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AUTHOR Kenney, Martin
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ABSTRACT

Even at this early date in the application of biotechnology to agriculture, it is clear that agriculture may provide the largest market for new or less expensive biotechnologically manufactured products. The chemical and pharmaceutical industries that hold important positions in agricultural inputs are consolidating their positions by purchasing other input producers such as seed, bioinsecticide, and inoculant companies. Recently the role of the land grant universities and the entire agricultural research system has become an issue of intense debate; multinational corporations have been urging the universities to shun "applied" research and conduct "basic" research, i.e., the type of research that is suitable for commercialization by multinationals. Meanwhile private universities such as Harvard, The Massachusetts Institute of Technology, and Stanford are becoming interested in agricultural research, and there is an effort under way to open the United States Department of Agriculture research funding to these new entrants in the field. In all of this debate the farmer has been largely ignored, and the ultimate effects of biotechnology on the farmer have yet to be considered. Although the transformation of agricultural research is already underway, it is in no sense determined, and the debate over the purposes and social consequences of biotechnology will continue. A seven-page list of references concludes the report. (JHZ)

BIOTECHNOLOGY AND AGRICULTURE*

Martin Kenney
Assistant Professor
Department of Agricultural Economics
and Rural Sociology
2120 Fyffe Road
The Ohio State University
Columbus, Ohio 43210

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ABSTRACT

Biotechnology is becoming a technical wedge with which agriculture is being transformed. The scientific techniques that are making up the biorevolution were largely developed outside the land grant university system, but now a number of important actors in the research agenda setting for U.S. universities have determined that biotechnology is important. This paper examines the types of products being developed for agriculture and the social institutions that are important in this development process. The paper does not confine itself to traditional agricultural input producers, but also discusses the role of the food processing industry in this transformation. The crucial role of the Science for Agriculture report is discussed because this is a watershed in the attempts to transform the agricultural research system. It is however recognized that this process of change is not "directed" in the strong sense of the term. The results of this process of realigning agricultural research is no sense determined and the debate will continue in many fora.

AGRICULTURE AND BIOTECHNOLOGY

> A revolution in biological research is occurring--one that promises to transform the industries that serve agriculture, and thus, eventually, farming. The innovators are companies like Monsanto, Stauffer Chemical, Dow Chemical, Eli Lilly, Rohm and Haas, Merck, Du Pont. Each is in the business of selling new products and services to modern farmers and cattlemen. Many of these corporations, through links with top geneticists, biochemists, and molecular biologists in universities in the U.S. and, increasingly, abroad are sowing the seeds for what they hope will be a new industrial revolution in agriculture (Lepkowski 1982:8).

> I think it is important to note that these sorts of technologies historically have not improved the financial position of the farmer. Where the impact has been is to lower food cost in the end because of the competitive nature of this society and so on (George Seidel Jr., associate professor of physiology and director of the Embryo Transplant Laboratory at Colorado State University, in Congressional testimony, 1982:166).

The opportunities biotechnology opened in agriculture were discovered a few years after its applications to medicine were recognized. This lag is due to the fact that molecular biology was largely confined to medical schools and non-land-grant universities (non-LGUs)--institutions until recently uninterested in agricultural problems. In the 1976-1978 period biotechnologists' interests were chiefly human health care products such as insulin, HGH, and interferon. As the implications of biotechnology for human health care became clear, it was only natural that veterinary applications should also become obvious. This awareness probably first came to companies such as Lilly and Upjohn, which already had significant animal health and nutrition divisions. The introduction of biotechnology to agriculture will change the agricultural production system and has already set in motion changes in the agricultural research system

This paper discusses the unique aspects of biotechnology's impact on agriculture, examining the increasing role of non-LGUs in plant molecular biology, the technical impetus biotechnology is providing toward concentration in the agricultural inputs sector, and the unique development of high technology biotechnology firms specializing in agricultural applications. There is an ongoing shift in emphasis in the agricultural inputs industry from a very applied routinized technology such as fertilizers to advanced technologies that produce patentable materials. The technical basis of this shift is the increased ability to rigorously characterize the activities of plant-chemical interactions.

Biotechnology is providing a common technical base on which the pharmaceutical, chemical, agricultural, and food processing industries can be united. In agriculture all four of these can be united. The public institutions currently providing research support for agriculture are already evolving to provide support for new clients. Also, new public and private institutions or (old institutions that have changed focus) are beginning to find agriculture a fruitful research area. These new institutions include Harvard, MIT, Rockefeller University, The California Institute of Technology, Scripps Clinic and Research Foundation, and Washington University. Further, the entire chemical-pharmaceutical industry is mobilizing to participate in the impending agricultural biorevolution. Finally, genetic engineering companies specifically targeting agricultural biotechnology have been founded to take advantage of the new market opportunities in agriculture.

What Is Technically Possible in Agriculture?

> Obviously, the $50-100 billion market value for the most radical group of genetically engineered [agricultural] products in the third time frame [1990 and beyond] does not include overall price effects or any synergisms currently inestimable (Murray and Teichner 1981:119).

The above quote makes quite clear the enormous size of the agricultural market that could be impacted by biotechnology. Contemplation of the essential role of agriculture in producing the food, fiber, and wood so necessary for civilization indicates the profound impact biotechnology will have on our lives. World agriculture in the year 2000 will be transformed, and our food will be produced with new techniques in a changed social environment.

