The Economic Status and Performance of Plant Biotechnology in 2003: Adoption, Research and Development in the United States

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Introduction

Plant biotechnology in the United States is a growing industry offering remarkable economic, social and environmental opportunities in the years ahead. The adoption of biotech crops by farmers has been rapid and profitable. Progress on the research front has moved into a new phase, with biotech traits promising an increasingly wide range of consumer and environmental benefits. Plant biotech is also creating new jobs – and good jobs – beyond the farm gate. Sustaining the revolution in plant biotechnology will require a continued commitment to both public and private sector research and development.

- The purpose of this study is to put progress in plant biotechnology in context, and to appraise both its current place and likely future. It is an economic assessment of the status and performance of plant biotechnology and ongoing research and development in the United States.

- The study is focused on eight crops: corn, soybeans, cotton, rapeseed/canola, wheat, potatoes, sugar beets and rice. Given this focus it assesses four fundamental issues:

  1) What is the current level of adoption of plant biotechnology and its value to producers and how have adoption decisions affected farm-level profits in the United States?
  2) What are the main R&D activities in plant biotechnology, by crop and by trait, in both the private and public sector, based on available data?
  3) What are the probable economic impacts of the technology beyond the farm gate in the creation of jobs and new economic opportunities, and what role do individual states play in value creation and research?
  4) What is the future direction of both public and private R&D for the plant biotechnology sector?

- The 2003 levels of adoption of biotech corn, soybeans, cotton and rapeseed/canola in the U.S. were 40 percent for corn, 81 percent for soybeans, 73 percent for cotton and 70 percent for rapeseed/canola. All four crops have shown steady increases in adoption rates. These biotech adoption rates result directly from increases in farm-level profits. Estimates vary by crop and by area, but average profits rose from $5.00 to as much as $60 per acre for corn, on the order of $15.00 per acre for soybeans and from $15.00 to several hundred dollars per acre for cotton.

- The main R&D activities in plant biotechnology are conducted by large private companies such as Syngenta, Monsanto, Bayer CropScience, DuPont/Pioneer Hi-Bred, Dow AgroSciences and BASF. Together, these companies spent $2.7 billion on R&D in 2002, much of it on biotech. Scores of smaller start-ups are also engaged in the R&D process. In the public sector, research by the U.S. Department of Agriculture, land-grant universities and other academic research centers resulted in billions of dollars in additional research investment. In 2000, total U.S. public agricultural research spending was $3.5 billion. New biotech traits are now commercialized for corn, soybeans, cotton and rapeseed/canola, especially traits conferring insect and herbicide resistance. Scores of new traits in the pipeline were field tested by both private and public institutions from 2001 to mid-2003.

- The economic impacts of plant biotechnology are also increasingly evident beyond the farm gate, and in individual states active in biotech research and development. Beyond the more than $20 billion in biotech crops grown in 2002, new plant biotech firms and research facilities are being created throughout the U.S. Agricultural and food scientists are increasingly attracted to the biotech sector's above average wages, and a large number of individual states are reaping the benefits of this investment and job-related economic activity.

- The future direction of both public and private research and development in plant biotechnology will affect and be affected by producers, the input supply industry, private research and development investments, educational and research institutions, the federal government and increasingly consumers.

Current Adoption, Value and Profitability

- The growth of value and benefits of plant biotechnology explain producer demand for biotech varieties in the U.S. Adoption rates for corn rose from 4 percent of corn acres in 1996 to 40 percent in 2003, worth $7.0 billion in 2002. Biotech soybeans rose from 9 percent of planted soybean acres in 1996 to 81 percent in 2003, worth $11.0 billion in 2002. Biotech cotton rose from 17 percent of planted cotton acres in 1996 to 73 percent in 2003, worth $2.7 billion in 2002. Biotech rapeseed/canola accounted for 70 percent of all acres planted in 2003, worth $115 million in 2002. All told, over $20 billion in crop value was associated with biotech crop varieties in 2002.

- When evaluated state-by-state, four states (Iowa, Illinois, Minnesota and Nebraska) accounted for 60 percent of the value of biotech corn production. Four states (Iowa, Illinois, Minnesota and Indiana) accounted for 54 percent of the value of biotech soybean production. Four states (Texas, California, Mississippi and Georgia) accounted for 68 percent of the value of biotech cotton production. Two states (North Dakota and Minnesota) accounted for 95 percent of the value of biotech rapeseed/canola production.

- In 2003, no biotech varieties of wheat, potatoes, sugar beets or rice were planted commercially, although grower organizations remain keenly interested in ongoing research and development of the technology.

- Numerous studies have estimated the benefits of adopting biotech varieties for producers. A survey of these studies shows widespread improvements in profits and management capacity compared with conventional crops.

Private and Public R&D by Crop and by Trait

- Suppliers of plant biotechnology include numerous private and public sector actors. In the private sector, although hundreds of companies are invested in some aspect of plant biotechnology, six companies lead the sector: Syngenta, Bayer, Monsanto, DuPont/Pioneer Hi-Bred, Dow and BASF. In 2002 these six companies together had sales in their agricultural divisions of roughly $28 billion. When research and development investments are calculated as a percentage of these sales, they average about 10.8 percent.

- Despite the prevalence of large biotech companies, there are many examples of smaller companies that have found niche markets in the industry. Illustrative examples include Mendel Biotechnology, Arcadia Biosciences and Shoffner Farm Research, which are briefly surveyed.

- Plant biotech research rests on a wider platform of genomics, which is the latest episode in a tradition of modern plant breeding going back over a century. The cumulative nature of the research process means that research and development by both private and public plant scientists has accumulated over more than 100 years. It is the *accretion* of this knowledge, and not just its leading edges, which defines the R&D mission in plant genetics, including plant biotech.

- Estimates of the stock of plant breeding knowledge and its value, compared with the value of agricultural output, show that from 1850 to 1995 (allowing for depreciation of past research) the ratio of value was 10:1. In other words, in 1995, for every $100 of agricultural output there was $1,000 stock of knowledge to draw on.

- The role of the public sector in plant science research relates specifically to this stock of knowledge, which is held in large part in the public domain by universities, experiment stations and federal research facilities. It also relates to the fact that agricultural research investments often pay out only after 20-30 years. The public sector is often the only party willing and able to wait for these payoffs to accrue.

- Despite this long accrual process, the social rates of return to these investments are impressive by any standards. In a 2000 study comparing estimates of rates of return to agricultural research from 292 studies since 1958, the average annual rate of return was an extraordinary 81 percent (77 percent after inflation). In corn research, the rate of return was 134.5 percent, in wheat 50.4 percent and in rice 75 percent.

- Biotech plants are the latest phase in this effort. The role of the public sector in these and forthcoming biotech innovations should not be discounted, despite substantial increases in the private share of agricultural research and development. If anything, returns to research in plant biotech will exceed the high rates calculated for agricultural research as a whole.

- In 1960, private R&D was 90 percent of public. During the 1970s, private R&D rose to outstrip public spending. By 1980 it exceeded it by 8 percent. In 1990 it exceeded it by 17 percent. By 1996 it was 32 percent higher.

- The growth of private sector R&D in plant science grew most rapidly from 1960-1996 in plant breeding, which increased at an annual rate of 13.7 percent. From 1990-1996, plant breeding research grew at an annual rate of 9.4 percent, more than any other category of private agricultural R&D.

- Public sector research institutions in agriculture have operated largely through connections from USDA to the land grant Universities and their Experiment Stations. Knitting together the system of land grant institutions are various branches of USDA, notably its Agricultural Research Service (ARS), Cooperative State Research, Education and Extension Service (CSREES), Economic Research Service (ERS) and National Agricultural Statistics Service (NASS). USDA expenditures for the four programs in 2002 were $2.3 billion, of which CSREES accounted for nearly half. CSREES is the main federal partner with land grant research, teaching and extension activities. No budget items are designated “plant biotech”, but ARS has a $314 million line item for plant sciences, and ERS has a small $1.1 million “genomics initiative”.

- The changing emphasis of federally funded research is reflected in National Science Foundation data for 1990-99, which shows major gains in the share of the life sciences as a research category. Life sciences outstripped every other research category in its gains, and exceeded the gains of the next largest category, computer sciences, by more than 10 times. Between 1996 and 2002, nationwide NSF funding increased 70 percent in the biological sciences sector.

- Ongoing commercial activity in plant biotech and R&D in the pipeline were examined by describing all traits and varieties of biotech crops approved for commercial sale, and all plant biotech traits in field trials from 2001 to mid-2003. In the first case, USDA, FDA and EPA information was used to construct tables of commercial activity. In the second case, data from USDA’s Agricultural Plant Health Inspection Service (APHIS) was used. The APHIS data set is described in detail in Appendix I.

- Ongoing commercial activity shows a growing list of approvals in corn, soybeans, and cotton through 2001, led by the largest companies. In the remaining crops in the study, some approved varieties exist but are not being commercially sold.

- Plant biotech R&D in the pipeline as of 2001 through mid-2003 indicates almost a hundred new traits in testing. Represented in these activities are about 40 universities (mainly land grants) and about 35 private sector companies. Without question, more research and development as measured by field tests has been devoted to biotech traits in corn than to any other crop, attracting scores of public and private institutions. Among the traits in testing for corn were 19 new agronomic properties, four traits for fungal resistance, seven for herbicide tolerance, four for insect resistance, ten trials focusing on some form of marker genes, and over 30 for output and other end-use traits.

- Soybean research, in which the public and private sector are about equally represented, involved three field tests from 2001 to mid-2003 for agronomic properties, three for fungal resistance, eight for herbicide tolerance, one for insect resistance, one for marker genes, and eight for output traits related to product quality or environmental and health benefits to consumers.

- Cotton research was led by the six major private companies from 2001 to mid-2003, one land grant and the Agricultural Research Service (ARS) of USDA. Testing of biotech traits focused on four agronomic properties, one fungal resistance trait, three herbicide resistance traits and one trait for insect resistance.

- Rapeseed/canola field testing was actively pursued by numerous smaller companies as well as major players such as Monsanto and Cargill and two state universities. Four tests were made on agronomic properties, one each on fungal resistance, herbicide tolerance, insect resistance, and marker genes. Four tests were conducted on output traits for enhanced product quality and alternative uses for canola oil.

- Wheat field testing was quite active despite the absence of marketed biotech varieties, reflecting continued interest in their commercial potential. Testing of agronomic properties related to starch, yield and drought tolerance was pursued at three land grants. Fungal resistance traits were tested by ARS, Syngenta and three land grants. Herbicide tolerance and virus resistance was tested by ARS, Monsanto and the University of Idaho. Marker genes were tested by Montana State. Finally, output traits for digestibility, starch metabolism, and improved bread making characteristics, among others, were tested by several small companies, as well as ARS and Montana State.

- Sugar beets also saw a limited number of field trials from 2001 to mid-2003, notwithstanding the absence of commercial sales. Two herbicide tolerant traits and a virus resistant trait were tested by Syngenta, Monsanto and two small privates.

- Rice was the subject of numerous field tests from 2001 to mid-2003, suggesting the potential opportunities once commercial markets open up. Two agronomic properties were tested by both large and small privates and two states. Bacterial resistance traits were tested by Louisiana State University and the University of California-Davis. Fungal resistance and herbicide tolerance were tested at Louisiana State and by Aventis and Monsanto. Insect resistance traits were tested by Syngenta. Marker genes were tested by the University of California-Davis, Louisiana State University and ExSeed Genetics. Lastly, output traits including heavy metal bioremediation, starch level changes, novel protein production and carbohydrate metabolism changes were tested by two small companies, as well as Aventis and BASF.

- Potatoes were also the subject of considerable field testing of biotech traits from 2001 to mid-2003. Traits tested include bacterial resistance by ARS, fungal resistance by Syngenta, ARS and three land grants, and insect resistance by Michigan State University and the University of Idaho. Virus resistance traits were tested at ARS, the University of

Idaho and the Oregon State University. Gene marker traits were tested by Syngenta, ARS and two land grants. Last, a number of product quality traits were tested such as increased beta-carotene, starch content and reduced bruising properties. These tests involved major privates like Syngenta, potato producers such as J.R. Simplot, as well as ARS and several land grants.

Economic Impact Beyond the Farm Gate and the Role of the States

- Looking beyond the farm gate, it is clear that the plant biotech industry is creating jobs unknown a decade ago. The stock of knowledge associated with the R&D leading to the biotech revolution, if the formula developed by analysts of agricultural research is used, is worth at least $200 billion. Maintaining this stock of knowledge will require high skill levels and will demand high wages.

- The number of biological science degrees, one measure of this trend, rose dramatically in the 1990s. In the U.S. as a whole, the number of bachelor's, master's and Ph.D.'s in the biological sciences rose from 45,000 in 1990 to 73,000 in 2000, an increase of 62 percent.

- The Minneapolis Federal Reserve District Bank estimated the number of R&D firms in engineering, physical and life sciences in Minnesota at 178 in 2001, followed by Wisconsin with 128, Montana with 53, North Dakota with 20 and South Dakota with 17, or 396 in the five states. Employment in these firms grew at least 50 percent from 1998 to 2002 in Minnesota and Wisconsin, adding 1,000 jobs each.

- There is reason to believe that many estimates of plant biotech activity have been substantially understated, even by industry spokesmen. The Biotechnology Industry Organization (BIO), for example, identified only 64 biotech companies in the Midwest. Yet a 2003 survey of Minnesota firms by the state's Department of Employment and Economic Development found 170 firms in scientific biotech in Minnesota alone, of which two in five were in the agricultural and industrial sectors.

- The Wisconsin Association for Biomedical Research and Education (WABRE) in 2001 identified almost 200 Wisconsin bioscience companies, including 56 in the agricultural sector. These companies employed some 21,000 workers, with an additional 5,000 employed in R&D at Wisconsin universities and laboratories. WABRE estimated total industry activity at $5 billion, about 3 percent of gross state product.

- Bureau of Labor Statistics from the U.S. Department of Commerce's Occupational and Employment Survey (OES) were examined for evidence of plant biotech impacts. Plant biotech does not fit neatly into OES categories. We examined three U.S. sectors: crop services (with 128,500 workers in 2001); agricultural chemicals (46,490 workers in 2001); and farm products – raw materials (97,180 in 2001). Apart from these sectors, plant biotech firms employ many of the same skilled workers as other sectors of the economy (managers, computer programmers, legal advisors, etc.).

- What makes plant biotech different is the reliance on life science workers, including food scientists, microbiologists, biochemists and biophysicists. These workers typically require advanced degrees and training, and receive above-average wages. In 2001, the OES estimated 13,470 agricultural and food scientists (AFS) alone employed in public and private institutions with an average salary of $52,310 a year, more than one and one-half times the U.S. average of $34,020.

- The states which have been the most rapid adopters of biotech corn and soybeans up to 2003 were compared with the size of the AFS job category. Those states with the highest levels of biotech crop adoption had more AFS jobs per 100,000 in 2003 than states with lower levels.

- The distribution of wages in the AFS sector showed that overall, AFS workers in the states with the highest levels of biotech plant adoption made between 1.5 and 2.0 times the average wage. These wages exceeded averages throughout the career life cycle.

- The states' role in value creation shows that commercial plantings of biotech crops have benefited a wide range of individual state economies. These include especially the corn and soybean producing states of Iowa, Illinois, Minnesota, Nebraska, Indiana, South Dakota, Missouri, North Dakota, Ohio, Wisconsin and Michigan. They also include cotton producing states such as Arkansas, Mississippi, Texas, California, Georgia and others.

- On the research side, state land grant universities and the U.S. Department of Agriculture have been active in plant biotech research. Among the research institutions involved are Universities in Arizona, California, Colorado, Connecticut, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Montana, Nebraska, New Jersey, New York, North Carolina, North Dakota, Ohio, Oregon, Pennsylvania, Texas, Virginia, Washington and Wisconsin.

Future Directions for Plant Biotechnology

- In conclusion, plant biotech and its future is of growing importance to producers, to the input supply industry, to private research and development investors, to educational and research institutions, to the federal government and increasingly to consumers.

- For producers, valuable benefits conferred by plant biotech since commercial introduction in 1996 reached over $20 billion in 2002. In addition to direct improvements in profits, biotech varieties offer management efficiencies worth almost 65 percent more in economic benefits in some cases. Multiplied times the growing number of acres in biotech varieties nationally, these are significant contributions to farm income, especially in the Corn and Cotton Belt states.

- In the input supply industry, the introduction of biotech varieties has forced changes in the "bundles" of crop protection products, seeds and fertilizers sold to farmers, and promoted rapid consolidation of chemical and seed companies. Biotech varieties have given new impetus to precision agriculture, and offer traits that will yield social rewards not only for productivity but resource conservation and environmental improvements.

- Investors find that high investments are matched by high returns, but that long lags intervene between costs and benefits. These long lags mean that only companies able to commit resources over extended periods will direct the R&D process. In general, these are larger, well-capitalized firms. Venture capitalists with shorter time horizons will need to find start-ups able to attach themselves to the R&D process of larger companies.

- Public sector R&D will remain important due to the leads and lags in the agricultural research process. Activity will continue to grow in the life sciences as public institutions remain repositories of knowledge worth hundreds of billions of dollars a year. The erosion of funding for land grants and state and federal budget deficits will therefore have negative consequences for the entire plant biotech sector. New directions must maximize the complementarities between private and public science.

- The federal government's role will become even more important as the regulatory scope of plant biotech requires oversight by not only USDA and its sub-agencies, but FDA, EPA and other agencies such as the Small Business Administration or the export-promotion arms of the Department of Commerce. NSF and NIH will also play key roles.

- The ultimate arbiter of market growth and development is the consumer. As consumer confidence grows, it will feed the demand for new biotech varieties, support those who supply them, and build a base for public investments in the plant biotech research base, resulting in more jobs at higher wages.

