperature drying is as much as 50 percent efficient, Roa says, and significantly faster than leaving the crop out to dry naturally. Red beans, for example, dry four times as quickly in the solar drier. The experiments and simulations with the mathematical models have now been used to determine the optimum drying conditions for half a dozen different grains.

The lack of prior research on drying in Brazil means that even modest advances can have a major impact. The Campinas results have begun to interest bin manu-

facturers and agricultural cooperatives throughout Brazil. Cocoa, for example, is an important export crop that commands a high price. Drying the cocoa beans is a major cost, however, and the traditional process is slow—beans are laid out in the sun in shallow trays and stirred by hand. The Campinas group added a solar collector and a blower to these trays to move hot air through the cocoa from below and found that they could reduce the drying time by a factor of 4 and eliminate the need for stirring completely. When this was demonstrated to officials of the government organization that coordinates cocoa production, it so impressed them that the Campinas researchers only narrowly dissuaded them from carrying away the experimental equipment itself. The cocoa research institute in the state of Bahia will conduct the next round of cocoa drying experiments, and plans for commercial production of collectors and other necessary equipment are under way.

Soybean drying with solar energy is also nearing the point of commercial feasibility, Roa believes; a major bin manufacturer has given Campinas two 60-ton bins, the standard industrial size, for the next round of soybean experiments, which are to start this month. Other experiments are planned for drying fish and meat. The experimenters acknowledge that even widespread adoption of solar drying techniques, which is unlikely to happen overnight, will have a small impact on the country's energy situation. It can, however, have a major impact on food supply.

The Campinas solar energy group is also developing new types of solar collectors with an emphasis on designs that are easy and inexpensive to manufacture. Several different types that use air as the collecting fluid are being carefully compared for their absorbancy, efficiency, and durability. One design being considered, for example, would use polyvinyl chloride sheets to cover the collector; this material degrades rapidly when exposed to ultraviolet light, but it is so inexpensive that it may prove feasible in some applications to simply replace the cover at regular intervals. Collectors with water or other liquids as the working fluid are also being designed for such applications as an absorption refrigeration unit that could find wide use in Brazil for storing perishable foods.

The main thrust of the solar architecture research effort is to improve the thermal design of houses. Under a government program, hundreds of thousands of inexpensive houses are built in Brazil every year, but their design often does not reflect the environmental conditions of the region or take advantage of such things as natural draft cooling or roof overhangs that could make life in a tropical climate more comfortable. The Campinas group is building four prototypes to demonstrate various options, hoping to alert Brazil's architectural community to the energy implications of what they do. But the researchers think their main impact is likely to be in comfort and health, not energy use.

In addition to solar energy, the Campinas group has a research project on hydrogen, which is being actively discussed in Brazil as a possible means of tapping huge hydroelectric resources (estimated at 150 gigawatts) located in the Amazon Basin, far from industrialized areas. In such a scheme hydropower would be used to electrolyze water; the resulting hydrogen would be piped thousands of kilometers and reconverted to electricity in a fuel cell or a turbine. The hydrogen might also be used in chemical processing or as a fuel.

A Hydrogen Economy?

Before such a hydrogen economy could come into being, however, a great many technical uncertainties need to be resolved, and that is what the Campinas group is trying to do. They have built a small pilot system that includes generation, transport, and storage, and a larger system capable of processing 1 cubic meter per hour is under construction. According to Mark Zwanziger, the key problems are the durability of the electrodes in existing electrolysis units, the tendency of most compressors to leak hydrogen, and materials problems associated with metal hydride storage systems. Research projects on these are under way, and the group is planning to build a small hydrogen pipeline within the university in another year.

The conditions under which the Campinas group works, although not untypical for Brazil, would surprise many U.S. researchers. The new hydrogen laboratory, for example, was quite literally built by the researchers themselves, including some of the major pieces of experimental equipment. Spending research funds involves an enormous amount of paper work—as many as 50 signatures on a purchase order for a single $50 pump—and the red tape gets much worse if an item of equipment has to be imported from the United States or Europe. Nonetheless, the esprit de corps among the Campinas researchers is very high, perhaps because, as one member told *Science*, "We have a sense of mission." When Meyer was asked why he decided to give up a permanent job at CERN and a successful career in high-energy physics and come back to Brazil after 20 years in Europe, he replied that it is easier to abandon "big science" after you have done it and that he feels more useful here.

Campinas is not the only research center getting involved in unconventional energy sources. Funding from the national program is also going to several other universities and government research laboratories. According to Affonso Telles, who heads the Finep energy program, "the main product of these centers is to get people interested in solar energy and in energy research" as a precondition to any widespread applications. Nonetheless, he is pushing the idea that excess electrical capacity from a new hydropower plant being built in the Amazon could be used to make ammonia (with hydrogen as an intermediate step); some 300 megawatts are expected to be available, and Telles says that the ammonia produced would be cheaper than that made from imported oil. Telles also hopes to stimulate the use of urban wastes and sewage as an alternate source of town gas for Rio de Janeiro and Brasilia; it is now made from naphtha. He is supporting research aimed at improving the production of charcoal, which could be used in place of imported coke in the blast furnaces used to make steel. In combination with Petrobras, the Brazilian national oil company, Finep is studying two proposed coal gasification plants that could provide fuel gas for local use as well as a feedstock for chemical manufacture. Finep also sponsored a recent conference on conservation to stimulate interest on the subject within the government, and will propose a research program in this area too.

Conservation—or rather, the lack of it despite an acknowledged shortage of indigenous energy supplies—illustrates one of the greatest difficulties Brazil faces in coming to grips with its energy problems. And that is the gap between the research community and the policy makers. José Miccolis—a Brazilian official who is now on leave to direct a science policy project at George Washington University in the United States, but who was formerly at Finep, where he originated the unconventional energy research program—says that "institutionally there is a vacuum—these ideas have to get out of Finep and into the operational ministries and from there to the productive sector if they are to take hold." For now, however, Finep is simply building for the future.

—ALLEN L. HAMMOND