Animal production has been the first industry to receive new production techniques from biotechnology and the animals affected range from cattle to abalone. Total U.S. animal health sales were $1.9 billion in 1982 but were expected to increase to $3 billion by 1983 (Anderson 983:8). Large mammals have received the greatest attention--in large part because in the U.S. livestock rearing is a $70 billion industry. The poultry industry also is receiving greater research attention and will be another area of innovation. The growth of global meat consumption, much of which will come from the adoption of modern production techniques, may increase the size of the animal health market even more.

Biotechnology's first impacts are already being felt in beef and dairy cattle farming. The life cycle of the cow will be more rigorously controlled by the new biological techniques. For example, new reproductive technologies have made it possible to induce a cow to produce an average of eight and up to twenty ova at an ovulation (superovulation). It is now possible to "twin" embryos to produce identical twins, quadruplets, octuplets, etc. These ova are artifically inseminated and then flushed from the cow after 6 days. These embryos can be sexed so that dairy farmers need only implant female embryos--cattlemen would chose males--into "surrogate mothers." The surrogates have had their estrus synchronized with the donor cow so as to be prepared to receive the embryos. The embryos can also be frozen for transportation or future use. Bovine reproduction is being completely transformed through the application of new biomedical knowledge (Business Week 1982; Genetic Engineering, Inc. 1982; Pramik 1983a; 1983b). Indeed, in the near future bovine reproduction will be an entirely managed process and the calf will be a genetically select individual.

The next step in the life cycle is the healthy growth of the calf to maturity. The newly born calf is subject to a diarrneal disease, scours, that affects 16 to 17 percent of U.S. calves, with a 30 percent mortality rate (Cane 1983:14). A new vaccine has been developed by available from Molecular Genetics, Inc. to prevent scours. Companies are also developing vaccines for other bovine diseases, including foot and mouth disease (Molecular Genetics, Inc. 1982). Bovine interferon is being tested for efficacy against shipping fever which occurs when cattle are shipped to feedlots and costs the cattle industry more than $250 million annually (Hoozer 1982:15; WSJ 1983:36). The cumulative effect of these vaccines will be to shorten animal turnover time and allow cattle raising to be carried out under less sanitary conditions and with increased population densities. Also, there are possibilities of developing farmer-administered diagnostics based on MABs, thus lessening the need to use expensive veterinary services.

Feed is a major cost factor in the bovine production system and it too will be affected by biotechnology. The two major constituents of animal feed are carbohydrates and proteins. In the U.S. these proteins are largely provided by soybean meal. Biotechnology may make it possible to meet this need with single cell protein (SCP), cons ·ting of bacteria or yeast grown on a feedstock such as methanol or, perhaps, agricultural wastes. Currently SCP is not cost competitive with soybean meal if the carbon-based feedstock is purchased on the world market (Yanchinski 1981). However, in countries flaring natural gas the process could be quite economical. The other bovine feed innovation is the possibility of genetically engineering yeast or bacteria to superproduce the amino acids lacking in most feed. A final possibility is to genetically engineer maize (the major animal feed) to produce amino acids such as lysine that must be added to cattle feed as a supplement (J. Fox 1981).

Another intriguing commercial possibility created by genetic engineering is the microbial production of bovine growth hormone (BGH). BGH when administered to dairy cows has been shown to increase lactation more than 10 percent with no increase in feed consumption (Peel et al. 1981). Although a hormone delivery system has not been perfected, it has obvious economic potential. Genentech estimates that the global market for BGH is $500 million (Business Week 1982:130). If an oral delivery system can be perfected, BGH could become a standard feed additive and a number of companies are currently scaling up for commercial microbial BGH production.

The pork industry is only slightly behind the beef and dairy industries and will experience similar technical change. In fact, growth hormone, interferon, and various vaccines are already in preparation for pork. On the other hand, for a number of technical and economic reasons reproductive technologies are not as developed for the pork industries. The poultry industry has traditionally been deficient in basic research (Smith 1982). But already Amgen has successfully cloned a gene to produce chicken growth hormone, which Amgen hopes will decrease broiler turnover times by 15 percent--from eight to seven weeks (Amgen 1983). Finally, there are many other biotechnological applications such as in cloning salmon (Johnstone 1983:328).

Animal-based food production systems offer opportunities that are only now becoming apparent. New products and processes for animal production will be invented over the next decade that will provide still more new markets. Some of these new products such as a foot and mouth disease vaccine will be very important in Third World countries. Preventing foot and mouth disease could make the cattle export trade in countries such as Argentina and Brazil much more lucrative and simultaneously affect U.S. cattle producers. The market for animal biotechnologies is already worldwide in scope, and countries such as Argentina and Brazil could become important markets.

Even though biotechnology for mammals is presently more advanced, plant biotechnology offers the greatest long-term agricultural potential. There are a number of different ways in which biotechnologically produced inputs will affect arable agriculture. The most important markets center upon the seed--that little package of genetic information that determines a plant's agronomic characteristics. But there are other areas in biotechnology including manipulation of soil microorganisms or other microorganisms that live on plants either symbiotically, parasitically, or neutrally. Another area of some corporate interest is the production of plant diagnostic kits to assist in disease identification. The range and size of these markets is tremendous.

Plant diagnostics will not be such an important market but could be lucrative markets on a smaller scale. The types of plants for which diagnostics might be useful are, for example, turf grass and citrus (DNA Plant Technology, Inc. 1983:21)--that is, markets in which customers are not likely to be price conscious; country clubs and owners of expensive homes would be willing to pay relatively high prices for healthy turf, and high value orchard crops require assured diagnosis--mistakes are very expensive. An orange tree at its productive peak is very valuable, and in groves with diseased trees the extra cost of an easy-to-handle reliable diagnostic might be perceived as neglible. There are no estimates of the size of the plant diagnostics market, and thus far there have been few entrants in this field.