Introduction

Biotechnology represents a wave of innovation comparable to informatics in the late 20th century, and the internal combustion engine in the early 20th century.[1] Like other waves of change, biotechnology has evoked both praise and reaction, and has led to debate over its potential for good or ill. Because the debate is partly about food, it evokes strong opinions. It is often forgotten that the tomato, when first introduced, was widely regarded as poisonous. When brought to the United States and Europe in the 1830s it was known as "wolf's peaches." In 1830, U.S. Colonel Gibbon Johnson set out to prove its safety by publicly eating one on the courthouse steps in Salem, New Jersey. A crowd of two thousand came to see a suicide. A band played a dirge before Johnson addressed the crowd, saying "The time will come when this delicious scarlet apple . . . will form the foundation of a great garden industry, and will be enjoyed as an edible food . . ." Johnson proceeded to bite into a tomato as the crowd shouted "No! No!" He survived, and New Jersey became the garden state to New York, growing fruits and vegetables for the burgeoning metropolis. Today, Americans rank the tomato (technically a fruit) as their favorite vegetable.[2]

Plant biotechnology has provoked an even more widespread debate, perhaps because the technology involves transferring and transforming genetic material – the building blocks of life itself. In effect, genetic information can be rearranged and recombined like words on a page. Genomics, the general biological science of which biotechnology is a part, is really the application of informatics to genetics. The power of

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[1] Vernon W. Ruttan. *Technology, Growth and Development: An Induced Innovation Perspective.* New York: Oxford University Press, 2001, p. 177.
[2] David Aaron, "Chairman's Comment," in David G. Victor and C. Ford Runge. *Sustaining a Revolution: A Policy Strategy for Crop Engineering.* Council on Foreign Relations, 2002, p. xi.

informatics has been key to developing the capacity to map and rearrange genetic information to express functional genetic traits such as insect resistance. Interestingly, information technology has also allowed criticism of biotechnology to spread, worldwide, in ways that cause alarm to the public before scientific evidence is clear. Opponents of biotechnology have exploited the power of Internet communications to spread criticism and condemnation of the technology and the companies and governments that have led in its development.

The purpose of this study is to put progress in plant biotechnology in context, and to appraise both its current place and likely future. The study was funded by the Council for Biotechnology Information (CBI). In it, we attempt to provide a balanced and objective assessment of the industry as of late 2003. This is not a scientific study of the microbiology and genetics which lie at the base of biotechnology. It is, rather, an economic assessment of the status and performance of plant biotechnology and ongoing research and development in the United States. In addition to its primary economic focus, it covers only the United States, reserving for further studies the international reach and scope of the industry. It is focused on plant biotechnology and not on animal research or medical advances in the pharmaceutical sector, both of which are being profoundly shaped by many of the same forces. While we have written elsewhere on environmental issues and biotechnology[3], it is not primarily an environmental assessment. It is focused on eight plants: corn, soybeans, cotton, rapeseed/canola, wheat, potatoes, sugar beets and rice. Given this focus we assess four fundamental issues:

[3] Ibid. Victor and Runge, 2002.

(1) What is the current level of adoption of plant biotechnology and its value to producers and how have adoption decisions affected farm-level profits in the United States?

(2) What are the main R&D activities in plant biotechnology, by crop and by trait, in both the private and public sector, based on available data?

(3) What are the probable economic impacts of the technology beyond the farm gate in the creation of jobs and new economic opportunities, and what role do individual states play in value creation and research?

(4) What is the future direction of both public and private R&D for the plant biotechnology sector?

We begin with a careful assessment of U.S. farm-level adoption. We calculate the value of plant biotechnology to producers in the U.S. and leading states, and survey findings on farm-level profitability. We then assess investments and trends in private and public plant biotech activity and R&D based on industry and public data. Third, we examine some of the probable economic and employment impacts of the growing sector beyond the farm gate, and consider the role of individual states in value creation and research. Finally, we offer an opinion as to the likely path and direction of the industry as it enters its second decade of large-scale commercial applications.

Developments in the Adoption of Plant Biotechnology

In 1988, the Office of Technology Assessment (OTA) guardedly appraised the future of plant biotechnology and its future commercialization. Noting the limited knowledge base underlying biotechnology research and development (R&D), the OTA report observed:

> "The level of basic scientific knowledge about plants is rudimentary and limited to certain species. Basic biochemistry of plants and plant systems is poorly understood. For example, the metabolic basis of drought resistance is not understood, let alone the genetics of this trait. The same holds true for many plant traits. Knowledge about gene expression and developmental regulation of plants is not well defined, and while plants are a major source of pharmaceuticals and other specialty chemicals, biotechnological applications are poorly exploited; only one product is currently under production."[4]

In 2003, seven years after primary commercialization in 1996 (Flavr Saver tomatoes had been released in 1994), and 15 years after OTA's assessment, the pace and progress of the industry has quickened, but so have the objections of industry critics. Plant biotechnology was optimistically described by a leading research firm in mid-2003 as "at a crossroads," with new enabling technologies – the basic tools for sequencing genetic material – improving "at rates faster than Moores Law."[5] Yet in its 2003 overview of the industry, Burrill and Company, the life sciences merchant bank, warned of an industry "in the doldrums," noting Monsanto's ledger loses and declining stock market price, Syngenta's decision to close its Torrey Mesa Research Institute in California and relocate many of its researchers to the Research Triangle Park campus in North Carolina, and the downsizing of Bayer Crop Science AG after its merger with Aventis Crop Science. As the 2003 Burrill report noted, "No new genes were commercialized in any crops this past year and very few deals were completed between Agbio companies and the big five multinationals."[6]

The Burrill Agbio Index fell 9.4 percent for all of 2002, less than the 16.8 percent loss for the Dow Jones Industrial Index, but hardly a strong performance.[7] These

[4] Office of Technology Assessment (OTA). *New Developments in Biotechnology: U.S. Investment in Biotechnology*. Washington, D.C., 1988, p. 210.
[5] Bio Economic Research Associates. "Rapid Advances in Enabling Biotechnologies: Implications for Biotech, Agriculture and Food." Bio-era teleconference record, 2003. www.bio-era.net
[6] G. Steven Burrill. *Biotech 2003: 17th Annual Report on the Industry*. 2003, p. 190.
[7] Ibid. Figure 11.5, pp. 396-397.

setbacks were combined with what Burrill described as a “pummeling” of GMO’s by critics and “extraordinarily stringent” labeling requirements in the European Union and possibly in Canada and elsewhere.[8]

Still, the view of seasoned observers in the industry was that there was “no going back.” Entomologist Anthony Shelton, author of more than 300 articles on various issues related to crop science, stated in an interview with *Business Week* in July, 2003 that plant biotechnology would soon be widely accepted, noting an expansion in planted acreage worldwide since 1996 from 4.3 million to 145 million acres in 16 countries. Acceptance will come rapidly as “output traits,” benefiting consumers’ health and nutrition, as well as the environment, come to market.[9] If there is “no going back,” then what is the way forward for the industry? To understand this path, we need first to look at the basic economics driving adoption demands, as well as the factors driving investment on the supply side.

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[8] Ibid. pp. 191-192.
[9] *Business Week*, July 8, 2003. “Special Report: Biotech Foods: No Going Back?” See also David McElroy, “Sustaining ag biotechnology through lean times.” *Nature Biotechnology* 21(9)(September 2003): 996-1002.

Producer Demand for Plant Biotechnology: Total Value and Benefits

Adoption Rates and Total Value

Farmers, especially in corn, soybean and cotton-producing areas of the United States, have been rapid adopters of plant biotechnologies. Here, we examine the value and benefits of this adoption to producers, given the relatively short time span (1996-2002) for which data are available. The National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA) reports aggregate area planted, yields and prices for all eight crops covered in this study, which we include as baseline data. Table 1 shows data for these crops in 2002, ranked by value, planted acres, value per planted acre, and average yield times average price. Corn had both the highest crop value and number of planted acres, followed by soybeans, wheat, cotton, potatoes, sugar beets, rice and rapeseed/canola, with the value for all eight crops totaling $50.5 billion on 234 million acres of U.S. cropland. The highest value per planted acre was in potatoes ($2,863), followed by sugar beets ($734). Corn ($268), soybeans ($201), cotton ($244), and rice ($262) clustered in the two-hundred dollar range, while rapeseed/canola ($113) and wheat ($98) had the lowest value per planted acre. These results are consistent with the average yield times average price data, which show roughly the same rankings.

Table 1. Crop Value, Planted Acres, Value per Planted Acre and Average Yield x Average Price. Eight Crops, 2002.

U.S. 2002	crop value	planted acres	value per planted acre	avg. yield * avg. price
corn	$21.2 billion	79.1 million	$268	$305
soybean	$14.7 billion	73.0 million	$201	$204
wheat	$5.9 billion	60.4 million	$98	$127
cotton	$3.4 billion	13.9 million	$244	$292
potato	$3.2 billion	1.31 million	$2,863	$2,475
sugar beet*	$1.1 billion	1.43 million	$734	$747
rice	$841 million	3.20 million	$262	$253
rapeseed/canola	$165 million	1.46 million	$113	$129
all 8 crops	$50.5 billion	234 million		

* sugar beet crop value and average price unreported for 2002, used average 2000-2001
Source: USDA, NASS.

What is the share in these totals attributable to biotech varieties? For corn, soybeans and cotton, NASS has reliable data on biotech crop planted acres from 1996-2003 (Table 2, Figure 1). Much less data is available for the other five crops covered in this study. Accordingly, corn, soybeans and cotton will be discussed first, followed by rapeseed/canola. These four crops are the only ones with commercial value in biotech varieties in 2002. The others – wheat, potatoes, sugar beets and rice, do not yet have biotech varieties in commercial production.

At the national level, biotech corn varieties (primarily B_t-corn resistant to European corn borer) rose from 4 percent of corn acres planted in 1996 to 40 percent in 2003. Biotech soybeans (primarily herbicide-resistant varieties) rose from 9 percent of planted soybean acres in 1996 to 81 percent in 2003. Biotech cotton (both herbicide and insect-resistant) rose from 17 percent of planted cotton acres in 1996 to 73 percent in 2003.

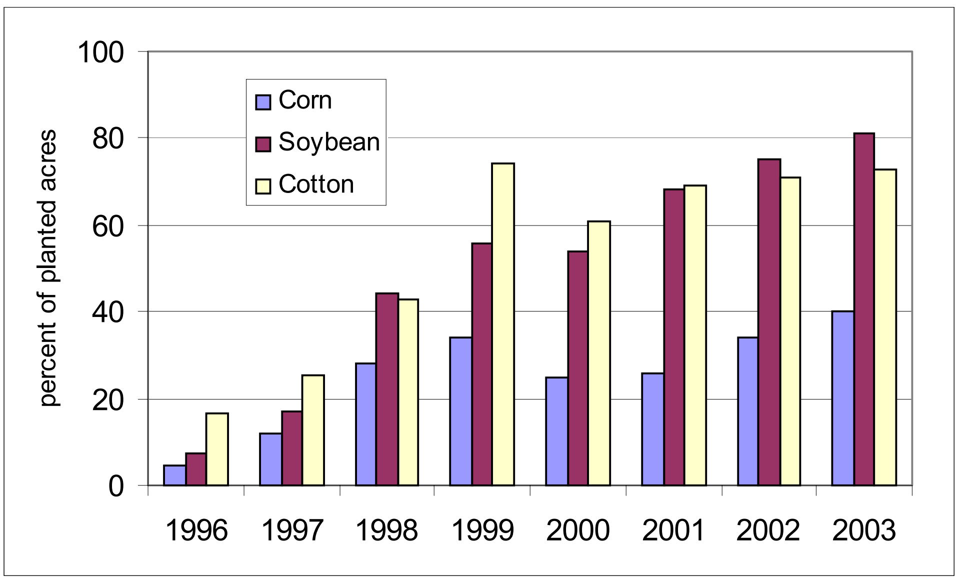
Table 2. Percent of Planted Acres in Biotech Variety

Percent of crop acres planted to biotech varieties, 1996-2003

	1996	1997	1998	1999	2000	2001	2002	2003
Corn	4	12	28	34	25	26	34	40
Soybean	7	17	44	56	54	68	75	81
Cotton	17	26	43	74	61	69	71	73

Source: USDA, NASS

Figure 1. Percent of Crop Acres Planted to Biotech Varieties, 1996-2003.



Source: Table 2

These numbers can be broken down further into the type of biotech trait with data from USDA's Economic Research Service[10] (Table 3). For each crop, input traits are distinguished as B_t (insect resistant), herbicide tolerant, or "stacked," meaning a combination of these characteristics. As can be seen in Table 3, the total percentage of

[10] Jorge Fernandez-Cornejo and William D. McBride. *Adoption of Bioengineered Crops*. ERS Agricultural Economics Report No. AER810, May, 2003.

acres in these three crops is the sum of the acres in each biotech category. In corn, for example, 25 percent of planted acres in 2003 was in B_t varieties, 11 percent in herbicide-tolerant varieties and 4 percent in "stacked" varieties, totaling 40 percent. With this overview, we turn now to a more detailed assessment of biotech adoption in each crop, a breakdown of adoption in the lead producing states, and the value of these crops at the producer level.

Table 3. Adoption of Biotech Corn, Soybeans and Cotton by Year and Trait, 1996-2003.

crop year	1996	1997	1998	1999	2000	2001	2002	2003
Corn	4.4	11.9	28.1	33.9	25	26	34	40
Bt corn	1.4	7.6	19.1	25.9	18	18	22	25
Herbicide-tolerant	3	4.3	9	8	6	7	9	11
Stacked	0	N/A	N/A	N/A	1	1	2	4
Soybean								
Herbicide-tolerant	7.4	17	44.2	55.8	54	68	75	81
Cotton	16.8	25.5	43	74.4	61	69	71	73
Bt cotton	14.6	15	16.8	32.3	15	13	13	14
Herbicide-tolerant	2.2	10.5	26.2	42.1	26	31	36	32
Stacked	0	N/A	N/A	N/A	20	24	22	27

Source: *Adoption of Bioengineered Crops*, by Jorge Fernandez-Cornejo and William D. McBride, ERS Agricultural Economic Report No. AER810. 67 pp, May 2002; Acreage, 2003, USDA, NASS

<u>Corn</u>

As noted, corn accounted for the largest number of acres of any crop. It was planted on 79.0 million U.S. acres in 2003, an area unchanged from 2002. Nearly all corn acres (72 million) were harvested for grain, with the rest used for silage. Total production in 2002 topped 9.0 billion bushels, down from 9.5 billion in 2001 and 9.9

billion in 2000. The average U.S. corn yield was 130 bushels per acre in 2002, off the historically high 138 bushel yield in 2001. Average 2002 prices at $2.35 a bushel were higher than they had been since averaging $2.43 in 1997. The total 2002 corn crop was valued at $21.2 billion, also the highest since 1997. Within this valuable commodity category, biotech corn varieties continued their growth in share, accounting for 40 percent of 2003 seeded acres. From 2000 to 2002, adoption rates increased from 25 percent to 26 percent in 2000-2001, and to 34 percent in 2001-2002. Expressed as acres of planted corn, transgenic varieties accounted for 31.6 million acres in 2003, up from 19.7 million acres in 2000.

Biotech corn currently has two main traits: B_t resistance to insects and herbicide tolerance. The 25 percent of 2003 U.S. corn acres planted to B_t was up from 22 percent in 2002. The herbicide resistant corn seeded to 11 percent of the 2003 acreage was up from 9 percent in 2002. Four percent of the 2003 corn crop had both traits – double the level of 2002.

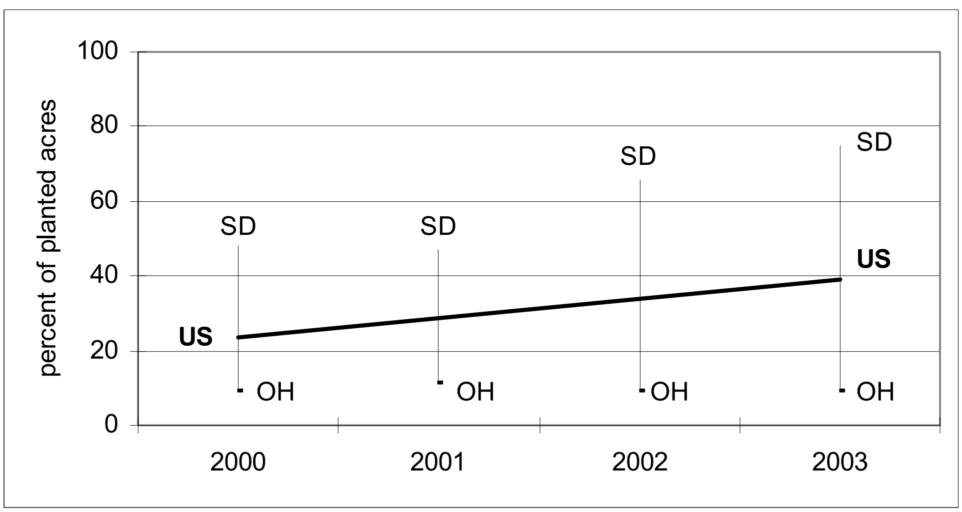
When looked at on a state-by-state basis, there was considerable variability among the states in the adoption of biotech corn varieties. South Dakota farmers reached a 75 percent adoption rate, while in Ohio just 9 percent of planted acres were transgenic (Table 4). The variation in state-level adoption rates for biotech corn appears to be due primarily to geographic differences in pressure from European corn borer. For the U.S. as a whole, the adoption curve for biotech corn varieties is clearly on an increasing trend (Figure 2).

Table 4. Biotech Corn Adoption Rates by State: 2002-2003.

CORN	*percent planted acres in biotech variety*			
	2000	2001	2002	2003
US	**25**	**26**	**34**	**40**
SD	48	47	66	75
MN	37	36	44	53
NE	34	34	46	52
KS	33	38	43	47
IA	30	32	41	45
MO	28	32	34	42
MI	12	17	22	35
WI	18	18	26	32
IL	17	16	22	28
IN	11	12	13	16
OH	9	11	9	9
Oth Sts	17	20	27	36

Source: USDA, NASS

Figure 2. Percent of Planted Acres in Biotech Corn Varieties, 2000-2003



Source: Table 4

With this information, it is possible to calculate the total value of U.S. corn production associated with biotech varieties, for both the U.S. and leading states (Table 5). Table 5 shows harvested acres for corn in 2002, its value for the U.S. and by state, and the percentage of these categories in biotech varieties. For the U.S. as a whole, the value of these biotech varieties was $7.0 billion in 2002. The leading states by value were Iowa, with $1.8 billion of biotech corn, and Nebraska, with $1.0 billion in biotech varieties. These states were followed by Minnesota ($995 million), Illinois ($790 million), South Dakota ($441 million), Kansas ($312 million), Missouri ($236 million), Wisconsin ($224 million), Indiana ($201 million), Michigan ($118 million) and Ohio ($57 million). All other states combined accounted for $816 million. All told, four states – Iowa, Illinois, Minnesota and Nebraska, accounted for 60 percent of this value.

Table 5. Corn Harvested and Value of Biotech Varieties, U.S. and by State, 2002

CORN			*GM corn*		
2002	harvested	crop value	% biotech	bio hvst	bio value
	(1)	(2)	(3)	(4)	(5)
US	72.1	$ 21,213	34%	24.5	$ 7,040
IA	11.9	$ 4,418	41%	4.9	$ 1,811
IL	11.4	$ 3,590	22%	2.5	$ 790
MN	6.8	$ 2,262	44%	3.0	$ 995
NE	8.1	$ 2,258	46%	3.7	$ 1,039
IN	5.3	$ 1,547	13%	0.7	$ 201
WI	2.8	$ 861	26%	0.7	$ 224
KS	3.0	$ 725	43%	1.3	$ 312
MO	2.7	$ 695	34%	0.9	$ 236
SD	3.7	$ 669	66%	2.4	$ 441
OH	3.0	$ 631	9%	0.3	$ 57
MI	2.1	$ 534	22%	0.5	$ 118
All other	11.5	$ 3,023	27%	3.1	$ 816

(1) corn harvested in million acres
(2) total value in millions of dollars
(3) percent of acres planted in GM corn
(4) implied acres (millions) harvested GM corn
(5) implied value of GM corn crop in millions of dollars
Source: USDA, NASS

Soybeans

Because soybeans are often planted in rotation with corn, soybean acreage is similar in magnitude to corn acreage nationwide. The 2003 U.S. planted soybean crop was estimated at 73.7 million acres. Planting was up 700,000 acres from 2002, but below the all-time high of 74.5 million acres in 2000. Total production in 2002 was 2.73 billion bushels, off the 2001 all-time peak of 2.89 billion bushels. The 2002 average yield of 37.8 bushels per acre was also below the near record 39.6 bushel yield in 2001. The average price per bushel for soybeans in 2002 was $5.40, the highest since $6.47 in 1997. Soybean production in 2002 was valued at $14.7 billion, up from $12.6 billion in 2001.

Adoption rates for biotech soybean varieties revealed extremely strong producer demand. The 2003 U.S. soybean planted crop was composed of 81 percent herbicide resistant varieties. When USDA began detailed reporting of biotech planted acres in 2000, 54 percent of planted soybean acres were transgenic. Adoption increased to 68 percent of soybean acres in 2001, and 75 percent in 2002. A total of 59.7 million acres was planted to biotech soy in 2003, compared to 54.7 million acres in 2002, 50.4 million acres in 2001, and 40.1 million acres in 2000.

Transgenic soybean adoption also varies by state, although much less so than for corn. This is due primarily to the widespread challenge of weed-pressure for soybeans, making herbicide-resistant varieties broadly appealing compared with the more localized problems of European corn borer. The adoption rates for biotech soybeans are shown in Table 6. U.S. adoption by year is depicted in Figure 3, which again shows a strong upward movement.

When examined state-by-state, the big-producing states of Iowa and Illinois have the most acres planted to soybeans: 29 percent of the total 2003 soybean acres. In these states, biotech varieties are 84 percent and 77 percent of total planted soybean acreage respectively. The range among the major soybean producing states is from South Dakota at 91 percent to Michigan at 73 percent. Over time, the spread between state-level adoption rates has narrowed.

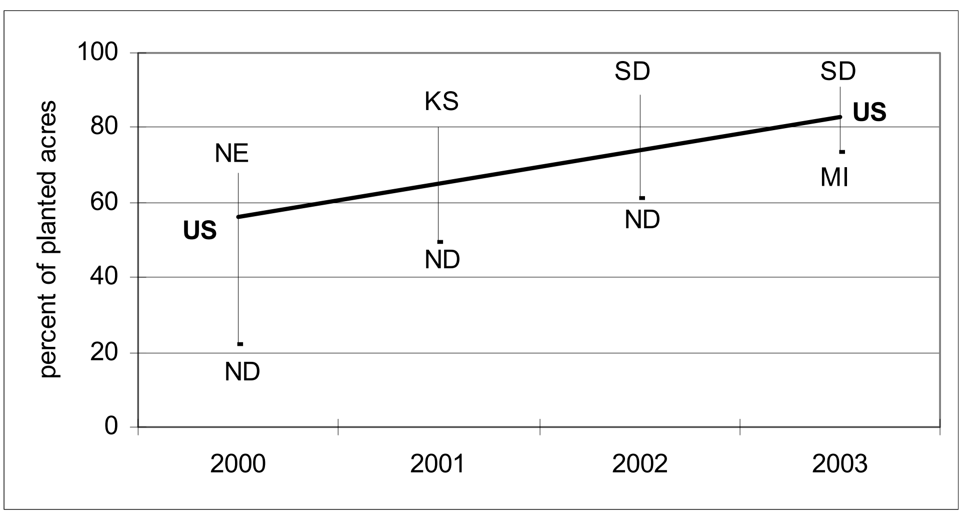
Once again, it is possible to calculate the total value of U.S. soybean production associated with biotech varieties for the nation as a whole and state-by-state (Table 7). In 2002, this biotech value was $11.0 billion for the U.S. At the state level, the biotech leader was Iowa ($2.0 billion), followed by Illinois ($1.8 billion), Minnesota ($1.2 billion), Indiana ($1.1 billion), Nebraska ($802 million), Missouri ($661 million), South Dakota ($581 million), Ohio ($562 million), Arkansas ($371 million), Michigan ($309 million), North Dakota ($275 million), Wisconsin ($274 million), Kansas ($262 million), and Mississippi ($195 million). All other states combined totaled $766 million. Four states account for about 54 percent of this biotech value – Iowa, Illinois, Minnesota and Indiana.

Table 6. Biotech Soybean Adoption Rates by State: 2000-2003.

Soybean	percent acres in biotech variety			
	2000	2001	2002	2003
US	54	68	75	81
SD	68	80	89	91
MS	48	63	80	89
IN	63	78	83	88
KS	66	80	83	87
NE	72	76	85	86
AR	43	60	68	84
IA	59	73	75	84
WI	51	63	78	84
MO	62	69	72	83
MN	46	63	71	79
IL	44	64	71	77
ND	22	49	61	74
OH	48	64	73	74
MI	50	59	72	73
Oth Sts	54	64	70	76

Source: USDA, NASS

Figure 3. Percent of Planted Acres in Biotech Soybean Varieties, 2000-2003



Source: Table 6

Table 7. Soybeans Harvested and Value of Biotech Varieties, U.S. and by State, 2002

SOYBEAN 2002	harvested (1)	crop value (2)	*GM Soybean* % biotech (3)	bio hvst (4)	bio value (5)
US	72.0	$ 14,755	75%	54.0	$ 11,026
IA	10.7	$ 2,672	75%	8.0	$ 2,004
IL	10.2	$ 2,474	71%	7.2	$ 1,756
MN	6.9	$ 1,621	71%	4.9	$ 1,151
IN	5.7	$ 1,273	83%	4.7	$ 1,057
NE	4.8	$ 943	85%	4.1	$ 802
MO	4.7	$ 918	72%	3.3	$ 661
OH	4.7	$ 770	73%	3.4	$ 562
SD	4.2	$ 653	89%	3.7	$ 581
AR	2.9	$ 545	68%	2.0	$ 371
ND	2.4	$ 451	61%	1.5	$ 275
MI	1.9	$ 430	72%	1.4	$ 309
WI	1.4	$ 351	78%	1.1	$ 274
KS	2.8	$ 315	83%	2.3	$ 262
MS	1.4	$ 243	80%	1.1	$ 195
All other	7.4	$ 1,094	70%	5.2	$ 766

(1) million acres harvested
(2) total crop value in millions of dollars
(3) percent of acres planted in herbicide resistant variety
(4) implied acres (millions) harvested from GM variety
(5) implied value of GM crop in millions of dollars
Source: USDA, NASS

Cotton

Cotton is planted on far fewer acres than corn or soybeans, but is a high-value crop. Because it is often grown in humid or irrigated areas, pest and weed pressures can be severe, raising the appeal of both herbicide-resistant and insect-resistant varieties. In 2003, cotton was planted to 13.9 million acres, unchanged from 2002. Nearly the entire crop was upland cotton, although 176,000 acres were seeded in 2003 to American-Pima cotton – down 27 percent from 2002. Of the 13.9 million cotton acres planted in 2002, 12.4 million acres were harvested. Total U.S. cotton production in 2002 was 17.15 million bales – each weighing 480 pounds – a 15 percent decline from 20.3 million bales in the record 2001 crop. Cotton yields averaged 663 pounds per acre in 2002, down from the near-record 705 pounds the prior year. In addition to ginned or lint cotton, the 2002 crop also produced 6.4 million tons of cottonseed. The 2002 U.S. cotton crop had an estimated total value of $3.59 billion, up from the multi-year low of $3.12 billion during the bumper 2001 crop.

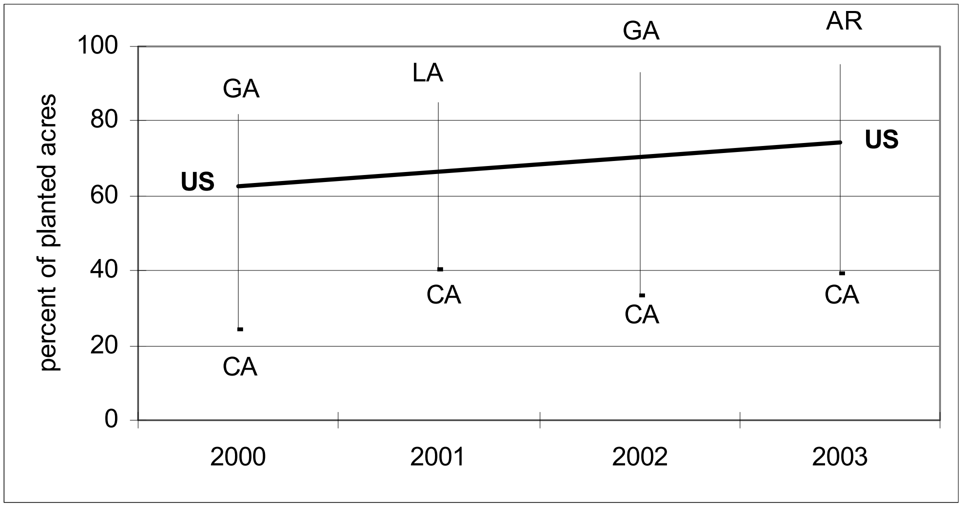
Table 8 shows that 73 percent of the 2003 Upland cotton crop was seeded with biotech varieties, up 2 percent from a year earlier. (Planted biotech acres are reported for Upland cotton, but not American-Pima.) Varieties with stacked genes for both insect and herbicide resistance were used on 27 percent of Upland acres, an increase from 22 percent from 2002. Herbicide resistant varieties were planted on 32 percent of Upland acres, down from 36 percent the previous year. Insect resistant-only cotton acreage increased in 2003 to 14 percent, up 1 percent over the previous year. The current adoption rate (73 percent) represents 10.0 million acres of Upland biotech cotton. The rate of biotech cotton adoption can be seen in Figure 4.

Table 8. Biotech Cotton Adoption Rates by State: 2000-2003.

Upland cotton	Percent of Upland cotton acres in biotech varieties			
	2000	2001	2002	2003
US	61	69	71	73
AR	70	78	90	95
GA	82	85	93	93
NC	76	84	86	93
MS	78	86	88	92
LA	80	91	85	91
TX	46	49	51	53
CA	24	40	33	39
Oth Sts	74	84	86	88

Source: USDA, NASS

Figure 4. Percentage of Planted Acres in Biotech Cotton Varieties, 2000-2003



Source: Table 8

As in corn and soybeans, the value of cotton in biotech varieties can be reported for the U.S. and many of the key producing states (Table 9). For the U.S. as a whole, the value of biotech cotton varieties in 2002 was $2.7 billion. The states' share of this biotech value was led in 2002 by Texas ($489 million), followed by California ($404 million), Mississippi ($334 million), Georgia ($328 million), Arkansas ($299 million), Tennessee ($138 million), Louisiana ($126 million), Arizona ($119 million), Missouri ($108 million), and Alabama ($101 million). Six other states (Oklahoma, New Mexico, South Carolina, Virginia, Florida and Kansas) together accounted for a value of $125 million. Four states (Texas, California, Mississippi and Georgia) accounted for 68 percent of this biotech value.

Table 9. Upland Cotton Harvested and Value of Biotech Varieties, U.S. and by State, 2002

2002 cotton	Harvested Acres (1)	Crop Value (2)	% UP biotech (3)		GM value (5)
US	12,412	3,593,816	71%		2,707,811
TX	4,518	934,120	51%		489,232
CA	686	606,201	33%		403,796
MS	1,150	379,210	88%		333,705
GA	1,360	353,232	93%		328,506
AR	920	332,640	90%		299,376
TN	535	159,998	86%	*	137,598
NC	920	159,264	86%		136,967
LA	495	147,960	85%		125,766
AZ	220	137,802	86%	*	118,510
MO	368	125,904	86%	*	108,277
AL	540	117,300	86%	*	100,878
OK	180	36,480	86%	*	31,373
NM	57	30,356	86%	*	30,747
SC	190	24,960	86%	*	21,466
VA	98	19,388	86%	*	16,674
FL	115	15,139	86%	*	13,020
KS	60	13,862	86%	*	11,921

(1) thousands of acres of cotton harvested
(2) value of all cotton crop in thousands of dollars
(3) share of upland cotton from transgenic variety
(4) default share of american-pima cotton from transgenic variety
(5) implied value of GM cotton crop in thousands of dollars
* default value for share from transgenic variety
Source: USDA, NASS

Rapeseed/Canola

Rapeseed/canola (also known as Argentine canola) was planted to 1.16 million acres in 2003, with 88 percent of this acreage in North Dakota. Some 85 thousand acres were planted in Minnesota, and the remaining 58 thousand acres were scattered among 15 other states, from Alabama to Washington. The 2003 planting is smaller than the 1.46 million acres planted in 2002, of which 1.3 million acres were also in North Dakota. Total production in 2002 reached 1.55 billion pounds with an average yield of 1,218 pounds per acre, considerably below the 2.0 billion pounds or (1,374 pounds per acre) in

2001. The 2001 crop total production was virtually unchanged from 2000, which saw a record crop ten times larger than in 1991. Prices averaged $10.60 a hundredweight in 2002, up from $8.77 in 2001 and $6.71 in 2000. The total value of production in 2002 was $165 million, down from a 2001 value of $175 million, but up from $134 million in 2000.

Biotech varieties of rapeseed/canola, primarily herbicide-resistant, have made heavy inroads into the market. Although USDA does not collect data on biotech varieties in this crop, industry experts report that approximately 70 percent of U.S. canola acres are now herbicide resistant biotech varieties. Of these, roughly 65 percent are planted with Roundup Ready® glyphosate tolerant varieties and the remaining 35 percent with LibertyLink® herbicide resistance. The latter product appears to be gaining market share.[11] Based on these estimates, the U.S. value of biotech rapeseed/canola in 2002 was $115 million. North Dakota accounted for $102 million of this value, Minnesota for $8.0 million and the remaining states $5.75 million.

Wheat

Wheat comes in many varieties: hard red, soft red and white winter wheat; hard red and white spring wheat; and durum wheat. Winter wheat varieties account for 71 percent of total U.S. production, led by hard red varieties, which account for 38 percent of the total. Hard red spring wheat is 22 percent of total wheat production for 2002. Planted acres for all wheat varieties totaled 60.9 million acres in 2003, up slightly from 2002. Harvested acres were expected to total 52.7 million acres in 2003 compared to 47.6 million acres harvested in 2002. The 2002 average yield was estimated at 35.3

[11] Barry Coleman, Executive Director. Northern Canola Growers, Bismarck, North Dakota. Personal communication, September 11, 2003.

bushels per acre, down from 40.2 bushels in 2001 and 42.0 bushels in 2000. Total wheat production was just 1.62 billion bushels in 2002, versus the 1.96 billion bushels in 2001 and 2.23 billion bushel crop of 2000. Wheat prices were higher in 2002, averaging $3.60 per bushel, compared to the average price of $2.78 in 2001 and $2.62 in 2000. The total value of production remained relatively stable, however, over the three years. The wheat crop was valued at $5.86 billion in 2002, compared with $5.44 billion in 2001 and $5.78 billion in 2000. Four states accounted for 48 percent of the 2002 wheat crop: Kansas, North Dakota, Washington and Montana (see Table 10).

There are no biotech wheat varieties available for commercial sale in the United States, and no value at the farm level has been realized. Whether and when biotech wheat sales will commence remains an open question. Wheat growers are aware of the potential improvements in management and profits which have been shown in corn, soybeans and cotton, but are also mindful of refusals to purchase biotech crops by some governments in Europe and Asia. Despite this uncertainty, research into biotech wheat continues, as will be documented below.

Table 10. Wheat Planted, Harvested, Yield, Production, Price and Value, U.S. and States, 2002

All Wheat 2002	Planted (1)	Harvested (2)	Yield (3)	Production (4)	Price (5)	Value (6)
US	**60,085**	**47,628**	**35.3**	**1,616,441**	**$ 3.60**	**$ 5,863,378**
KS	9,500	8,000	33.0	267,300	$ 3.45	$ 922,185
ND	9,080	8,820	27.3	216,610	$ 4.00	$ 864,828
WA	2,440	2,385	54.8	129,695	$ 4.10	$ 537,039
MT	5,690	4,880	23.1	109,895	$ 4.25	$ 466,748
OK	6,000	3,500	28.0	98,000	$ 3.50	$ 343,000
ID	1,280	1,220	73.1	87,660	$ 3.85	$ 339,628
MN	2,030	1,928	33.9	62,240	$ 4.00	$ 248,690
TX	6,400	2,800	29.0	78,300	$ 3.00	$ 234,900
NE	1,650	1,450	32.0	48,640	$ 3.70	$ 179,968
SD	2,975	2,372	25.9	42,235	$ 4.05	$ 170,162
OH	870	800	62.0	50,220	$ 3.20	$ 160,704
CO	2,375	1,674	23.1	38,700	$ 3.85	$ 148,875
OR	960	905	40.0	34,010	$ 4.00	$ 135,565
CA	575	400	80.8	31,500	$ 3.65	$ 114,300
AR	980	800	46.0	38,640	$ 2.90	$ 112,056
MI	500	490	67.0	32,830	$ 3.30	$ 108,339
MO	940	760	45.0	34,200	$ 3.15	$ 107,730
IL	680	650	49.0	31,850	$ 3.05	$ 97,143
NC	650	480	42.0	20,160	$ 3.00	$ 60,480
IN	350	330	53.0	17,490	$ 3.20	$ 55,968
All Other	4,160	2,984	51.2	146,266	$ 3.17	$ 455,070

(1) planted acres in thousands, (2) harvested acres in thousands
(3) yield per acre in bushels, (4) total production in thousands of bushels
(5) price per bushel in dollars, (6) total value of production in thousands of dollars
Source: USDA, NASS

Potatoes

Potatoes are classified as spring, summer, fall and winter; sweet potatoes are reported separately. The fall crop is the most significant. For all potatoes, 1.31 million acres were planted in 2002, above the 2001 planting, but off the record high 2000 planting of 1.38 million acres. The 2003 plantings have not been reported. The average yield in 2002 was 363 hundredweight (cwt) compared to 358 cwt in 2001 and 381 cwt in 2000. Total production reached 463 million cwt in 2002 versus 438 million cwt in 2001 and 513 million cwt in 2000. In 2002 the average price per cwt was $6.82, compared to $6.99 in 2001 and $5.08 in 2000. The total value of production topped out at $3.15

billion, versus $3.0 billion in 2001 and $2.6 billion in 2000. Three states accounted for 49 percent of the potato crop value in 2002: Idaho, Washington and California (see Table 11).