The first arable agricultural biotechnology to be marketed will probably be genetically engineered bacteria to prevent crop frost damage (Tangely 1983; David 1983). There are no estimates of the market size available, but in Florida the December 1983 frost cost $500 million. The potential for frost damage preventitive bacteria on a global scale could be several billions of dollars annually. Another commonly discussed use of genetically engineered microorganisms is to more efficiently fix nitrogen. The USDA estimates that U.S. farmers spent $10 billion for fertilizers and soil conditioners in 1980 (Marx 1982:67), so the market potential is enormous and the applications of genetically engineered microbes to arable agriculture is still largely unexplored.

The most intriguing possibility biotechnology opens is that of genetically engineering the whole plant or linking the plant's growth to certain specified inputs such as pesticides or desired fertilizers.(1) Currently, excision of desired genes and transferring them to another species is still rudimentary, and although progress is being made this possibility is many years in the future. In 1983 a bacterial gene was spliced into a plant cell, but the gene was not expressed in the whole plant (Chemical and Engineering News 1983:6). Research in plant genetics engineering receiving ever-greater investment and is advancing very rapidly, but plants with entirely new genes may still be 5 to 10 years in the future.(2)

The techniques of protoplast fusion and plant tissue culture have much more immediate application to plant breeding (Evans et al. 1983). Plant tissue culture techniques make it possible to regenerate exact replica plants from single plant cells. Though, in fact, the tissue culture process itself gives rise to unique variation, i.e., somoclonal variation. Cell fusion and tissue culture will soon provide breeders with new material and new techniques for rapidly scanning plant cells for desired characteristics.

Farther, in the future, the discoveries of plant molecular biology will make it possible to understand how herbicides and plant growth regulators operate. This knowledge would make it possible either to design better chemicals or perhaps design plants that would respond to crop chemicals in a desired fashion. Conversely, it might be possible to design plants with better natural pest defenses. But all plant design work begins with reprogramming DNA; the ability to reprogram DNA will mean the ability to determine the characteristics to which a particular plant responds. This suggests that with proper engineering a plant could be produced that would only respond to particular proprietary chemicals. The market for these "packages" could be in the billions of dollars.

This introductory section has very briefly highlighted some of the major markets, technologies, and their implications for agricultural production. It is obvious that tremendous markets and market shifts will occur because of biotechnology. This will profoundly alter the social arrangements and actors in agriculture. Old institutional actors in the food and fiber system will, in some cases, atrophy, while others will increase their strength. The next sections will examine the response of these various actors to the increasingly obvious fact that biotechnology is forming a new technical base for agriculture.

Industry, Biotechnology, and Agriculture

> It's no coincidence that companies involved in herbicides get into biotechnology . . . . What's happening is, they're trying to cover themselves (Chemical Week 1982:40).

> [Corn seed] is not nearly as big a market potential--we have a lot narrower focus--as a company the size of Monsanto foresees. They can span the range from the crop all the way to animal growth hormones, to some process that would enhance their chemical operations. Monsanto could use a biological product, an enzyme or a culture for fermentation to do something that they are now using expensive fossil fuels on, thus they can afford to expend a lot more dollars because they have larger potential payoff than Pioneer, who only sells seed of six agronomic crops. The markets are just different (Nicholas Frey, Pioneer Seed's Coordinator of Johnston Research, 1982:121).

In contrast to biomedical applications of biotechnology, which originated in the university, the use of biotechnology in agriculture has been pressed by MNCs whose executives grasped biotechnology's possible applications to agriculture even earlier than the university administrators.

The implications of the trajectory of biotechnical change offer many possibilities, but even the best innovations need a market. Agriculture provides numerous commercial opportunities. In 1980 farmers spent $128 billion for operating costs. Outlays for fuel, oil, and fertilizer were nearly $17 billion (Budiansky 1983:19). As mentioned earlier Monsanto's Roundup herbicide alone had sales that approached the $500 million mark in 1982 (Chemical

Week 1983:47). Finally, increasing world food demand means that agricultural markets have important future growth potential.

The seed will become the proprietary nexus for plant genetic engineering.(3) The seed is a vehicle for conveying the fruits of molecular biological research to the farmer and thereby realizing a profit on the incorporated research.(4) The large-scale drive to develop in-house molecular biology staffs by multinational chemical companies has overlapped and accentuated a movement already under way among them to purchase seed companies (Mooney 1979; Kenney et al. 1982; Kloppenburg and Kenney 1984). Table 1 is a illustrative listing of a number of MNCs that have purchased seed companies and also have in-house biotechnology research capabilities.

In agriculture every MNC is staking out a market sector where its competitive position appears to be strong. Monsanto has placed its emphasis on two different aspects--animal nutrition and health and pesticide-plant interactions (Storck 1983:11). Allied Chemical, on the other hand, had initially embarked upon building expertise in biological nitrogen fixation, but retreated from this area in 1984 (Journal of Commerce 1982:22B; Table 2). DuPont is investing in pesticide development. Each company is seeking to acquire protectable niches or areas in which it will be very competitive.

The first important agricultural product development project launched was the 1979 Genentech-Monsanto alliance to produce BGH.

Other MNCs producing animal nutrition products rapidly formed alliances to develop their own BGH production processes including: Biogen-International Mineral and Chemicals, Molecular Genetics-American Cyanamid, Amgen-Upjohn, and Collaborative Research-Akzo. If effective, simple-to-use delivery systems can be developed, the BGH market will be very competitive. On the other hand, smaller feed companies unable to develop and produce BGH may be displaced because their feed packages do not contain the growth-speeding hormone. BGH may be a technical change that contributes to and speeds consolidation of the smaller feed additive producers.

The biorevolution also provides important commercial opportunities for food processors. Specially engineered microbes can convert wastes or low-value products to those of much higher value. For example, whey, a waste from cheese production, can be converted into marketable lactose (Food Engineering 1979). French researchers are attempting to develop a microbial process to transform inexpensive vegatable oils into oils with a flavor similar to that of expensive oils such as cocoa oil (Cantley and Sargeant 1981:331).

Companies such as General Foods, Ralston Purina, Campbell Soup, Nestle, Hershey, and Frito-Lay are actively developing in-house research capacities and also funding university and biotechnology startup research (Food Engineering 1983:21). Jose Pellon, of the Institut de Gestion Internationale Agro-Alimentaire, and Anthony Sinskey, of MIT's Department of Food

Sciences, have commented on the role biotechnology will play in the food industry:

> The impact of genetic engineering in the food processing industry will be piecemeal rather than industry-wide, mainly because of the inability to identify commercially significant functions. This inability stems from insufficient biochemical and genetic knowledge, the low profitability of products and the resistance of the food industry to investment in research and development. In the next decade we will probably see a number of companies with a high-technology base entering the food processing field. Also, some food processing industries [companies?] will invest in genetic engineering firms to strengthen their inadequate in-house research capabilities (Pellon and Sinskey n.d.:15).

The threat that the large chemical and pharmaceutical companies may become involved in food processing has spurred processors to make investments in genetic engineering in-house research and in biotechnology startups (DNA Plant Technology, Inc. 1983; Genetic Engineering News 1983b:50; Morris 1983).

Food processing companies have production processes and markets very different from the chemical and pharmaceutical companies, but biotechnology is increasingly providing all three industries with a common technical base. Furthermore, the strategic moves of the food industry companies in regard to biotechnology have roughly paralleled those of the chemical industry--only the food industry moved approximately three years later. Perhaps, the most involved food processor is General Foods, which has followed the example of the chemical industry (see Table 3). Bob Carbonell, Nabisco's executive vice president for technology, describes Nabisco's reasons for investing in Cetus:

> Genetic engineering probably will demonstrate its potential worth in food processing in the next three to five years . . . We're involved in the research venture with Cetus primarily because, when the value of biotechnology becomes apparent, we want to be there (Genetic Engineering News 1983b:50).

This reasoning is almost verbatim that of chemical industry spokesmen in 1978.

The final group of investors in biotechnology are farmers--not just any farmers, but rather big farmers. These large integrated farmers could derive great benefits from plants designed to their specifications. Thus, Boswell Farms, a large California cotton grower, has funded and now purchased Phytogen to produce new and better varieties of cotton (Genetic Engineering News 1983c:3; Miller 1985:26). Similarly, Brown and Williamson Tobacco Co. has contracted with DNA Plant Technology, Inc. (1983) to produce improved tobacco varieties. It should be noted that only the largest farmers (actually plant-growing corporations) can afford to fund this type of research. Most farmers either depend on public research or merely buy finished inputs.

Agriculture provides an ideal market for the MNC's biotechnology investments for a number of reasons. First, the agricultural MNCs already have marketing networks in place; any new products are merely new lines. And where seeds and chemicals can be linked in a package, the separate marketing networks for seeds and chemicals can be combined, thus decreasing overhead. Conversely, the dispersion of farmers and the consequent need for large marketing networks are an important barrier to entry for smaller firms. Second, farmers are an ideal market in that they rapidly adopt innovations. In the U.S. any innovation promising increased profits has a ready reception from farmers.

As was discussed earlier, a primary reason corporate managers are emphasizing agricultural applications is to secure the large profit margins to be had from a proprietary molecule. Most of the large MNCs view biotechnology as merely another tool in their diversification away from bulk commodities. For example, Allied Corporation recently divested its liquid fertilizer business (Journal of Commerce 1983b:22B). Monsanto has undergone a similar restructuring and rationalization, shedding products in which it did not have a strong competitive position. At the same time, these companies have begun massive efforts to further build their in-house agricultural research staffs.

But the building of research operations has been difficult because of the lack of skilled plant biologists. Responsibility (blame) for this shortage was quickly placed upon the LGU system--America's agricultural universities--for not doing basic research and training the manpower the companies desired (to be discussed in the next section). In actuality competent scientists in plant molecular biology were unavailable because there was no important constituency demanding their training or providing for their employment. The blame for being unprepared thus should not be placed on the servants of industry, the university, but rather on the master, the chemical industry. It is not difficult to remember that less than ten years ago there was a glut of molecular biologists.

To secure the necessary agricultural biotechnology research expertise the MNC's both raided universities and signed long-term research agreements with universities. These arrangements were in addition to normal grants of various types. For example, Monsanto had until 1983 provided significant amounts of funds to Mary Dell Chilton's Washington University plant molecular biology laboratory. But in a stunning raid, Ciba-Geigy acquired Chilton's services in appointing her director of its new agricultural biotechnology research center in North Carolina (Journal of Commerce 1983a:22B)(5). The rush to secure the services of the few available plant molecular biologists paralleled what occurred five to six years earlier in the medical area.