Biotech potato varieties made a limited and brief appearance from 1998-2001 with commercialization by Monsanto's NatureMark branch of New Leaf potatoes. These B_t potatoes were first approved by U.S. regulatory agencies in 1995. In 1998, a New Leaf Plus variety was approved which combined B_t with resistance to Potato Leaf Roll Virus (PLRV). In 1999, Monsanto added New Leaf Y, which combined B_t with resistance to Potato Virus Y (PVY). Biotech potatoes never reached more than 2-3 percent of the U.S. market for several reasons. First, they ran into stiff competition from new insecticides that effectively controlled the potato beetles to which they were targeted. Second, in the U.S. several large potato processors including McDonalds, Burger King, Frito-Lay and Proctor and Gamble stated that they would accept only non-transgenic potatoes.

On March 21, 2001, Monsanto discontinued New Leaf potatoes, the only transgenic variety on the market. None were sold to growers from 2001 onward, although residual traces may be present in potato starches.[12] Subsequently, Japan declared zero-tolerance for transgenic potatoes. A spokesman for the potato industry believes that until attractive consumer traits are developed, and approvals exist in all major export destinations, growers will not plant biotech varieties. Even so, the industry recognizes the promise of the technology, and continues to work with researchers in the

[12] Cornell University Cooperative Extension Service. *Genetically Engineered Organisms*. Public Education Project, August 20, 2003. http://www.geo.pie.cornell.edu

private and public sector.[13] At this time, despite continuing research efforts to be detailed below, no value at the farm level from biotech varieties can be stated.

[13] John Keeling, Executive Vice President and CEO, National Potato Council. Washington, D.C. Personal communication, September 18, 2003. John Toastbern, Vice President-International. U.S. Potato Board. Personal communication, September 22, 2003.

Table 11. Potatoes Planted, Harvested, Yield, Production Price and Value, U.S. and States, 2002

Potato 2002	Planted (1)	Harvested (2)	Yield (3)	Production (4)	Price (5)	Value (6)
US	1,311	1,277	363	463,214	$ 6.82	$ 3,151,178
ID	375	373	358	133,385	$ 5.40	$ 720,279
WA	170	170	560	95,200	$ 5.40	$ 514,080
CA	45	45	394	17,695	$ 17.40	$ 307,024
WI	85	83	375	31,125	$ 7.10	$ 220,988
CO	78	78	388	30,189	$ 7.15	$ 216,186
ND	118	102	230	23,460	$ 5.95	$ 139,587
FL	34	33	293	9,659	$ 14.00	$ 135,448
OR	50	50	501	24,936	$ 5.40	$ 134,908
ME	64	64	265	16,960	$ 7.05	$ 119,568
MN	61	55	340	18,700	$ 6.30	$ 117,810
MI	47	46	305	13,878	$ 7.40	$ 102,697
NY	23	22	250	5,500	$ 11.70	$ 64,350
TX	21	20	264	5,360	$ 10.70	$ 57,156
NE	22	22	395	8,611	$ 5.95	$ 51,235
MT	11	10	310	3,224	$ 11.40	$ 36,754
NC	22	21	170	3,570	$ 8.35	$ 29,810
AZ	8	8	270	2,106	$ 13.40	$ 28,220
PA	15	14	185	2,590	$ 8.95	$ 23,181
VA	7	6	220	1,386	$ 12.70	$ 17,602
NM	7	6	371	2,336	$ 6.45	$ 15,035
NV	8	8	340	2,584	$ 5.35	$ 13,824
IL	7	6	310	1,984	$ 5.80	$ 11,507
MD	5	5	250	1,175	$ 9.30	$ 10,928
OH	4	4	240	1,008	$ 9.45	$ 9,526
DE	4	4	260	936	$ 10.00	$ 9,360
MO	7	5	240	1,296	$ 6.50	$ 8,424
KS	3	3	340	986	$ 8.25	$ 8,135
NJ	3	3	265	689	$ 9.50	$ 6,546
AL	3	3	185	554	$ 11.60	$ 6,426
MA	3	3	255	740	$ 7.35	$ 5,439
IN	3	3	260	728	$ 5.85	$ 4,259
SD	1	1	300	330	$ 6.60	$ 2,178
UT	1	1	305	244	$ 8.20	$ 2,001
RI	1	1	180	90	$ 7.85	$ 707

(1) planted acres in thousands
(2) harvested acres in thousands
(3) yield per acre in hundredweight
(4) total production in thousands of hundredweight
(5) price per hundredweight in dollars
(6) total value of production in thousands of dollars
Source: USDA, NASS

Sugar beets

The 2003 sugar beet crop was planted on an estimated 1.36 million acres. Sugar beets were planted to 1.43 million acres in 2002, an increase from 1.37 million acres in 2001. The 2000 crop was planted to 1.56 million acres. Ninety-five percent of the 2002 acres were harvested, compared to the 10 percent field loss in 2001 and 13 percent loss in 2000. The average yield for the 2002 crop was 20.2 tons per acre, down from 20.7 tons in 2001 and 23.7 tones in 2000. Total production in 2002 topped 27.5 million tons, compared to 25.8 million tons in 2001 and 32.5 million tons in 2000. The 2002 average price per ton was $38.10, and the total crop had a value of $1.06 billion. Four states accounted for 83 percent of all sugar beet production in 2003: Minnesota, North Dakota, Michigan and Idaho. State level prices and crop values for sugar beets for the 2002 crop will not be reported until February 2004, but the 2001 values are available (Table 12).

USDA does not collect data on biotech sugar beets since none have been planted commercially to date and they have no market value. Although herbicide resistant (LibertyLink) sugar beets are fully approved in the U.S., the industry has been reluctant to commercialize them. This reluctance was initially based on concerns that if some growers adopted while others did not, the non-biotech growers might seek market advantage. A related issue was that beet sugar, which competes with cane sugar, would face corresponding competitive pressures if cane sugar was non-biotech.[14] Finally, some major food companies that use sugar widely are concerned over commingling of biotech and non-biotech sugar in the face of consumer resistance, especially in foreign markets. Because the regulatory response to biotech crops has been inconsistent and

[14] Don Lilleboe, Editor. *The Sugarbeet Grower*, Fargo, North Dakota. Personal communication, September 12, 2003.

unsynchronized across countries, it has added further complexity. According to industry experts, if more widespread approvals occur in various countries, markets for some biotech varieties may open up.[15]

Table 12. Sugar beets Planted, Harvested, Yield, Production, Price and Value, U.S. and Selected States, 2001

Sugar beet 2001	Planted (1)	Harvested (2)	Yield (3)	Production (4)	Price (5)	Value (6)
US	1,371	1,243	21	25,764	$ 39.8	$ 1,025,306
MN	468	426	18	7,796	$ 40.3	$ 314,179
ND	261	237	18	4,290	$ 46.1	$ 197,769
ID	199	179	26	4,636	$ 40.5	$ 187,758
MI	180	166	19	3,220	$ 34.8	$ 112,056
CA	47	45	36	1,596	$ 33.4	$ 53,306
MT	57	54	22	1,150	$ 38.8	$ 44,620
WY	49	42	21	857	$ 39.7	$ 34,023
NE	49	41	20	840	$ 36.9	$ 30,996
CO	42	37	22	824	$ 34.2	$ 28,181
OR	12	10	30	290	$ 40.5	$ 11,745
WA	7	7	36	253	$ 40.5	$ 10,247
OH	1	1	20	12	$ 35.5	$ 426

(1) planted acres in thousands
(2) harvested acres in thousands
(3) yield per acre in tons
(4) total production in thousands of tons
(5) price per ton in dollars
(6) total value of production in thousands of dollars
Source: USDA, NASS

<u>Rice</u>

Rice is classified as long grain, medium grain, and short grain. Long grain is the most significant variety economically. Rice production is reported for six U.S. states: Arkansas, California, Louisiana, Mississippi, Missouri and Texas. Rice was planted to 3.0 million acres in 2003, down from 3.2 million acres in 2002. Nearly all planted acres are ultimately harvested. The 2002 average yield was 6,578 pounds per acre, for a total

[15] Joe Dahmer, President. Beta Seed, Inc., Shakopee, Minnesota. Personal communication, September 17, 2003.

production of 211 million hundredweight. Long grain rice accounted for 157 million cwt, on a yield slightly below the overall rice average. The average price for a hundredweight of rice was $3.85 in 2002, compared to $4.25 in 2001 and $5.61 in 2000. The total value of production in 2002 was $841 million, off the 2001 value of $925 million and below the $1.0 billion total value of the 2000 rice crop. Arkansas accounts for 41 percent of U.S. rice production, followed by California, which contributes another 26 percent (Table 13). Arkansas rice is predominantly of a long grain variety, while California rice is almost exclusively medium grain.

Biotech rice varieties, despite much research news, have not been commercialized in the U.S. Herbicide tolerant rice was cleared for commercial production in 1999 and given FDA approval in 2000. Its developer, Aventis CropScience (now merged to form Bayer CropScience), awaits EPA approval. No commercial value has yet been realized behind the farm gate.

Table 13. Rice Planted, Harvested, Yield, Production, Price and Value, U.S. and Selected States, 2002

RICE 2002	Planted (1)	Harvested (2)	Yield (3)	Production (4)	Price (5)	Value (6)
US	3,251	3,227	6,578	210,960	$ 3.85	$ 840,727
AR	1,540	1,530	6,440	96,752	$ 3.60	$ 348,307
CA	510	508	8,140	42,989	$ 5.00	$ 214,945
LA	520	515	5,500	29,400	$ 3.90	$ 114,660
MS	265	263	6,400	16,192	$ 3.85	$ 62,339
TX	200	199	7,100	14,616	$ 4.20	$ 61,387
MO	216	212	6,050	11,011	$ 3.55	$ 39,089

(1) planted acres in thousands
(2) harvested acres in thousands
(3) yield per acre in pounds
(4) total production in thousands of hundredweight
(5) price per hundredweight in dollars
(6) total value of production in thousands of dollars
Source: USDA, NASS

Producer Benefits

Numerous studies have estimated the benefits of adopting biotech varieties for producers. Using a variety of methodologies, these studies help to explain why producers have been enthusiastic adopters. They also suggest that while consumers may benefit in the future, their gains in the short-run have been more modest. In a 2002 study for the International Food Policy Research Institute (IFPRI), Marra, Pardey and Alson examined farm level impacts of biotech varieties for several crops after pooling results from 75 previous studies.[16] Citing different studies of B_t corn, they found that profits rose in the Corn Belt as a whole by an average of $60 per acre, and in Illinois by $23 per acre. For the U.S. overall, another study found a rather lower profit increase of about $5.00 per acre. For herbicide-resistant soybeans, average profit increases were reported for Ohio of $14 per acre. Biotech potato varieties increased profits by an average of $15.5 per acre in Illinois, and $22.4 per acre in the U.S. as a whole. In cotton, estimates by state for B_t cotton varieties included increases in profit per acre for Alabama ($77.6), Arizona ($57.5), Georgia ($92), Louisiana ($16.5), Mississippi ($34.5), North Carolina ($20.5), Oklahoma ($53.8), South Carolina ($51.8), Tennessee ($67.5), Texas ($46) and Virginia ($41.7). Estimates of additional profits per acre for herbicide-resistant cotton were available for Arkansas ($17.1) and Tennessee ($74.3), and for stacked insect and herbicide-resistant cotton for Arkansas ($243).[17]

In a study focused specifically on corn rootworm, for which biotech varieties are just being commercialized, some of the same authors found support for likely rapid adoption of the new varieties. Using regional prices for corn in 2000 and different

[16] Michele C. Marra, Philip G. Pardey and Julian M. Alson. "The Payoffs to Agricultural Biotechnology: An Assessment of the Evidence." IFPRI, Environment and Production Technology Division, Washington, D.C. EPTD Discussion Paper No. 87, January 2002, Table 7, p. 28.
[17] Ibid, Table 6, p. 27.

scenarios for corn rootworm pressure, these authors estimated an average benefit per acre treated with biotech varieties of $16.49, with total benefits in the U.S. of $239 million. If a ten-year corn price average is used instead of the 2000 price of corn (which was 20 percent below this average), benefits rise for the U.S. as a whole to $319 million, or about $23 per acre treated.[18] In addition to these producer benefits, benefits to non-farmers were estimated at $171 million, for a total of $402 million at 2000 price levels, and $490 using ten-year average prices.[19]

The same authors also commissioned a survey by Doane Marketing Research, Inc. in April, 2002 to help determine if other factors would affect farm-level adoption rates, and what value these factors would have for producers. For all those surveyed, farmers attributed values in dollars per acre to: handling and labor time savings of the biotech variety ($1.87), improvements in human safety ($1.68), environmental safety ($1.34), reduced yield risk ($3.80), equipment cost savings ($1.46) and better "standability" (less corn lost from falling or lodging) ($4.99) for a total of $15.14 per acre in additional benefits. Multiplying these benefits times the acreage treated for corn rootworm in 2000 added another $58 million of benefits from adoption to the 2000 figure of $402 million, for a grand total of $460 million.[20] In other words, to the $23.00 per acre in benefits to this biotech corn can be added another $15.00 in management advantages, an increase of 40 percent.

[18] Julian M. Alston, Jeffrey Hyde, Michele Marra and Paul D. Mitchell. "An Ex Ante Analysis of the Benefits from the Adoption of Corn Rootworm Resistant Transgenic Corn Technology." *AgBio Forum* 5(3)(2002): 72-84. Table 5, p. 80.
[19] Ibid, p. 79.
[20] Ibid, Table 7, p. 82.

In a 1999 study, Falck-Zepeda, Traxler and Nelson examined B_t cotton. Using economic measures of changes in welfare,[21] during 1996 and 1997, B_t cotton increased the producer surplus of U.S. cotton producers equivalent to $200 million per year.**[22]** In a 1999 paper based on USDA survey data, Fernandez-Cornejo, Klotz-Ingram and Jans estimated a model that indicated significant increases in yields for farmers who adopted herbicide-tolerant cotton or soybeans.[23] In a 1998 paper, Roberts, Pendergrass and Hayes reinforced these results, concluding that the use of glyphosate herbicide on herbicide-tolerant soybeans had the highest yields and net returns of any of the management regimes tested.[24]

In general, producers will benefit from reduced herbicide applications, other things equal. While herbicide-tolerant crops reduce the use of some herbicides, they generally tend to reinforce the use of the herbicides to which they are tolerant. In the case of glyphosate, this may result both in net cost reductions to farmers, and a more benign impact on the environment because of glyphostate's properties.[25] In a 1998 study of herbicide-tolerant cotton, Culpepper and York found that use of glyphosate required fewer herbicide treatments and less herbicide in total to produce equivalent yields and

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[21] "Welfare" as used by economists has a different meaning than in common language. It refers to the measurement of changes in the "surplus" of consumers or producers due to changes in the price or availability of goods and services. These welfare benefits are often reported in money-equivalent terms, but are not actual payments or transfers to consumers or producers. See Robin W. Broadway and Neil Bruce. *Welfare Economics*, Oxford: Basil Blackwell, 1984.
[22] J. Falck-Zepeda, G. Traxler and R. Nelson. "Rent Creation and Distribution from Biotechnology Innovations: The Case of B_t cotton and herbicide-tolerant soybeans." Paper presented at Transitions in Agbiotech: Economics of Strategy and Policy. NE-165, June 24-25, 1999. Washington, D.C.
[23] J. Fernandez-Cornejo, C. Klotz-Ingram and S. Jans. "Farm-Level Effects of Adopting Genetically Engineered Crops in the U.S.A." Selected paper presented at the international conference entitled, "Transitions in Agbiotech: Economics of Strategy and Policy," NE-165, Washington, D.C., June 24-25, 1999.
[24] R.K. Roberts, R. Pendergrass and R. M. Hayes. "Farm-Level Economic Analysis of Roundup Ready™ Soybeans." Presented at the Southern Agricultural Economics Association Meeting, Little Rock, AR, Februrary 1-4, 1998.
[25] C. Ford Runge and Richard S. Fawcett. "Sustainability and the Roundup Ready® Soybean System: An Analysis of Economic and Environmental Issues." A study prepared for Monsanto. March 31, 1998.

returns.[26] A 2001 USDA survey concluded that although studies of herbicide use on biotech crops have had varying results, planting herbicide-tolerant corn appears to reduce significantly the applications of acetamide herbicides, as well as other alternatives to glyphosate such as 2, 4-D, aciflourfen, bentazon, clomozone, pendimethalin and trifluralin.[27] On insect-resistant B_t crops in general, the 2001 USDA survey noted:

> "Many studies have concluded that B_t varieties have higher yields and lower insecticide costs than their conventional counterparts, which may translate into a significant increase in farmer profits, depending on adoption rates and the nature of demand for the commodity."[28]

Specifically, B_t cotton appears to lower the need for insecticides such as pyrethroids, aldicarbs, chloropyrifos, oxamyls and endosulfans.[29] Although B_t corn resulted in more limited reductions in insecticide applications, corn yields were clearly greater, causing returns to rise above the level needed to offset seed premiums and technology fees, resulting in net gains from $3.00-$16.00 per acre.[30]

A final perspective on farmers' incentives to adopt new biotech varieties is offered by the USDA's Agricultural Resources Management Study (ARMS).[31] On herbicide-tolerant soybeans, USDA found a small increase in yields, a decrease in the use of some synthetic herbicides, and an increase in glyphosate. On herbicide-tolerant cotton, it found an increase of from 1-5 percent in both yields and net returns for a 10 percent increase in adoption. On B_t cotton, it found a similar increase in yields and net

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[26] Alfred S. Culpepper and Alan C. York. "Weed Management in Glyphosate-Tolerant Cotton." *Journal of Cotton Science* 2(1998): 174-185.