The other corporate strategy has been to sign contracts with agricultural biotechnology startups. The MNCs' motives were to secure access to expertise not available through other channels. Because the MNCs moved rapidly in plant agricultural applications, the growth of startups was limited. In veterinary applications the startups are more important, because animal health products are direct spinoffs from human health--i.e., HGH-animal growth hormones, human monoclonal diagnostics-animal monoclonal diagnostics, and various human and animal vaccines.

Agricultural Biotechnology Startups

The number of startups specifically dedicated to agriculture is comparatively small. Table 4 lists these companies and their principal scientists, investors, and research goals. A few other smaller agricultural biotechnology firms exist, but none of these have gone public and they maintain a relatively low profile. Additionally, some large biotechnology startups have research under way that has agricultural applications--e.g., Genentech, BGH; Cetus, scours vaccine; and Collaborative Research, rennin for cheese-making. A more unique distinguishing feature of truly agricultural biotechnology startups is that their research concentrates upon plants. Plant biology is distinctly separate from mammalian and microbial biology and requires special expertise.

The first company dedicated to plant biotechnology was IPRI, which was founded by a UCSF professor, Martin Apple, in 1978. The other important companies were formed in the next three years. All of these companies survive on contract research, with the exception of Agrigenetics (now part of Lubrizol Corporation), which has purchased 13 seed companies and thereby secured revenues with which to finance its research. Molecular Genetics, Inc.

conducts research in both animal and plant biotechnology and has already begun sales of its scours vaccine (Molecular Genetics, Inc. 1982), which is already beginning to bring in product revenues.

The staffs of these companies are partially drawn from the LGUs, such as the University of California at Berkeley and at Davis, the University of Minnesota, the University of Wisconsin, Kansas State University, Cornell University, and Michigan State University. The other universities also have a number of important plant molecular biologists. For example, at Harvard, scientists such as Lawrence Bogorod (Advanced Genetic Sciences) and Frederick Ausebel (Biotechnica International) are faculty members. However, the shortage of plant molecular biologists is so acute that a number of European and Third World scientists, including Hungarians and Brazilians, have been recruited into U.S. companies (Advanced Genetic Sciences 1983; DNA Plant Technology, Inc. 1983).

With certain exceptions, the agricultural biotechnology startups (for example, Calgene, Phytogen, and Plant Genetics, Inc.), though important, will find survival in the seed-agricultural chemical industry very difficult, as the long-term nature of plant biotechnological research condemns these companies to contract research. The tremendous investments and market power of the MNCs will in all likelihood overwhelm these smaller companies, though their ability to secure critical patents could negate corporate market power. Calgene, for example, has secured a patent on a gene that confers in vitro cell resistance to Roundup, Monsanto's herbicide, to soybean plant cells (Comai et al. 1983). Calgene now owns that DNA sequence. Calgene's ability to regenerate the whole plant and express the Round-up resistance gene would be extremely valuable. Otherwise, the startups must acquire relatively sheltered niches, in which to survive. An example of this is DNA Plant Technology, Inc.'s strong emphasis on tomatoes through its linkage with Campbell Soup and its strong tropical commodity orientation. Advanced Genetic Sciences is developing expertise in frost protective bacteria, and Molecular Genetics has developed numerous animal vaccines. Startups that secure a niche early and can protect it with patents and strategic alliances do have a possibility of surviving in the extremely competitive agricultural market.

The survival of agricultural startups is predicated on a relative lack of accomplished scientists being available on the job market. The startup company's SABs, which contain the top university scientists, can secure preferential access to the products and scientists produced in SAB members' laboratories. And the startups' laboratories are, in fact, located conveniently close to major universities. For example, AGS has a Berkeley, California laboratory[6]; Agrigenetic's main laboratory and Cetus' agricultural laboratory are located in Madison, Wisconsin; and Plant Genetics and Calgene are in Davis, California--in each case close to the vital professors.

Biotechnology and the Agricultural Research System

> The seriousness of this situation [the state of the U.S. agricultural research system] highlights two major issues: 1) there is a critical need for more high quality, perceptive leaders of national stature in agricultural research; and 2) it is unclear who represents and can speak for the various components of the agricultural research system. The resulting leadership vacuum leaves agricultural research with inadequate, confused, and often contradictory representation at the national level during a critical period for the country, for agriculture, and for agricultural research (Rockefeller Foundation 1982:1).

The U.S. agricultural production system has had its own publicly funded research system for over 100 years. The mission of this research system has been to provide applied research for the various clientele groups that are of the U.S. food and fiber system. This has translated into close connections between producer groups and research institutions as agricultural scientists undertake problem-specific research (Hightower 1973; California Rural Legal Assistance 1981). Scientists respond to immediate needs or, as in the case of seeds, there is a division of labor between what the private and public sectors undertake in the entire process of producing a marketable seed (National Association of State Universities and Land-Grant Colleges 1982:26). The mission of the agricultural research system is to provide applied research "for the farmer."

This very "applied" emphasis proved to be detrimental when the formerly "basic" science of molecular biology became applied because traditional agricultural researchers were not expert in this new applied science. The few LGU scientists skilled in plant molecular biology were quickly recruited by companies, while the changing technical base made universities from outside the LGU system important competitors in the plant sciences. Simultaneously, various LGU constituencies experienced shifts in knowledge and manpower needs. Some constituencies such as the small private seed companies and the farm block were weakened, and other constituencies such as the large multinational agribusiness input companies became more assertive. These latter companies began to apply pressure on the LGUs to retreat from "applied" to "basic" research.

The agricultural research system as early as 1972 received severe criticism from a National Academy of Science (1972) report for being parochial and doing too much marginal research (Marshall 1982:33). These criticisms were ignored throughout the 1970s but surfaced again in 1982 as the research system was severely criticized in two separate reports by the Office of Technology Assessment (1982) and the Rockefeller Foundation (1982). The latter's criticisms included the charge that the system does not do sufficient basic research.

The central research pivot in the LGU and agricultural research in general has been the plant breeder. The breeder was the person who integrated the knowledge of the meteorologist, soil scientist, plant pathologist, entomologist, etc., into the seed. The breeder produced plants able to respond to the particular environments and various inputs and cultural practices. The breeding process has traditionally been a time consuming, craft discipline tracing its roots back through Mendelian genetics to prehistoric times.

Now genetic engineering threatens to change the plant breeder's position, because genetic engineers try to develop techniques to design new plants by simply deleting or adding genes. If this becomes possible, the plant breeder's role would be less central; breeders (privately or publicly) would grow the plant and polish it for release. The creative and important role would increasingly be that of the gene splicer. Consequently, the brash boasts and threats of the molecular biologists has led to resistance among some plant breeders to molecular biology (Sprague et al. 1980). How this resistance will be overcome is as yet unclear--perhaps it will be overcome by attrition due to retirement.

The LGUs with important molecular biology research are limited to large universities such as the University of Wisconsin, the University of California at Berkeley and Davis, the University of Minnesota, and Cornell University. In fact, in a recent poll only the University of Wisconsin and UCB were ranked as top 10 universities in cellular and molecular biology. With these few exceptions, the large private universities and medical schools have the greatest expertise in molecular biology.

The emergence of the biotechnology industry in the late 1970s therefore largely bypassed the LGUs, and many of the best LGU molecular biologists left for other universities or industry. For example, Wisconsin's Timothy Hall and Julian Davies went to Agrigenetics and Biogen, respectively, Michigan State's Peter Carlson went to Zoecon, and Kansas State's James Shepard went to Advanced Genetic Sciences and, eventually, Allelix. For the LGUs already weak in molecular biology the losses were severe.

The corporations flocked to the universities to purchase access to molecular biologists, and from Table 5 it can be seen that the bulk of these institutions were not the LGUs. As MNC interest turned to agriculture and plant molecular biology, the LGUs were lacking in expertise, and a large amount of the funding for plant research went to universities not traditionally known for agricultural research, e.g., Rockefeller University, Harvard Medical School, MIT-Whitehead Institute, and Washington University. This corporate funding is building these universities' expertise and making them de facto competitors with the LGUs.

Plant molecular biology is still a fledgling science and a large amount of "basic" (not immediately profitable) research must be done before commercial products can become available. The corporate sector is not willing to bear this financial burden and thus feels it necessary to induce universities to shoulder this burden. The logical agency to undertake this research is the USDA, but its funds are allocated in such a way that it usually does not provide sufficiently large quantities of capital for launching a concerted effort in this capital-intensive research. The current grant allocation system provides money only to the agricultural research system and not to outside institutions, and the USDA competitive grant system, as practiced by NIH and NSF, will only allocate approximately $17 million (FY84) (Lepkowski 1983:15). Agricultural research funding in the USDA is regional, which has guaranteed that research is decentralized and, in many cases, underdeveloped, but the nearly $470 million that the USDA disburses annually for research is an inviting target for non-LGUs that are seeking increased research funding. The MNCs also feel that their funding would be better levered if USDA monies were available to non-LGUs.

The clearest expression of the strategy of opening USDA funds to more competition comes in the report Science for Agriculture, issued after a two-day conference held at the Winrock International Conference Center in 1982. The conference sponsors were the Rockefeller Foundation and the White House Office of Science and Technology Policy. The 15 participants included representatives from industry, the LGUs, the USDA, the Rockefeller Foundation, and the OSTP (See Table 6 for a list of participants and their affliations.)

> in the public sector and their development and commercialization by industry.
>
> Public-private sector relationships should be actively promoted by including industry scientists in symposia, consultants, and research review teams, and by seeking the contributions of such professional scientific associations and organizations as the Industrial Research Institute (Rockefeller Foundation 1982:26).

The only mention of farmers and consumers in the report alleges them to be the groups diverting the USDA's attention from "basic" research to political concerns.

The Winrock Report can be viewed as the opening salvo in a campaign to accomplish two objectives: The first is an attempt to restructure the agricultural research system into a few "peaks" or "centers of excellence" more amenable to direction from the national level (Kenney and Kloppenburg 1983). This process is similar to the effort pioneered by Flexner (1910) and the Rockefeller Foundation with reference to the medical schools (Kohler 1976; Yoxen 1981). The second objective is to allow non-LGUs to compete with LGUs for the USDA research monies. This would assist in the weeding out of the weaker LGUs and experiment stations. The smaller institutions would be left to survive on state monies and what other income they could generate.

The obvious "ideal" model that many of the confereees had in mind was that of NIH (Hardy 1982). This NIH funding structure allows the top 10 institutions, 0.8 percent of all funded, to

The Winrock report bluntly indicted the agricultural research system for parochialism and lack of "cutting-edge" basic science (Rockefeller Foundation 1982:12). The report, acknowledging political reality, recommends that formula funds should not be diminished, but that all future real increases in funding should go to the competitive grants program to be used to fund "basic" research. The competitive grants program is intended to be the cutting edge of a new method of funding agricultural research.

Further, the report urges the USDA and the LGUs to sponsor "workshops, seminars, symposia, etc., designed to bring together experts from all relevant research settings to discuss the state-of-the-art of various basic science areas, identify research needs, and explore collaborative arrangements for meeting those needs" (Rockefeller Foundation 1982:2). The entire thrust of the report is to have the agricultural research system learn from industry and universities outside the system.