[27] U.S. Department of Agriculture. Economic Research Service. "Farm-Level Effects of Adopting Genetically Engineered Crops: Preliminary Evidence from the U.S. Experience." In *Economic Issues in Agricultural Biotechnology*. Agriculture Information Bulletin 762. Washington, D.C., February 2001, p. 11.

[28] Ibid, p. 12.

[29] Fernandez-Cornejo, et al. Op cit note 23. See also M. Marra, G. Carlson and B. Hubbell. *Economic Impacts of the First Crop Biotechnologies*. North Carolina State University, Department of Agricultural and Resource Economics, 1998. <http://www.ag-econ.ncsu.edu/faculty/marra/FirstCrop/sld001.htm>

[30] Marra, et al. Ibid.

[31] See <http://www.ers.usda.gov/data/arms/>

returns of 1-5 percent, and a decrease in some insecticides.[32] Based on these results, USDA indicated that overall, "one might expect a rapid diffusion of their use," although regional differences in weed and pest pressure would likely cause adoption to fall short of 100 percent.[33]

Overall, producer enthusiasm for biotech crop varieties is quite clear, especially for soybeans, corn and cotton. The reasons for this are not difficult to see: these varieties are generally more profitable and easier to manage than conventional crops. Not only are they "here to stay;" they are likely to diffuse more widely as new traits are stacked on those already developed. Further support for this trend in the corn market comes from special analysis from USDA in 2003.[34]

[32] USDA, 2001, Table 3, p. 14.
[33] Ibid, p. 14.
[34] USDA, NASS. "Corn and Biotechnology Special Analysis." Cr Pr 2-3. Washington, D.C., July 11, 2003.

Investing in Plant Biotech: The Suppliers of Technology

We turn now to the supply side of these technologies, and to the U.S. firms and institutions responsible for the R&D which underlies them. The biotechnology sector has both a private and a public sphere. We consider each sphere and its investments, as well as interactions and complementarities between the spheres, and the specific crops and traits in which different private and public institutions have invested.

The Private Sector

Table 14 shows the sum of private sector companies holding field testing permits from the Agricultural Plant Health Inspection Service (APHIS) for some type of plant biotech crop from 1985 to 2003 (see Appendix I). While hundreds of companies are invested in some aspect of plant biotechnology, six companies lead the sector: Syngenta, Bayer, Monsanto, DuPont/Pioneer Hi-Bred, Dow and BASF. In 2002, the Annual Reports of these companies showed sales in their agricultural divisions of roughly $28 billion. All six are invested in plant protection and biotech research and development. When research and development investments are calculated as a percentage of these sales, they range from a low of 7.5 percent (BASF) to a high of 12.7 percent (Bayer), averaging 10.8 percent (Table 15). While industry structure is not our focus, many analysts believe that only large firms have the research budgets and legal/regulatory expertise necessary to gain government approvals and to secure adequate intellectual property protections. By aggregating (a) the tools for genetic transformation; (b) the genes; and (c) crop germplasm in one company, large firms can exploit complementarities among and between these assets.[35] Such capacity creates barriers to

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[35] G.D. Graff, G.C. Rausser and A.A. Small. "Agricultural Biotechnology's Complementary Intellectual Assets." *Review of Economics and Statistics* 85(2)(May 2003): 349-363.

smaller firms who cannot exploit these economies of scale and scope, and may also discourage venture capital from investing in start-ups.[36] When looked at individually, each of the six largest companies has a distinct profile.

Table 14. Private Companies Filing for Plant Biotech Field Testing Permits, 1985 2003(1)

Abbott and Cobb	Barham Seeds	Crows
Advanced Genetic Science	BASF	Dairyland Seeds
Agracetus	Bayer CropScience	DeKalb
AgraTech Seeds	Becks Superior Hybrids	Delta and Pine Land
AgReliant Genetics	Bejo	Demegen
AgrEvo	Betaseed	DNA Plant Tech
Agrigenetics	BHN Research	Dow
AgriPro	Biogemma	Dry Creek
Agritope	Biosource	Du Pont
AgriVitis	BioTechnica	Dunn
All-Tex Seed	Boswell	Emlay and Associates
Amer Crystal Sugar	Brownfield Seed	Exelixis
American Cyanamid	Cal West Seeds	ExSeed Genetics
American Takii	Calgene	FFR Cooperative
Amoco	Cameron Nursery	Forage Genetics International
Anton Caratan & Son	Campbell	Frito Lay
Applied PhytoGenetics, Inc.	Canners Seed	Gargiulo
Applied Phytologics	Cargill	Garst
Applied Starch Tech	Chembred	GenApps
ArborGen	Chlorogen, Inc.	Genetic Enterprises
Arcadia Biosciences	Ciba-Geigy	Goertzen Seed Research
Asgrow	Coors Brewing	Golden Harvest Seeds
Aventis	Crop Genetics	Great Lakes Hybrids
Ball Helix	CropTech	Harris Moran

[36] Op cit., note 9. David McElroy. See also M. Fulton and G. Konstantinos, "Agricultural biotechnology and industry structure." *AgBio Forum* 4(2001): 137-151.

Table 14 cont.

Heinz	NC+ Hybrids	Seminis Vegetable Seeds
Hilleshog	Nestle	Shoffner Farm Research, Inc.
Hoechst-Roussel	Northrup King	Stine Biotechnology
Holdens	Novartis Seeds	Stine Seeds
Horan Bros. Agri. Enterprises	PanAmerican Seed	Sunseeds
Hunt-Wesson	Pebble Ridge Vineyards	Syngenta
ICI	PetoSeed	Targeted Growth, Inc.
ICI Garst	Pioneer	Thermo Trilogy
Integrated Plant Genetics	Plant Genetic Systems	Tilak Raj Sawheny
InterMountain Canola	Plant Genetics	Union Camp
International Paper	Plant Science Research	United Agri Products
Interstate	Plant Sciences	United States Sugar
Interstate Payco Seed	ProdiGene	Upjohn
J. R. Simplot Company	Pure Seed Testing	Van den Bergh Foods
Jacob Hartz	R J Reynolds	VanderHave
Land O Lakes	Research for Hire	Vector Tobacco
Large Scale Biology	Rhone-Poulenc	Ventria Bioscience
Limagrain	Rogers	Western Ag Research
Lipton	Rogers NK	Westvaco
Mendel Biotechnology	Rohm and Haas	Weyerhaeuser
Meristem Therapeutics	Sandoz	Williams Seed
Midwest Oilseeds	Sanford Scientific	Wilson Genetics
Miles	Scotts	W-L Research
Monsanto	Seedco	WyFFels Hybrids
Mycogen	SemBioSys Genetics	Yoder Brothers
National Starch & Chemical		Zeneca

[(1)] Company names are reported as they appear in the APHIS permit application, as a result some may appear in the tables more than once, for example: Garst, ICI, and ICI Garst.

Source: USDA, APHIS (see Appendix 1).

Table 15. Research and Development as a Percentage of Agriculturally-Related Sales: Top Five Agbiotech Companies[a/]

2002	Sales (millions)	R&D (millions)	R&D/Sales
Syngenta	$ 6,197	$ 697	11.2%
Monsanto	$ 4,673	$ 527	11.3%
Dupont/Pioneer Hi-Bred	$ 4,510	$ 506	11.2%
Bayer CropScience	€ 4,697	€ 598	12.7%
BASF	€ 4,924	$ 367	7.5%
Dow	$ 2,700	n/a	
Total	27,701	2,695	10.8 (average)

Source: Company Annual Reports
[a/] Assumes $1.00 = €1.00.

Syngenta

The number one company by sales, Syngenta AG, is headquartered in Basel, Switzerland but operates in the United States through its Golden Valley, Minnesota-based Northrup King seed division and its sugar beet business, Hilleshög. In 2002, Syngenta showed a slight decrease in sales from 2001 (down to $6.2 billion from $6.3 billion), but outperformed the Dow Jones Industrial Average and the Burrill Agbio index throughout the year.[37] In 2001, prior to its closure, Syngenta's Torrey Mesa Research Institute announced that it had completed mapping the rice genome in collaboration with Myriad Genetics, Inc., the first such map to be completed in a crop plant.[38] Because rice makes up 80 percent of the diet of half of the globe's population, cataloguing the genomic elements that control its biological functions is a major step. This information can now be used to study other cereals such as wheat, corn and barley, which share up to 98

[37] Op cit., note 6. Burrill, 2003, p. 197.
[38] Stephen Goff, et al. "A Draft Sequence of the Rice Genome (oryza satira L ssp.japonica)." *Science* 296(5565)(April 5, 2002): 92-100.

percent of their genes with rice. Donald Kennedy, editor of *Science*, the scientific journal publishing the findings, observed in the same issue: "Over the next 20 years, the rice genome will make more of a difference to global health than the human genome."[39] Syngenta supported public release of the rice genome information by placing over 100,000 gene sequences from its program on the Clemson University Genomics Institute (CUGI) website.

In December of 2002, Syngenta announced the closure of the Torrey Mesa facility, and a technology-for-equity collaboration with Diversa, leading to a relocation and consolidation of its biotechnology research activities in North Carolina's Research Triangle Park. The new research facility, Syngenta Biotechnology Inc., will build on the collaboration with Diversa (dating to 1999) to enhance the traits of animal feed. As the 2002 Burrill report noted (p. 197): "The move is a clear indication of the economic downturn in the sector, but a real boost for Diversa and Agbio."

In addition to these developments, Syngenta has numerous plant biotech products in the pipeline.[40] For the eight crops which are the focus of this study, these include second-generation European corn borer control (anticipated for release in 2005/2006), proprietary glyphosate tolerance (2006/2007), broad lepidopteran control (2006/2007), and corn rootworm control (2005/2006). As distinct from these input traits, Syngenta is developing output traits such as high phytase corn (2005/2006), which will increase feeding efficiencies and reduce phosphorus in animal waste. A second output trait

[39] Donald Kennedy. "The Importance of Rice." *Science* 296(5565)(April 5, 2002): 13. In the same April 5, 2002 issue, researchers from the Beijing Genomics Institute and other Chinese academies published their own draft sequence of the rice genome. Syngenta sequenced the rice sub-species *japonica*; the Chinese sequenced *indica*.
[40] Syngenta. "Tomorrow's Products." <http://www.syngenta.com/en/products-services/tomprod.aspx>

example is corn amylase (2006/2007), which will improve digestion efficiencies for corn in the manufacture of ethanol.

Syngenta has also focused on output traits associated with plant-made pharmaceuticals (PMPs), or "biopharming." Although regulatory hurdles and concerns over co-mingling of PMPs and conventional crops remain, the potential for manufacturing antibodies and other pharmaceutical agents in plant "factories" is clear. Such processes can produce more of these substances at lower costs.[41]

In cotton, Syngenta has broad-spectrum insect control ready for 2004, as well as proprietary glyphosate tolerance (2006/2007). In wheat, it has developed fusarium-mold resistance to reduce rot during storage (2007). In rapeseed/canola, it has a line of high-yielding fully restored hybrids ready for release in 2004. These biotech applications, as the rice example makes clear, are built on a larger foundation of genomics research and conventional plant-breeding.

<u>Bayer CropScience</u>

In June, 2002, the pattern of plant biotech acquisitions and mergers that characterized the previous decade continued with pharmaceutical giant Bayer's purchase of Aventis CropScience, creating Bayer CropScience. Bayer CropScience ended 2002 with sales of 4.7 billion Euros. Its objective, according to Chairman Dr. Jochen Wulff, is to overtake Syngenta's number one position by 2006.[42] Bayer sees its greatest growth opportunities in plant biotechnology. It plans to launch 14 new biotech products by 2005, estimated to add 800 million Euros in new sales by 2006, and announced a goal of 8-9 percent of sales dedicated to research and development.

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[41] Op cit., note 6. Burrill, 2003, p. 204. See also Karen K. Rogers, "The Potential of Plant-Made Pharmaceuticals." Paper commissioned by Monsanto Protein Technologies, St. Louis, MO, 2002.
[42] *Dow Jones Business News*. "Bayer Crop Wants to Overtake Syngenta as No. 1 by 06." September 3, 2003.

Bayer CropScience's principal North American locations are in Kansas City, Missouri, Research Triangle Park, North Carolina and Calgary, Alberta. Bayer CropScience sees the greatest opportunities for growth in the plant biotechnology segment. The BioScience business of Bayer CropScience is an international leader in the research, development and marketing of high quality seeds and innovative agricultural solutions derived through plant biotechnology. The business' Agricultural Crops group focuses on improving the agronomic performance of three important crops -- canola, cotton and rice -- using both biotechnology and conventional plant breeding approaches, while the New Business Ventures group is engaged in the development of novel plant-based products for use in industrial, nutritional and consumer health applications. Among the BioScience group's products currently marketed by Bayer CropScience are FiberMax® cotton, herbicide tolerant LibertyLink® corn and canola, and InVigor® Hybrid canola which is also tolerant to Liberty®-type herbicides.

Monsanto

Despite a leading role in many aspects of the plant biotechnology, St. Louis-based Monsanto has faced obstacles. The number two seed company (behind DuPont/Pioneer Hi-Bred), saw its share price fall nearly 50 percent from mid-2000 to mid-2002, sales decline 19 percent for the first nine months of 2002, and the loss of its second chief executive in three years in December, 2002.[43] Still, Monsanto shares the general optimism over plant biotech's potential. In May, 2002 the company predicted that in fiscal 2002 over half of its agricultural profits would come from products other than chemicals, with biotech genes expected to produce about $600 million in gross profits.[44]

[43] Op cit. Burrill, p. 196.
[44] David Barboza. "Monsanto Struggles Even as it Dominates." *New York Times*, May 31, 2003.

Monsanto relies heavily on two main products: the genetic traits of biotech seeds resulting from purchases of DeKalb and Asgrow branded seed and Holden's foundation seed company, and its chemical herbicide glyphosate (Roundup). The latter now commands over 90 percent of the world's herbicide market, although it went off-patent in 2000. The company also controls about 90 percent of the market for biotech plant traits. Analysis by the brokerage firm UBS Warburg suggests that the purchases of seed companies necessary to establish this leadership in plant traits weighed heavily on capital costs, contributing to a weakening stock price. Although Monsanto still has no real peer in plant biotech, Syngenta (see above) and DuPont (see below) are racing to release products that will compete one-on-one. To maintain its position, Monsanto plans to continue to spend heavily, especially on research. Eighty percent of its $500 million annual research budget will go to biotech, compared with about 20 percent devoted to biotech research by its major rivals.[45] Particular attention will be devoted to stacked biotech varieties, and output traits such as biotech seeds for soybeans, corn and canola fortified with Omega-3 fatty acids shown to benefit cardiovascular health.

Specific products with biotech traits marketed by Monsanto and/or licensed to other companies include glyphosate resistant corn, soybeans, cotton, canola and sugar beets. Insect protection is provided by B_t corn hybrids (YieldGuard®) and cotton seeds (Bollgard®). In early 2003, Monsanto received final U.S. approval for corn resistant to rootworm (YieldGuard Rootworm®) and a new generation of insect resistant cotton (Bollgard II®). In a joint venture with DuPont/Pioneer Hi Bred, YieldGuard Rootworm® will be licensed worldwide and royalties shared by the two companies.[46] In

[45] Ibid, Barboza.
[46] http://www.thefarmer.com/ME2 April 15, 2003.

another joint venture with Cargill, Inc. called Renessen, Monsanto is exploring biotech varieties with attractive traits to the animal feed industry, such as higher energy content for corn. As of 2002, Monsanto held 30 percent of U.S. plant biotech patents, conducted 42 percent of biotech field tests for USDA, and received 52 percent of biotech product approvals from the government. In the research pipeline are additional biotech traits for the promotion of higher yields, more efficient utilization of nitrogen, and drought-tolerance.[47]

DuPont

With its purchase of Des Moines based Pioneer Hi-Bred, Delaware-based DuPont entered the seed business. Its 2002 sales in its agriculture and nutrition segment were $4.5 billion, about 17 percent of its overall sales of $26.7 billion. In addition to the licensing agreement with Monsanto for rootworm resistant corn, the company announced in January 2003 that it would team with the international grain company Bunge to produce soy proteins and lecithins and biotech-based soybeans to support this effort.[48] DuPont Qualicon is a genetics-based service offering testing for bacteria and pathogens such as *listeria monocyfogenes* for USDA's Food Safety Inspection Service.

The many seed offerings from Pioneer Hi-Bred include its flagship corn hybrids, as well as soybeans, wheat, rapeseed/canola, sorghum, sunflowers and alfalfa. Biotech canola, for example, is offered in a glyphosate resistant variety. Herculex® I insect resistant corn (developed in collaboration with Dow AgroSciences) is a biotech variety resistant not only to European corn borer but to black cutworm, fall army worm and southwestern corn borer. In the pipeline for marketing within the next several years is a

[47] Monsanto Company. 2002. *Annual Report*. St. Louis. Monsanto Company, 2002, p. 13.
[48] *DuPont Annual Report*, 2002, p. 9.

biotech canola resistant to seed and root crop diseases such as *Solerotina*, a corn variety with traits that allow it to survive droughts by more efficiently exploiting soil moisture, another corn plant with traits to enhance digestibility by livestock, and a soybean variety for food soy that improves the quality of soymilk.

Dow AgroSciences

Dow AgroSciences, with sales of $2.7 billion in 2002, is based in Indianapolis, Indiana, and employs approximately 6,000 people worldwide. A subsidiary of the Dow Chemical Company, headquartered in Midland, Michigan, Dow AgroSciences began in 1989 as a joint venture between Dow Agricultural Products and the Plant Sciences division of Eli Lilly and Company, resulting in Dow Elanco. After Dow aquired Lilly's share in 1997, Dow AgroSciences was created in 1998. Subsequently, Dow AgroSciences purchased Mycogen Seeds and has since purchased several Brazil seed companies, the U.S seeds division of Cargill and the Rohm and Haas agricultural chemicals business. Like the other leading firms, Dow AgroSciences has both crop protection and biotechnology investments, with an increasing emphasis on genetically modified crops.[49]

The plant biotech portion of Dow AgroSciences is based in its Plant Genetics and Biotechnology business. Its strategy is investing in biotech and distributing this technology through seed companies, with an emphasis on insect management in crops. It is also creating markets for its low saturated, low trans-fat oils and oilseeds business from canola and corn. Furthermore, it is developing plant-derived vaccines and antibodies to prevent animal and human disease from bacterial infection. Plant biotech work at Dow

[49] Dow Chemical Company. *Annual Report 2002*, p. 25.

AgroSciences is integrated with its emphasis on weed, disease, insect and urban pest management.

Illustrative of recent biotech-drive market developments in plant biotech at Dow AgroSciences is the EPA registration amendment for Herculex® I Insect Protection which as noted above was developed with Pioneer Hi-Bred International Inc. This product provides insect protection for corn against European corn borer, with additional control of western bean cutworm, and other corn pests which have moved eastward from Colorado into the Midwestern Corn Belt. This relatively new threat to corn invades late in the season, with only one worm per ear resulting in $7-8 per acre losses. Several larvae can cause 30-40 percent yield reductions.[50]

<u>BASF</u>

BASF is a leading European manufacturer of fungicides, herbicides and insecticides. In 2002, BASF acquired the crop protection business of American Home Products Corporation. After closing its Princeton, New Jersey research facility, it concentrated research in the U.S. at the Research Triangle Park in North Carolina, where it employs about 500 people. In 2002, BASF saw sales decline in the crop protection categories, reducing revenues by 9.8 percent in its agricultural products and nutrition division. Despite this, BASF intends to launch innovative crop protection active ingredients in coming years. These include eight new fungicides from 2001-2005 applicable to cereals, rice and specialty crops, four new herbicides over the same period for corn and cereals, and two new insecticides from 2001-2006 for termite control and specialty crops. A final innovation to be offered from 2001-2006 is BASF's Clearfield®

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[50] Colorado State University estimates, quoted in Dow AgroSciences. Herculex® I Feature Story, "Only Herculex® I Protects Corn Against Western Bean Cutworm." http://www.dowagro.corn/herculex/story.htm.

Production System, an integrated crop protection program for wheat, rice, sunflowers, rapeseed/canola and corn.[51]

In the plant biotech sector, BASF has invested in biotech R&D since 1999, establishing in that year the BASF Plant Science subsidiary, which coordinates research at seven sites in Europe and North America. In 2002, BASF decided to invest about 700 million Euros in plant biotechnology over 10 years.[52] More efficient agriculture, better nutrition and plants as "green factories" are the goals of BASF plant biotech research. For example, the company aims to develop plants that are less sensitive to droughts, or that contain higher levels of vitamins or Omega-3 fatty acids to prevent cardiovascular disease.

Smaller Plant Biotech Companies

Despite the prevalence of the large biotech companies, there are many examples of smaller companies that have found niche markets in the industry. Because a study of this length cannot hope to survey the entire industry, we instead provide a few illustrative examples.

<u>Mendel Biotechnology</u>

Mendel, headquartered in Hayward, California, was founded in 1997 to develop a class of genes called transcription factors, which control the degree to which each gene in a cell is activated. For example, the 27,000 genes in the plant *Arabidopsis* genome are controlled by 1,800 transcription factors. Some of these factors control the ability of the plant to withstand freezing and drought or to use nitrogen more efficiently. The company has filed a large number of patents describing inventions based on these factors. An

[51] BASF. *Annual Report 2002*, pp. 36-37.
[52] Ibid, p. 39.

example is WeatherGard® genes to resist drought, freezing and high saline soils, which are now being licensed. The value of these genes is potentially huge; the company notes that a 1 percent increase in grain production due to drought or frost tolerance is worth from $3-4 billion per year.

In addition to these advances, Mendel is working to improve production of plant-made pharmaceuticals with funds from the Small Business Innovative Research (SBIR) arm of the National Cancer Institute. This work focuses on the production of Taxol®, an anticancer agent derived through biotech from plants other than its natural source in yew trees. Mendel, with cumulative revenue of $24 million in 2002, announced in 2001 a five year, $20 million partnership with Monsanto. As of late 2002, it had 61 full-time employees.[53]

Arcadia Biosciences

Arcadia, headquartered in Phoenix, Arizona but with facilities at the University of California-Davis, develops plant biotech solutions to environmental problems. Its core technologies focus on plant stress, nutrient use, crop protection and harvest quality. These are reflected in biotech plant traits which Arcadia is developing including salt tolerance and improved nutrient use efficiency. Its salt tolerant plants, including canola, tomatoes and alfalfa, can grow in soils with salt levels equal to one-third the salinity of seawater. It has also developed transgenic plants that produce high yields using as much as 50 percent less nitrogen fertilizer. Arcadia estimates that such reductions could save farmers up to $12 billion in fertilizer costs per year,[54] and significantly reduce nitrogen loading in rivers and streams, which have been shown to cause the hypoxic as "dead

[53] Mendel Biotechnology. *2002 Annual Report*. http://www.mendelbio.com. See also Sharon Stella. "New biotech lab crops up." *The Davis Enterprise*. http://www.davisenterprise.com/articles2003
[54] Arcadia Biosciences. 2002. http://www.arcadiabio.com

zone" in the Gulf of Mexico. A third biotechnology is a castor oil plant free of ricin, a highly toxic protein with no known antidote and a potential weapon of bioterrorism. Worldwide demand for castor oil is $500 million annually.

Shoffner Farm Research

Shoffner Farm Research, located in the Mississippi Delta region in Newport, Arkansas, was founded in 1987 to provide research to the agricultural chemical and seed industry. While not exclusively devoted to biotech, it is conducting field trials in a number of biotech applications and maintains 1,000 acres of irrigated river delta in Northwestern Arkansas. In addition to rice, it has testing systems for corn, soybeans and cotton, as well as peaches, pecans, peanuts, turf grass, vegetables and forages. Working on a contract basis with a small staff of plant physiologists, weed scientists, research technicians and crop scientists, the company has focused, among other things on feeding studies and experimental permit trials.

The Public Sector

Plant biotech research rests on a wider platform of genomics, which is the latest episode in a tradition of modern plant breeding going back over a century. Throughout this evolution, not only private but public sector investments have been key. To gain perspective on the slow accumulation of plant breeding knowledge (both public and private) that has brought us to this point, it is only necessary to consider the pedigree of a single (non-biotech) wheat variety marketed by Pioneer Hi-Bred, Pioneer 2375 (Figure 5). As its pedigree makes clear, Pioneer 2375 contained germplasm from grandparents, great-grandparents and so on, traceable (but still not ending) back to Turkey Red varieties in 1873. The nature of the process means that research and development by both private and public plant scientists has accumulated over more than a century. It is the *accretion* of this knowledge, and not just its leading edges, that define the R&D mission in plant genetics, now including plant biotech. Hence, the loss of a particular variety (or of the details of the breeding histories that brought it about) would mean the loss of part of this stock of knowledge.[55] Estimates of the stock of plant-breeding knowledge in the United States and its value, compared with the value of agricultural output, show that from 1850 to 1995 (allowing for the gradual depreciation of past research) the ratio of value was 10:1.[56] In other words, in 1995, for every $100 of agricultural output there was a $1,000 stock of research knowledge to draw upon.

The role of the public sector in plant science research relates specifically to this stock of knowledge, which is held in large part in the public domain by universities, experiment stations and federal research facilities. It also relates to the fact that agricultural research investments often are slower to mature than is acceptable in the commercial, earnings-oriented private sector. Figure 6 shows the typical payout for agricultural research in its R&D phase (often a period of 10 years), and the much longer adoption process, which may take up to 20 years.[57] With these long lags, the public sector is often the only party willing and able to wait for these payoffs to accrue.[58] Despite this long process, the rates of return to these investments are impressive by any standards. In a study comparing 2,000 estimates of rates of return to agricultural research from 292 studies since 1958, the average annual rate of return was found to be

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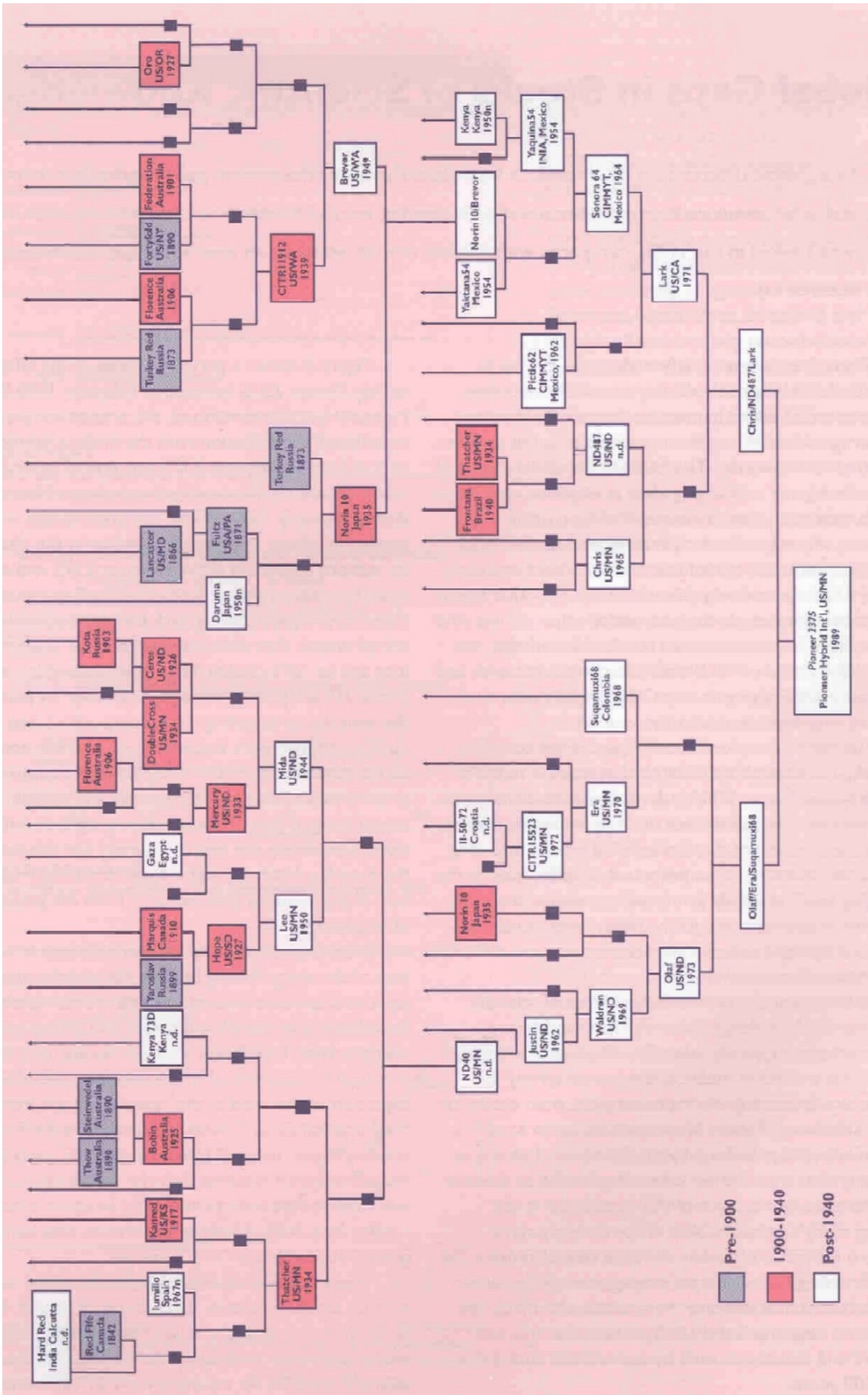
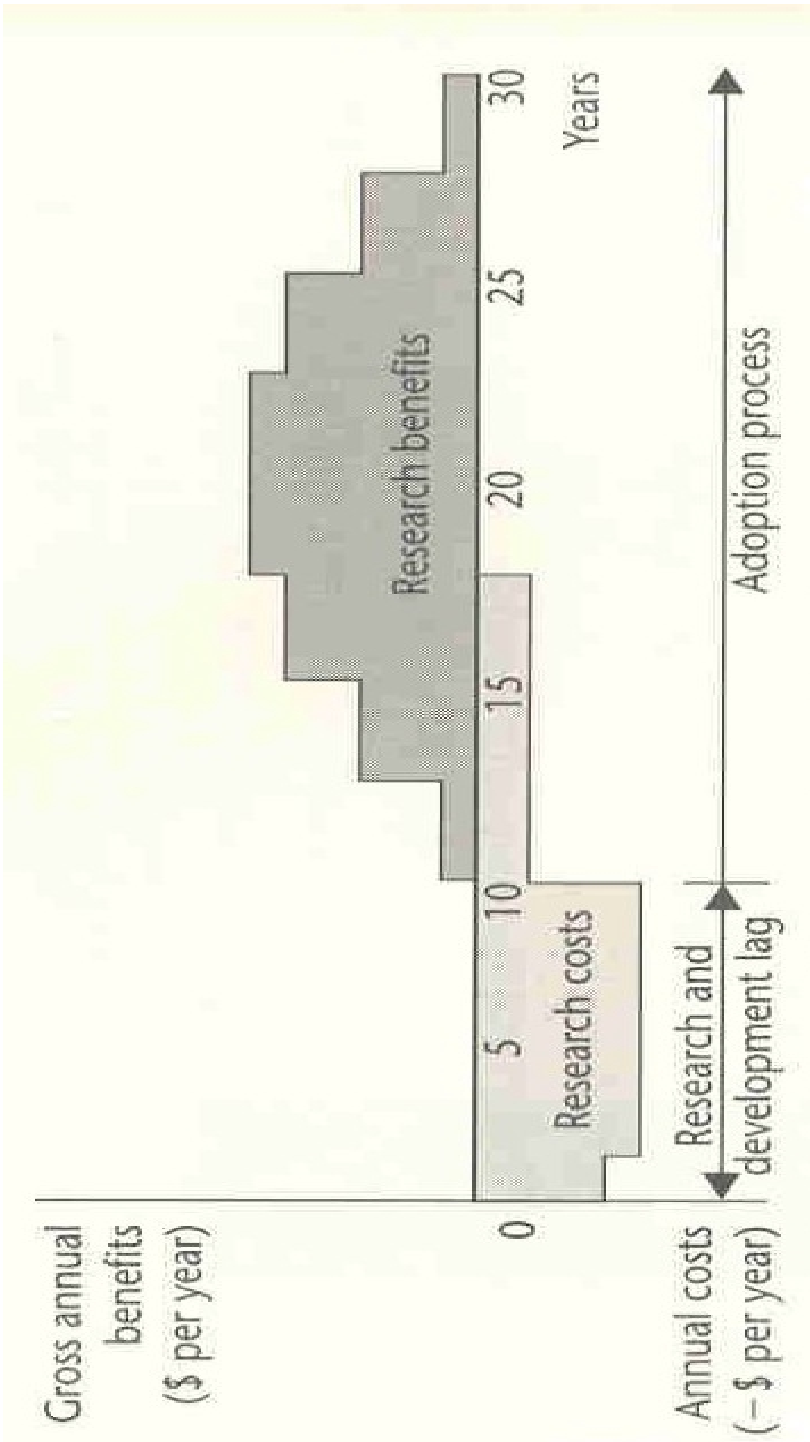
[55] C.F. Runge, B. Senauer, P.G. Pardey and M.W. Rosegrant. *Ending Hunger in Our Lifetime: Food Security and Globalization*. Johns Hopkins University Press, 2003, pp. 86-88.
[56] P.G. Pardey and N.M. Beintema. *Slow Magic: Agricultural R&D a Century After Mendel*. Food Policy Report. Washington, D.C., International Food Policy Research Institute, 2001.
[57] J.M. Alston, M.C. Marra, P.G. Pardey and T.J. Wyatt. *A Meta Analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem?* Research Report No. 113. Washington, D.C., International Food Policy Research Institute, 2000.
[58] USDA, ERS. "Public and Private Agricultural Research," in *Economic Issues in Agricultural Biotechnology*, AIB-762. Washington, D.C., February, 2001, pp. 36-46.

Figure 5. Pedigree of Pioneer 2375 Wheat



Source: P.G. Pardey and N.M. Beintema. *Slow Magic: Agricultural R&D a Century After Mendel*. Food Policy Report. Washington, D.C., International Food Policy Research Institute, 2001.

Figure 6. Flows of Research and Development Benefits and Costs Over Time



Source: Alston, et al., 2000.

an extraordinary 81 percent (77 percent after adjusting for inflation). U.S. government bonds, by comparison, yielded less than 5 percent in 2002. In several of the commodities treated in this study, the same work estimates a mean annual rate of return of 134.5 percent for research on corn, 50.4 percent for wheat, and 75 percent for rice.[59]

Biotech plants are the latest phase in this research effort, and are linked in key ways not only to genomics, but to the emergence of a new field of interdisciplinary agronomic research based on environmental impacts known as "precision agriculture." In the past twenty years, growing knowledge of the relationship between plant growth and soil and water resources has given rise to highly targeted seeds based on specific agro-climatic conditions. This targeting (by latitude, soil type, nitrogen levels, etc.) is known as precision agriculture because information in the field is matched with seeds, fertilizer and crop protection chemicals, using all of these inputs more efficiently. Biotech plant varieties fit well with these methods because they can be more precisely targeted to resist certain herbicides or pests. Glyphosate resistant soybeans, for example, work well with conservation tillage systems to reduce erosion and improve soil health and quality while raising yields.[60] Similarly, B_t corn and cotton reduce the need for heavy applications of some insecticides, providing solutions to pest infestations that pose fewer risks to water quality or human health.[61] A third example are biotech plants with high levels of salt tolerance. Not only do they allow plants to grow in what were previously sterile soils, they actually remediate these soils by extracting salt.[62]

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[59] Op cit., note 57.
[60] Op cit., note 25. Runge and Fawcett.
[61] L.P. Gianessi, C.S. Silvers, S. Sanuka and J.E. Carpenter. *Plant Biotechnology: Current and Potential Impact for Improving Pest Management in U.S. Agriculture*. National Center for Food and Agricultural Policy. Washington, D.C., 2002.
[62] M. Apse, G. Aharom, W. Snedden and E. Blumwald. "Salt Tolerance Conferred by Overexpression of a Vacuolar Antiport in Arabidopsis." *Science* 288:543 (August 1999): 1256.

The role of the U.S. public sector in these and forthcoming biotech innovations should not be discounted, despite substantial shifts in recent years from public agricultural research funding toward the private sector. USDA data showing federal and state-level expenditures for public agricultural research from 1960 to 1996 indicate the trend toward more private sector involvement (Table 16). In 1960, private R&D was 90 percent of public, and actually fell to 86 percent by 1970. During the 1970s, however, private R&D rose to outstrip public spending, so that by 1980 it exceeded it by 8 percent. In 1990, the excess of private over public R&D was 17 percent, and by 1996 it was 32 percent higher.[63]

Table 16. Public vs. Private U.S. Agricultural Research and Development Spending in Nominal Dollars, Selected Years

	Total U.S. Public Agricultural Research[1/] (millions)	Total U.S. Private Agricultural Research[2/] (millions)	Private / Public (%)
1960	227	206	90
1970	535	464	86
1980	1,341	1,453	108
1990	2,528	2,971	117
1996	2,979	3,961	132
2000	3,540	--	--

[1/2/] Source: Philip Pardey, University of Minnesota, 1996. Compiled from unpublished USDA data.