Finally, the report makes it very clear that agricultural research should find a new constituency:

> Private sector expertise should be fully utilized in efforts by the public sector to identify future research needs, estimate future demand for scientific and technical manpower, and define appropriate, complementary roles and responsibilities for the various sectors and institutions involved in science for agriculture.
>
> Mechanisms should be developed for strengthening the linkages between the findings of basic and applied research performed

receive 19.8 percent of the total NIH grants (NIH 1981). The desire to reproduce the NIH model in agriculture is understandable--it is hoped that commercial successes similar to those of biotechnology can be had in agriculture. Obviously, corporate representatives are pushing in this direction.

The media reaction to the Winrock report was immediate and overwhelming. Though the report itself makes no mention of creating a "National Institutes of Agriculture," the New York Times (1982:A30) in an editorial called explicitly for such a change. Similary, Science weighed in with editorials lauding the report and especially defending the the USDA competitive grants program (E. Marshall 1982:33; Walsh 1982; Norman 1982:1227). Similar laudatory articles appeared in Chemical and Engineering News (Lepkowski 1982); Chemical and Engineering News (1982:23) and Chronicle of Higher Education (McDonald 1983). The immediate assumption appeared to be that change was at hand.

Yet within the agricultural research system reaction to the report was generally negative. Obviously, the smaller, weaker institutions were vehemently opposed to its recommendations. And, in fact, the presence of representatives from the agricultural research system at Winrock had prevented the report's recommendations from being even more harsh. Further, even for the large LGUs--with the possible exception of the UC system, Wisconsin, and Cornell--the prospect of competition for funds with Harvard, MIT, and Stanford for research funds was daunting.

Moreover, the funding mechanism for agriculture is political, and the smaller states have no intention of sacrificing their research facilities for what certain groups claim is the good of the country. Even these furious attacks have not caused a blitzkrieg of change; the change unleashed by biotechnology will be more gradual.

The new biotechnology offers a technical wedge and an inducement to transform the agricultural research funding system. But the agricultural research system can also import the techniques of biotechnology to do applied research for the public domain. There are sectors and groups in the LGUs that will resist any change, but other applied scientists could use biotechnological techniques to develop more efficient conservation-oriented agricultural techniques, etc. (Pfund 1983; Buttel and Youngberg 1982). In fact, due to Congressional opposition little has changed in agricultural research system and the competitive grants program will grow only slowly.

The Land Grant Universities and Biotechnology

Even if there has been little change at the national funding level, the LGUs are investigating methods to increase their income from nongovernmental industrial sources. LGU administrators and faculty have seen the gold rush in the private universities and, spurred by the public funding crunch, have decided to secure a piece of the action. The LGUs have also developed some unique university-industry arrangements. For example, the Allied Corp-UCD arrangement, the Cornell Biotechnology Institute, and the Wisconsin Alumni Research Foundation's arrangements with Cetus Madison, Agrigenetics and AGS to name the most important (Kenney forthcoming). Cornell's Biotechnology Institute, WARF's arrangements and MSU's Neogen were purported to be unique arrangements designed to keep industry at arm's length. Yet there remain some questions regarding the ethics of entirely publicly supported institutions' entering into arrangements with profit-oriented entities.

In general, the LGUs as a group have not formulated a separate or explicit policy for dealing with the impacts of biotechnology on their institutions, and perhaps, given the wide diversity in the LGUs, no single policy is possible or desirable. The National Association of State Universities and Land Grant Colleges (1982 issued a report that provided little concrete guidance and, it is doubtful guidance would have been accepted. The LGUs are in the process of redefining their mission and searching for their constituency. The new chemical and pharmaceutical heavyweights centralizing the agricultural inputs industry are replacing former clients and demanding different services. For example, the MNCs buying seed companies want the LGUs to abandon traditional seed breeding and newly bred seed variety release and move to areas of basic research (Kloppenburg and Kenney 1984). Constituencies such as farmers and small independent seed companies rely on LGUs to perform relatively applied tasks; large integrated MNCs feel that they can accomplish these tasks profitably and would rather rid themselves of nonprofit competitors.

The LGU system is being pressured to transform itself and simultaneously being raided for its "hot" plant biologists. Pressure is also being applied for these universities to form multidisciplinary research teams to tackle problems--teams quite obviously parallel to corporate research teams. These university research teams will be more able to provide the type of research the corporate teams need. The LGU research agenda is currently in flux, and its ultimate shape is still uncertain.

Biotechnology and Agriculture--Concluding Thoughts

> The trend [manifested in the attendance at a recent plant genetic engineering conference held at UCD] towards involvement of primarily non-agricultural industrial companies in plant breeding and related "biotechnology" (including, ultimately, genetic engineering) is clear enough in the USA, but less obvious elsewhere" (N. Simmonds, professor at Edinburgh School of Agriculture, 1983:69).

> The major benefits from improving cereal grains are likely to be economic (production of cheaper animal protein in developed countries) rather than idealistic (feeding the malnourished populations of developing countries). Nevertheless, cheaper or more efficient animal protein production is a worthwhile aim as people in many societies would like to eat more meat but are constrained by economic factors (Bright and Shewry 1983:84).