Part of the explanation for these trends was the growing investment made by private companies in plant science, combined with budget pressures at the state and federal level, which reduced public funding. Table 17 shows that in the private sector, the growth of R&D by category occurred most dramatically from 1960-1996 in plant

[63] See J.M. Alston, P.G. Pardey and V.H. Smith. *Paying for Agricultural Productivity*. Johns Hopkins University Press, Baltimore, 1998.

breeding, which rose from a mere 6 million nominal U.S. dollars in 1960 to 526 million dollars in 1996 – an annual growth rate of 13.7 percent. From 1990 to 1996, the first year of commercial biotech crops, the annual growth rate in private plant breeding R&D was 9.4 percent, greater than any other category of agricultural R&D.

Public sector research institutions, at least in agriculture, have operated largely through connections from the USDA to the land grant Universities and their Experiment Stations, although private research universities are also actively engaged in many areas with direct applications to plant biotechnology. The Land-Grant system, originally dating to acts of Congress in the mid-19th century, has worked remarkably well on a state-by-state basis to discover and supply both basic and applied agricultural research and technology.[64] The research institutions involved in plant biotech from 1985-2003, according to USDA permit registration data, are listed in Table 18. Not all of these public institutions are land grants, although the majority are. Exceptions include the University of Chicago, Duke, and Stanford, for example. The land grants include both state and regionally focused institutions, such as SUNY/Albany, and some of the life-science powerhouses such as Cornell University, the University of California and the University of Wisconsin. These premier institutions combine basic and applied life sciences research, as well as world-class medical facilities, spanning plant and other forms of biotechnology.

When the number of institutions applying for biotechnology field trials permits is compared over time for private versus public institutions, the picture that emerges

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[64] Cochrane, W.W. *The Development of American Agriculture: A Historical Analysis.* Second Edition. University of Minnesota Press, Minneapolis, MN. 1993.

Table 17. Private Sector Agricultural Research and Development Spending by Category, 1960-1996.

Year	Input Oriented: Agricultural Chemicals	Machinery	Vet. & Pharm.	Plant Breeding	Post-Harvest & Food Processing	Total: Current	Real	
	(millions U.S. dollars)						(millions 1993 U.S. dollars)	(millions 1999 U.S. dollars)
1960	27	75	6	6	92	206	1,252	1,520
1965	64	96	23	9	131	323	1,592	1,933
1970	98	89	45	26	206	464	1,693	2,057
1975	169	138	79	50	273	709	1,958	2,379
1980	395	363	111	97	488	1,453	3,018	3,666
1985	683	304	159	179	842	2,167	3,151	3,828
1990	1,127	360	245	314	925	2,971	3,275	3,978
1995	1,480	447	316	496	1,146	3,885	3,639	4,420
1996	1,459	506	324	526	1,147	3,961	3,613	4,388
Annual growth rates								
				(percentages)				
1960-1996	12.4	6.1	12.7	13.7	7.5	8.7	3.1	3.1
1960-1969	14.3	3.5	23.3	16.7	8.1	8.4	3.2	3.2
1970-1979	14.3	12.2	11.3	14.2	8.9	11.2	5.1	5.1
1980-1989	12.7	1.4	9.9	13.4	8.6	8.8	1.9	1.9
1990-1996	6.7	7.0	4.9	9.4	3.3	5.4	1.9	1.9

[a] Deflated with a revised and updated version of the U.S. agricultural R&D deflator from Pardey, Craig, and Hallaway, 1989.
Source: Philip Pardey, University of Minnesota, 1998. Compiled from unpublished USDA data.

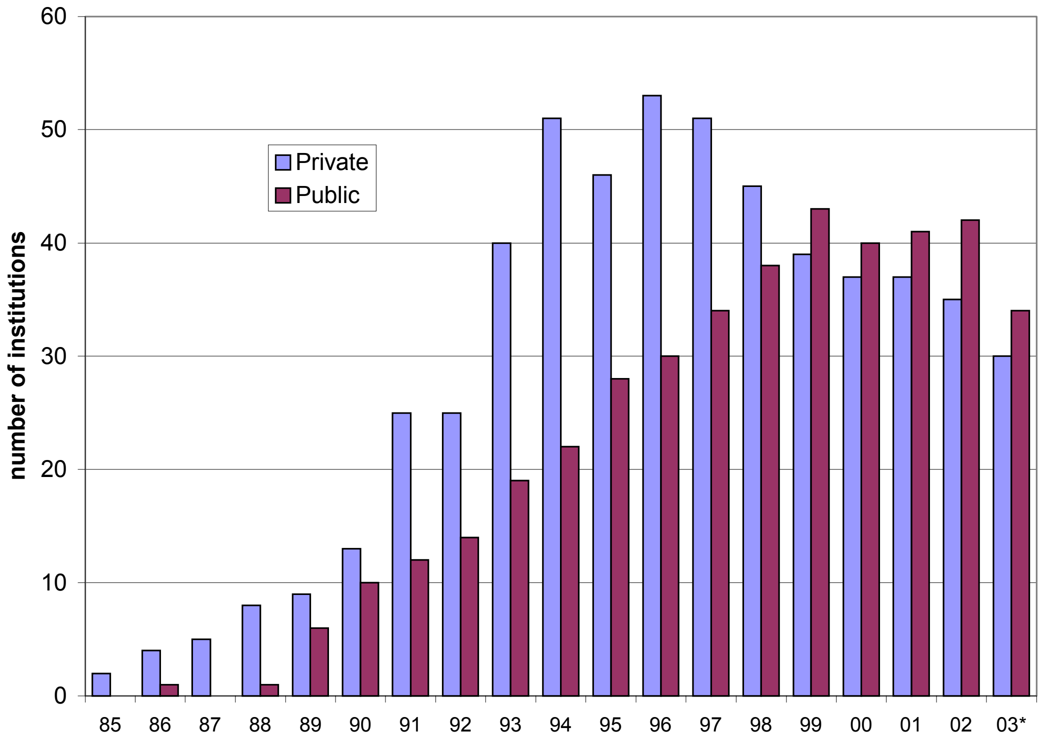
reinforces an apparent shift of activity from the public to the private sector (Figure 7). Careful interpretation suggests that private sector activity certainly expanded rapidly in the early 1990s compared with slow but steady growth in public sector activity; however, the apparent decline in private sector activity after 1996 is more likely due to rapid consolidation of many firms in the industry, leading to fewer private company filings.

Table 18. Public Institutions Filing for Plant Biotech Field Testing Permits, 1985-2003

ARS	New York State U/Albany	U of Connecticut
Auburn U	New York State U/Geneseo	U of Florida
Bowdoin C	Noble Foundation	U of Georgia
Boyce Thompson Institute	North Carolina Dept of Agr	U of Hawaii
Clemson U	North Carolina State U	U of Hawaii/Manoa
Cold Spring Harbor Lab	North Dakota State U	U of Idaho
Colorado State U	Ohio State U	U of Illinois
Connecticut Ag Exp Stn	Oregon State U	U of Kentucky
Cook C Rutgers U	Pennsylvania State U	U of Minnesota
Cornell U	Purdue U	U of Missouri
Duke U	Rutgers U	U of Nebraska
Fort Valley State University	Southern Illinois U	U of Nebraska/Lincoln
Hawaii Ag. Research Center	Southern Piedmont AREC	U of North Carolina
Illinois U	Stanford U	U of Rhode Island
Iowa State U	Texas A&M	U of South Carolina
Kansas State U	Texas Agricultural Exp Stn	U of Tennessee
Louisiana State U	Texas Tech U	U of Virgin Islands
Max Planck Ins Chem Ecology	Tuskegee U	U of Washington
Michigan State U	U of Arizona	U of Wisconsin
Michigan Tech U	U of California	U of Wisconsin/Madison
Mississippi State U	U of California/Berkeley	Virginia Tech
Montana State U	U of California/Davis	Washington State U
New Mexico State U	U of California/Kearney	Washington U
New York State Exp Stn	U of California/San Diego	West Virginia U
New York State U	U of Chicago	Wright State U

Source: USDA. APHIS (see Appendix I)

Figure 7. Number of Private and Public Institutions Granted APHIS Field Test Permits, 1985-2003



* Data for 2003 only includes the first 8 months. See Appendix 1

Knitting together the system of land grant institutions are various branches of the USDA. Grouped under the Research, Education and Economics mission of the Department of Agriculture, these include the Agricultural Research Service (ARS), the Cooperative State Research, Education and Extension Service (CSREES), the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS). Of these, CSREES is the main federal partner with land grant and other universities carrying out research, teaching and extension. No separate budget categories are identified as "plant biotech," but ARS has a $314 million line item for plant sciences, and ERS has a small $1.1 million "genomics initiative" as part of its overall budget.[65] Table 19 shows that USDA expenditures for the four programs in 2002 was $2.3 billion, and is expected to remain at roughly this level for 2003 and 2004 (assuming looming budget deficits do not affect it). The CSREES budget accounted for about $1.1 billion of this total, or nearly half.

Figure 8 shows the changes in federal academic research obligations by field from 1990-99, according to National Science Foundation data. The life sciences, where much of the activity is biotech-related (including medical and pharmaceutical research) outstripped every other research category. They exceeded the next largest category, computer sciences, by more than 10 times, and were one of only three research categories whose share moved upward. The loss in share experienced by six other research categories (physical sciences, engineering, environmental sciences, mathematics, psychology and social sciences) can nearly all be accounted for by the gains in life sciences research. Between 1996 and 2002, nationwide NSF funding increased 70 percent in the biological sciences sector.[66]

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[65] USDA, "Research, Education and Economics." http://www.usda.gov/agency/obpa/Budget-Summary/2004.
[66] Ronald A. Wirtz. "Biotech by any other measure." *Fedgazette*. Federal Reserve Bank of Minneapolis, September, 2003.

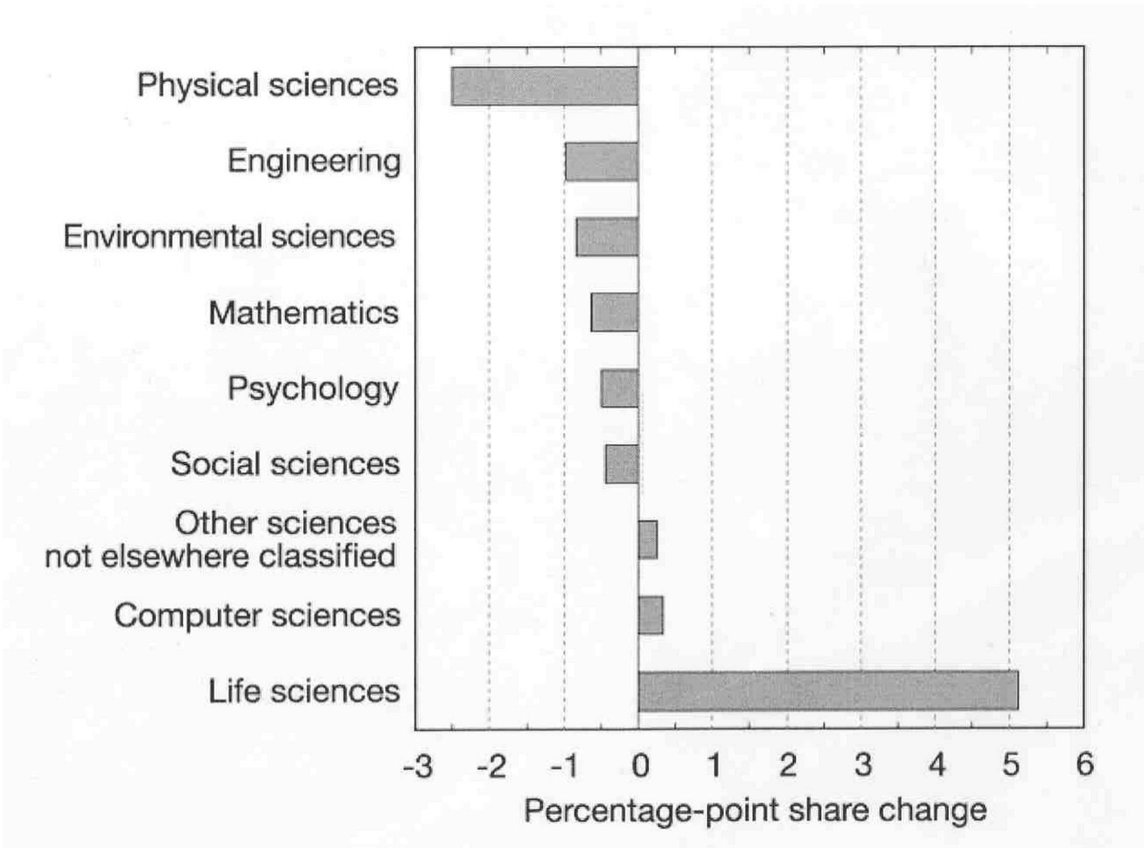
Table 19. Research, Education, and Economics Program Level (dollars in millions)

Program	2002 Actual	2003 Estimate	2004 Budget
Agricultural Research Service:			
Research and Information	$970	$958	$987
Buildings and Facilities	51	15	24
Homeland Security Supplemental:			
Research and Information	9	23	0
Buildings and Facilities	0	50	0
Trust Funds	20	20	23
Total, Agricultural Research Service	1,050	1,066	1,034
Cooperative State Research, Education, and Extension Service:			
Research and Education Activities	572	552	514
Extension Activities	440	418	422
Integrated Activities	43	45	63
Native American Endowment Fund and Interest	9	9	11
Outreach for Socially Disadvantaged Farmers	3	3	4
Community Food Projects	5	5	5
Initiative for Future Agriculture and Food Systems	a/	a/	a/
Total, Cooperative State Research, Education, and Extension Service	1,072	1,032	1,019
Economic Research Service	67	73	77
National Agricultural Statistics Service	114	141	136
Total, REE	$2,303	$2,312	$2,266

a/ Mandatory funding for this program is blocked.

Source: USDA

Figure 8. Changes in Share of Federal Academic Research Obligations, by Field: 1990-99



Source: National Science Foundation

Ongoing Commercial Activity and Plant Biotech R&D in the Pipeline

In order to provide a more detailed portrait of plant biotech activity by company and institution, we have divided our discussion into: (1) a summary of those traits and varieties of biotech crops that have already been approved for commercial sale (not all of which are on the market); and (2) a detailed assessment of traits which are in field trials. In effect, this allows us to summarize those biotech varieties already approved or present in the marketplace, and to look forward to the products which the research pipeline may produce in the next five to ten years. In the first case, we rely on summaries of USDA, FDA and EPA information to construct tables of ongoing commercial activity. In the second case, we rely on data from the USDA's Agricultural Plant Health Inspection Service (APHIS). APHIS is the agency responsible for regulating the field testing of transgenic plants and micro-organisms under the U.S. Federal Plant Protection Act (see Appendix I).

Ongoing Commercial Activity

In order to capture ongoing commercial activity, we developed tables, by commodity, indicating the companies and the specific varieties approved for human consumption and feed use, based on consolidated USDA, FDA and EPA data. These data were compiled by a Canadian information clearing house, AgBios.[67] As suggested above, six major companies lead commercial activity in the five crops that have or have had products commercially available (corn, soybeans, cotton, rapeseed/canola and potatoes). Biotech potatoes, rice, and sugar beets have approvals but the approved varieties are not currently being marketed. No approvals have occurred for wheat. Varieties are listed by company, beginning with the most recent approvals, and moving backward in time.

<u>Corn</u>

Corn approvals are shown by company and trade name if it exists, categorized by traits (Table 20). These traits are herbicide tolerance (HT), insect resistance (IR), stacked varieties with both traits (HT/IR), and any other agronomic or product quality traits. Finally, the year approval was received is listed. Monsanto accounts for eight varieties if two for DeKalb are included. Aventis (now Bayer CropScience) accounts for four.

[67] www.agbios.com

Syngenta accounts for two. DuPont/Pioneer Hi-Bred accounts for two and Mycogen (now Dow AgroScience) together with Pioneer for one more.

Soybeans

Soybean approvals are shown in Table 21, with the same trait categories as for corn. Three companies are represented. Aventis (Bayer CropScience) has a herbicide tolerant variety. DuPont/Pioneer-Hi Bred has a soybean variety – Optimum – which expresses high levels of oleic acid. Monsanto has its leading herbicide tolerant Roundup-Ready® variety.

Cotton

Cotton varieties approved since 1994 are shown in the same manner as corn and soybeans (Table 22). Monsanto accounted for three of these – for its glyphosate tolerant variety and its two Bollgard® varieties. Calgene (now Monsanto) accounted for two more, and Bayer CropScience and DuPont/Pioneer Hi-Bred for one each.

Rapeseed/Canola

Approvals for rapeseed/canola (Table 23) are dominated by Bayer CropScience and Aventis, which it acquired in 2002. In addition to herbicide tolerant rapeseed varieties, these also include traits which restore fertility for production of hybrid seed. Monsanto has three approved varieties, including one from Calgene received in 1994.

Potatoes

Although they are no longer on the commercial market, Monsanto received four separate approvals for various NewLeaf varieties, including Russet Burbank NewLeaf Plus, NewLeaf Y, Atlantic and Superior NewLeaf and Russet Burbank NewLeaf for the original set of lines (Table 24).

Rice

The only rice variety approved is from Aventis CropScience (now Bayer CropScience) for an herbicide resistant variety (Table 25).

Sugar beets

In sugar beets (Table 26) Novartis (later Syngenta) and Monsanto have a glyphosate tolerant sugar beet approval. Aventis CropScience (Bayer CropScience) has approval for varieties tolerant of other herbicides (Table 26).

Table 20. Corn (*Zea mays* L.) Production approvals of varieties for human consumption (wet mill or dry mill or seed oil), and meal and silage for livestock feed.