Even at this very early date in the application of biotechnology to agriculture it is becoming clear that agriculture may provide the largest market for new or less expensive biotechnologically manufactured products. And, in fact, many of biotechnology's first products will have impacts on agriculture--for example, Lilly's microbially produced imsulin displaces bovine and porcine insulin, a slaughterhouse by-product. There can, even at this very premature stage, be no doubt that agriculture as we know it will in the next thirty years be entirely transformed. This article has outlined the major axes of change that the biorevolution has unleashed.

The chemical and pharmaceutical industries that already had important positions in agricultural inputs are consolidating these positions by purchasing other input producers (with the exception of farm machinery) such as seed, bioinsecticide, and innoculant companies. At the farm output purchasing end, large food processors are examining biotechnology as a technique that can create new, lucrative markets and provide future profits. The ever-increasing importance of large multinationals in the agriculture and in producing the inputs for the system will inevitably affect the other social institutions of agriculture.

In the last three years the role of the LGUs and the entire agricultural research system has become an intense issue of debate. The debate is not expressed in terms of whose interests will be served, but, rather, in dichotomies such as "basic" versus "applied" or "politically" based funding versus "scientifically" based funding. The MNCs want them to increase "basic," "scientifically based" research, i.e., the type of research that does not produce marketable commodities. The MNCs feel that they have the financial muscle to breed new plants and want to end competition from the public sector.

Other new and increasingly important players in the agricultural research arena are universities such as Harvard, MIT, Washington University, and Stanford that traditionally have regarded agriculture and plant biology as peripheral and even "backward." These private universities have begun to see the "intellectual" value of this area. There is a concerted attempt underway to open the USDA research funding to these new entrants--most of whom regard their constituency as national not merely regional. Biotechnology and its potentialities are being used as the lever to create new constituencies for the LGUs and to ensure that biotechnology's technical possibilities are actualized in a manner suitable for commercialization by MNCs.

Farmers, an important group in our food and fiber system, have been largely ignored in this paper because the debate about the research system has treated them as mere consumers of technical innovation. And, in fact, farmers have--with the exception of Boswell Farms, the giant California cotton grower and, perhaps, companies such as Bud Antle--been unable to afford the investments in research needed to secure the benefits of biotechnology for themselves. The public reseach system, which observers have charged is preparing the conditions for capitalism in agriculture (Lewontin 1982; Perelman 1977) due to its current applied emphasis may now, in part, be a barrier to that further penetration. The system has therefore come under severe attack. A question that remains unasked, much less answered, concerns the ultimate effects of biotechnology on the farmer.

One obvious conclusion is that the large farmers will continue to grow at the expense of their smaller neighbors. The larger farm will be able to more rapidly adopt biotechnology and reap the benefits of early adoption. The transformation of the agricultural production process will be gradual but none the less revolutionary. In fact, the various biotechnologies will probably compete with each other, thereby quickening the pace of change. For example, one technique allows production of single cell protein (for animal consumption) from hydrocarbon feedstocks; protoplast fusion may allow breeding of more productive soybeans (the meal is a protein supplement for animals); genetic engineering may create microbes that more efficiently fix nitrogen, thus cheapening production; and by using biotechnology less expensive herbicides may be developed lessening production costs. Each of these possibilities has different implications for different groups and companies.

This article has provided an overview delineating the unique aspects of biotechnology's application to agriculture.

Although the transformative process is already under way it is neither inevitable nor entirely directed. The purposes and social consequences of biotechnology are presently quite open to public input. The shaping of the research agenda in the LGUs need not be determined by the MNCs alone. Research is not a free good--it costs money. And as with any human activity, he who controls the pursestrings has the ability to set the agenda. As the Rockefeller Foundation proved so many years ago, research agendas and entire disciplines can serve the purposes of different social groups, and there is no reason to believe this is untrue in agriculture.

FOOTNOTES

1. This linkage has already been partially developed in traditional plant breeding. For example, Green Revolution rice varieties require irrigation--in this case the required input is controlled, measured, and expensive water. Further, the rice to perform economically requires fertilization, a commercial input. This is not to say the rice will die without fertilizer, but the seed's purchase would be economically unjustifiable -- and economics is the only justification for adoption of the new varieties. Finally, new seeds and changed agricultural practices in the U.S. have required ever greater pesticide use to merely keep abreast of evolving pests (for further discussion see Kloppenburg and Kenney 1984).

2. In plant biotechnology the ability to transfer genes will probably come before sufficient knowledge has developed regarding which genes or gene complexes are worth transferring.

3. Biotechnology (molecular biology) offers the possibility of removing or inserting desired genes into a plant's DNA making possible specific, controlled mutations. A seed could then be programmed to respond to environmental conditions in particular ways. But molecular biology offers even more subtle possibilities. For example, a herbicide by definition in some way inhibits a plant's life functions--i.e., the molecules of herbicide bind with plant molecules, disrupting their activities and causing organism death. A more rigorous understanding of the molecular activity will make it possible to design or, more properly, to engineer plant resistance to herbicides. This new knowledge allows rationalization of the herbicide-plant interface, and this technical union facilitates a commercial union that would capture the synergies of this design process.

4. It is no exaggeration to say that nearly every companies from every industry with an interest in agriculture has made an investment in agricultural biotechnology--input producers, food processors, and even Martin Marietta (the possible exception is the farm machinery industry).

5. Chilton's move to industry was somewhat surprising given that she was quoted in <u>Newsweek</u> (1982:69-70) as saying, "The biggest danger [to science] is that the best people will be directed to applied research in industry." What a difference a year can make!

6. A Kansas laboratory was abandoned by AGS once James Shepard and the other important Kansas State University scientists left Advanced Genetics Sciences (WSJ 1984:25).

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