	Company	Trade name	HT[1/]	IR[2/]	HT/IR[3/]	Other[4/]	Approval[*]
1.	Monsanto	no trade name		X			2001
2.	Mycogen	Herculex			X		2001
3.	Aventis	InVigor	X			X	2000
4.	Monsanto	Roundup Ready	X				2000
5.	Pioneer	no trade name	X			X	1998
6.	Dekalb	Bt Xtra			X		1997
7.	Monsanto	Roundup Ready	X				1997
8.	Pioneer	no trade name	X		X		1997
9.	Dekalb	Line B16	X				1996
10.	Syngenta	no trade name			X		1996
11.	Monsanto	no trade name		X			1996
12.	Monsanto	Yieldgard			X		1996
13.	Monsanto	Yieldgard		X			1996
14.	Aventis	InVigor	X			X	1996
15.	Syngenta	NaturGard KnockOut			X		1995
16.	Aventis	StarLink			X		1995*
17.	Aventis	Liberty-Link	X				1995

[1/] herbicide tolerance; [2/] insect resistance; [3/] both; [4/] other; [*] approval received

1. Monsanto Co. - no trade name - (MON863) resistance to corn root worm (Coleopteran). U.S. approval for feed and/or food use 2001.

2. Mycogen (Pioneer) - Herculex I - (line TC1507) contains insecticidal protein derived from Bacillus thuringiensis to confer resistance to European corn borer, and phosphinothricin (PPT) herbicide tolerance, specifically glufosinate ammonium (Basta, Rely, Liberty, Finale). U.S. approval for feed and/or food use 2001.

3. Aventis CropScience - InVigor - (MS6) glufosinate ammonium herbicide tolerant (Basta, Rely, Liberty, Finale), and fertility restored. Herbicide tolerance is used as a selectable marker for male sterile plants in the production of hybrid seeds. U.S. approval for feed and/or food use 2000.

4. Monsanto Co. - Roundup Ready - (NK603) glyphosate herbicide tolerance. U.S. approval for feed and/or food use 2000.

5. Pioneer Hi-Bred International Inc. - no trade name - (lines 676, 678, and 680) glufosinate ammonium herbicide tolerance (Basta, Rely, Liberty, Finale), and male sterility for use in hybrid seed production. U.S approval for feed and/or food use 1998.

6. Dekalb Genetics Corp. - Bt Xtra - (line DBT418) contains insecticidal protein derived from Bacillus thuringiensis to confer resistance to European corn borer, and phosphinothricin (PPT) herbicide tolerance, specifically glufosinate ammonium (Basta, Rely, Liberty, Finale). U.S. approval for feed and/or food use 1997.

7. Monsanto Co. - Roundup Ready - (line GA21) confers glyphosate herbicide tolerance. U.S. approval for feed and/or food use 1997.

8. Dekalb Genetics Corp. - no trade name - (line B16) is glufosinate ammonium herbicide tolerant (Basta, Rely, Liberty, Finale). U.S approval for feed and/or food use 1996.

9. Syngenta Seeds, Inc. - no trade name - (line Bt 11) contains insecticidal protein derived from Bacillus thuringiensis to confer resistance to European corn borer, and tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (Basta, Rely, Liberty, Finale). U.S. approval for feed and/or food use 1996.

10. Monsanto Co. - no trade name - (MON80100) resistance to European corn borer. U.S. approval for feed and/or food use 1996.

11. Pioneer Hi-Bred International Inc. - no trade name - (MON809) glyphosate herbicide tolerance and resistance to European corn borer. U.S. approval for feed and/or food use 1996.

12. Monsanto Co. - Yieldgard - (MON802) glyphosate herbicide tolerance and resistance to European corn borer. U.S. approval for feed and/or food use 1996.

13. Monsanto Co. - Yieldgard - (MON810) resistance to European corn borer. U.S. approval for feed and/or food use 1996.

14. Aventis CropScience - InVigor - (MS3) glufosinate ammonium herbicide tolerant (Basta, Rely, Liberty, Finale), and fertility restored. Herbicide tolerance is used as a selectable marker for male sterile plants in the production of hybrid seeds. U.S. approval for feed and/or food use 1996.

15. Syngenta Seeds, Inc. - NaturGard KnockOut - (line CG 00526) contains insecticidal protein derived from Bacillus thuringiensis to confer resistance to European corn borer, and tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (Basta, Rely, Liberty, Finale). U.S. approval for feed and/or food use 1995.

16. Aventis CropScience - StarLink - (line CBH-351) contains insecticidal protein derived from Bacillus thuringiensis to confer resistance to European corn borer, and tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (Basta, Rely, Liberty, Finale). U.S. approval for feed use 1995.

17. Aventis CropScience - LibertyLink - (lines T14 and T25) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (Basta, Rely, Liberty, Finale). U.S. approval for feed and/or food use 1995.

Source: AgBios

Table 21. Soybeans (*Glycine max* L.) Production approvals of varieties for human consumption as oil, protein fraction, and dietary fiber, and/or animal feed as defatted toasted meal and flakes.

Company	Trade name	HT[1/]	IR[2/]	HT/IR[3/]	Other[4/]	Approval
1. Aventis	no trade name	X				1998
2. Dupont	Optimum				X	1997
3. Monsanto	Roundup Ready	X				1994

[1/] herbicide tolerance; [2/] insect resistance; [3/] both; [4/] other

1. Aventis CropScience - no tradename - (lines A2704-12, A2704-21, A5547-35, A5547-127, GU262, W62, W98) confers phosphinothricin (PPT) herbicide tolerance, specifically glufosinate ammonium (Basta, Ignite, Rely, Liberty, Harvest, and Finale). U.S. approval for feed and/or food use 1998.

2. Dupont Canada - Optimum - (lines G94-1, G94-19, G168) modified seed fatty acid content to express high levels of oleic acid. U.S. approval for feed and/or food use 1997.

3. Monsanto Co. - Roundup Ready - confers tolerance to glyphosate herbicide (Roundup). U.S. approval for feed and/or food use 1994.

Source: AgBios

Table 22. Cotton (*Gossypium hirsutum* L.) Production approvals of varieties of cotton fiber, cottonseed and cottonseed meal for livestock feed, and/or cottonseed oil for human consumption.

Company	Trade name	HT[1/]	IR[2/]	HT/IR[3/]	Other[4/]	Approval
1. Bayer	no trade name	X				2003
2. Monsanto	Bollgard II		X			2002*
3. Calgene	no trade name			X		1998
4. Dupont	no trade name			X		1998
5. Monsanto	Roundup Ready	X				1995
6. Monsanto	Bollgard		X			1995
7. Calgene	no trade name	X				1994

[1/] herbicide tolerance; [2/] insect resistance; [3/] both; [4/] other

1. Bayer CropsScience - no trade name - (line LLCotton25) confers herbicide tolerance to phosphinothricin (PPT). U. S. environmental release approval 2003.

2. Monsanto Co. - Bollgard II - (line DP50B) expresses insecticidal proteins derived from soil bacterium Bacillus thuringiensis to provide crop resistance to lepidopteran pests such as cotton bollworm, tobacco budworm, pink bollworm, and armyworm. U.S. approval for food use 2002.

3. Calgene Inc. - no trade name - (lines 31807 and 31808) confers resistance to lepidopteran insects (caterpillar pests) derived from transformation of soil bacterium Bacillus thuringiensis, and herbicide tolerance, principally bromoxynil (Buctril). U.S. approval for feed and/or food use 1998.

4. DuPont Canada - no trade name - (line 19-51a) confers sulfonylurea herbicide tolerance, specifically triasulfuron and metsulfuron-methyl. U.S. approval for feed and/or food use 1996.

5. Monsanto Co. - Roundup Ready - (lines 1445 and 1698) resistant to the non-selective herbicide glyphosate (Roundup). U.S. approval for feed and/or food use 1995.

6. Monsanto Co. - Bollgard - (lines 531, 757, and 1067) expresses insecticidal proteins to provide crop resistance to lepidopteran pests such as cotton bollworm, tobacco budworm, pink bollworm, and armyworm with transformation of soil bacterium Bacillus thuringiensis. U.S. approval for feed and/or food use 1995.

7. Calgene Inc. - no trade name - (line BXN) provides tolerance to herbicides in the oxynil family, principally bromoxynil (tradename Buctril). U.S. approval for feed and/or food use 1994.

Source: Ag Bios

Table 23. Rapeseed/Canola (*Brassica napus*) *P*roduction approvals of varieties for human consumption (oil), livestock feed, and industrial applications.

	Company	Trade name	HT[1/]	IR[2/]	HT/IR[3/]	Other[4/]	Approval
1.	Monsanto	Roundup Ready	X				2002
2.	Aventis	Westar OXY-235	X				1999*
3.	Bayer	no trade name	X				1998
4.	Aventis	no trade name	X			X	1996
5.	Aventis	no trade name	X			X	1996
6.	Aventis	no trade name	X			X	1996
7.	Monsanto	Westar R-R	X				1995
8.	Aventis	L-L Independence	X				1995
9.	Aventis	L-L Innovator	X				1995
10.	Calgene	no trade name				X	1994

[1/] herbicide tolerance; [2/] insect resistance; [3/] both; [4/] other

1. Monsanto Co. - Roundup Ready - (line GT200) confers glyphosate herbicide tolerance. U.S. approval for feed and/or food use 2002. (This experimental line will not be commercialized.)

2. Aventis CropScience - Westar OXY-235 - (line Oxy-235) tolerance to oxynil and bromoxynil herbicides, for broadleaf weed control. U.S. approval for food use 1999.

3. Bayer CropScience - no trade name - (line T45, synonym HCN28) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (such as Basta, Rely, Finale, Liberty). U.S. approval for food use 1998.

4. Aventis CropScience - no trade name - (lines MS1 and RF1) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (such as Liberty), and fertility restored for production of hybrid seed. In order to restore fertility in the hybrid progeny, male sterile line MS1 must be pollinated by the fertility restorer gene in line (such as) RF1. U.S. approval for feed and/or food use 1996.

5. Aventis CropScience - no trade name - (lines MS1 and RF2) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (such as Liberty), and fertility restored for production of hybrid seed. In order to restore fertility in the hybrid progeny, male sterile line MS1 must be pollinated by the fertility restorer gene in line (such as) RF2. U.S. approval for feed and/or food use 1996.

6. Aventis CropScience - no trade name - (lines MS1 and RF3) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (such as Liberty), and fertility restored for production of hybrid seed. In order to restore fertility in the hybrid progeny, male sterile line MS1 must be pollinated by the fertility restorer gene in line (such as) RF3. U.S. approval for feed and/or food use 1996.

7. Monsanto Co. - Westar Roundup Ready - (line GT73) confers glyphosate herbicide tolerance. U.S. approval for feed and/or food use 1995.

8. Aventis CropScience - Liberty-Link Independence - (line HCN10) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (such as Liberty). U.S. approval for feed and/or food use 1995.

9. Aventis CropScience - Liberty-Link Innovator - (line HCN92) tolerance to phosphinothricin (PPT) herbicide, specifically glufosinate ammonium (such as Liberty). U.S. approval for food use 1995.

10. Calgene Inc. - no trade name - (lines 23-198 and 23-18-17) modified to produce higher levels of laurate and myristic fatty acids. U.S. approval for feed and/or food use 1994.

Source: AgBios

Table 24. Potato (*Solanum tuberosum* L.) Production approvals of varieties for human consumption and livestock feed including potato process residue.

1. Monsanto Co. - Russet Burbank NewLeaf Plus - transgenic cultivars Russet Burbank lines (RBMT21-129, RBMT21-350, RBMT22-082) resistance to coleopteran Colorado potato beetle (CPB) using insecticidal protein derived from Bacillus thuringiensis, and resistant to potato leafroll luteovirus (PLRV). U.S. approval for feed and/or food use 1998. (All lines were commercialized, only RBMT21-350 continued beyond 2000)

2. Monsanto Co. - NewLeaf Y- transgenic cultivars Russet Burbank (RBMT15-101) and Shepody (SEMT15-02 and SEMT15-15) resistance to coleopteran Colorado potato beetle (CPB) using insecticidal protein derived from Bacillus thuringiensis, and resistant to ordinary strain of potato potyvirus Y (PVY-O). U.S. approval for feed and/or food use 1998. (All lines were commercialized, only SEMT15-15 continued beyond 2001)

3. Monsanto Co. - Atlantic and Superior NewLeaf - transgenic cultivars of Atlantic (ATBT04-6, -27, -30, -31, -36) and Superior (SPBT02-5) resistance to coleopteran Colorado potato beetle (CPB) using insecticidal protein derived from Bacillus thuringiensis. U.S. approval for feed and/or food use 1996. (SPBT02-5 and ATBT04-6, -30, -36 commercialized, the Atlantic lines have been withdrawn.)

4. Monsanto Co. - Russet Burbank NewLeaf - (lines BT6, BT10, BT12, BT16, BT17, BT18, BT23) resistance to coleopteran Colorado potato beetle (CPB) using insecticidal protein derived from Bacillus thuringiensis. U.S. approval for feed and/or food use 1994. (All lines have been withdrawn except BT6.)

Source: AgBios

Table 25. Rice (*Oryza sativa)* Production approvals of varieties for livestock feed, human food, and industrial uses.

1. Aventis CropScience - Liberty-Link - (lines LLRICE06 and LLRICE62) resistant to phosphinothricin herbicide, specifically glufosinate ammonium (Basta, Ignite, Rely, Liberty, Finale, RadicaleX). U.S. approval for feed and/or food use 2000.

Source: AgBios

Table 26. Sugar Beet (*Beta vulgaris)* Production approval of varieties for human consumption, fresh or processed.

1. Novartis Seeds and Monsanto Co. - InVigor - (line GTSB77) confers glyphosate herbicide tolerance (Roundup). U.S. approval for feed and/or food use 1998.

2. Aventis CropScience - no trade name - (line T120-7) confers resistant to phosphinothricin herbicide, specifically glufosinate ammonium (Basta, Ignite, Rely, Liberty, Harvest, Finale). U.S. approval for feed and/or food use 1998.

Source: AgBios

Plant Biotech R&D in the Pipeline

In order to evaluate plant biotech research in the pipeline in both the private and public sector, we examined the database maintained by the Agricultural Plant Health Inspection Service of USDA (APHIS). This database, described in detail in Appendix I, describes all public and private institutions seeking field permits for testing of biotech plant traits. Although data is available as far back as 1985, we restricted our focus to permit filings made between January, 2001 and July, 2003. We identified all private and public institutions working on some aspect of biotech traits for each of the eight crops in this study. These institutions are listed in Table 27. We organize the discussion by commodity, in the same way that we examined benefits of the technology behind the farm gate. Although four of the study commodities have no commercial biotech traits on the market (wheat, rice, sugar beets and potatoes) there is still considerable R&D activity reflected in the APHIS data, suggesting possible commercial developments in the next 5-10 years.

Corn

Without question, more research and development as measured by field tests has been devoted to biotech traits in corn than to any other crop, attracting the interest of scores of public and private institutions (Table 28). Seven main trait categories were field tested between 2001 and 2003. The first involves a long list of agronomic properties, ranging from sterility, fertility, maturation dates, germination and yield to cold and drought tolerance, stalk strength and amino acid levels. Monsanto, DuPont/Pioneer Hi-Bred, Syngenta and Dow represent the big private companies working in the area. Smaller privates include AgReliant Genetics, Biogemma, Garst and Stine Biotechnology.

In the public sector, seven land grant institutions have worked on some aspect of these traits.

A second category of traits, fungal resistance, is entirely led by large private researchers from Syngenta, Aventis/Bayer CropScience and Biogemma. The third category of trait research is herbicide tolerance, which is dominated by a variety of large and small privates including Aventis/Bayer CropScience, Monsanto, Dow, Syngenta, BASF, ExSeed Genetics and Stine Biotechnology. Two universities are also represented: the University of California-San Diego and the University of Illinois, both working on resistance to herbicides such as Liberty (phosphinothricin).

The fourth category of traits is insect resistance, which is led by the large privates Monsanto, DuPont/Pioneer Hi-Bred, Syngenta and Dow, as well as AgReliant Genetics and Biogemma. A fifth category involves marker genes, visually identifying genetic changes or coloring seeds that are transgenic, for example. This work, in contrast to other categories, is largely dominated by the public sector, with about a dozen universities – the majority land grants – working on the technology. In the private sector, Monsanto, Dow and Pioneer are also engaged in testing.

The sixth and seventh categories of traits tested from 2001-2003 involve many of the output traits and new uses, such as plant-made pharmaceuticals, which industry experts predict is the leading edge of plant biotech research. In the sixth category of product quality, the list extends from altering the starch, carbohydrate or carotenoid metabolism of corn to changing protein, amino acid or nitrogen composition. In the area of improved animal feeds, nutritional quality, lysine and methionine (amino acid feed ingredients) and seed size and weight changes have all been tested. So has phytate reduction in corn, designed to reduce the phosphorus content of animal wastes from feedlots. In the area of product quality, large private companies predominate, especially Monsanto, but also Dow, Aventis/Bayer CropScience, Syngenta and DuPont/Pioneer H-Bred. Several smaller privates are also involved, such as Abbott and Cobb, AgReliant Genetics, Biogemma and National Starch and Chemical. In the public sector, three universities are present: Iowa State, the University of Florida and Rutgers.

The final category is also largely related to output traits, such as altered coloration in corn (anthocyanin) which may also have medicinal or insecticidal properties.[68] A number of traits involve the production of pharmaceutical proteins or industrial enzymes, while still others yield new polymers for biodegradable plastics. Public sector institutions are particularly active in these areas, represented by the Universities of Arizona, Missouri, California, Wisconsin, Illinois, Iowa State and Hawaii, as well as Stanford. The private sector participants include Monsanto, Dow, Garst, and leaders in the plant-made pharmaceutical area such as Meristem Therapeutics and ProdiGene.

Soybeans

Soybean field trials from 2001 to mid-2003 may be divided into seven categories (Table 29), in which the public and private sector are about equally represented. The first involves agronomic properties such as traits which alter growth rates, increase yields or improve animal feed quality. In this category, Monsanto and Pioneer are the only applicants. The second category is fungal resistance. Here, two state universities and three privates hold permits. The third category is herbicide tolerance, extending beyond glyphosate to include a variety of other herbicides. Numerous privates are working in this area, as well as two land grant institutions. Fourth is insect resistance, with Bayer

[68] USDA, Agricultural Research Service. News release. "ARS Scientists Present Findings at Society Meeting." August 11, 2003.

CropScience and Monsanto joined by the University of Georgia. Fifth is virus resistance with trials conducted by the University of Kentucky. Sixth is marker gene work by ARS. Finally is a category with numerous output traits, including soybeans with altered proteins, oil content, amino acid differences, increases in key feed ingredients such as methionine, and reductions in phytates to lower the phosphorus content of animal wastes. In addition to Monsanto, numerous land grant universities are involved in these trials.

Cotton

Biotech cotton field trials are divided into four different categories (Table 30). First is a group of agronomic properties such as cotton seeds high in oleic acid, or with improved fiber quality. These are being tested by the federal government (ARS), the private sector (Aventis, now part of Bayer CropScience), and Texas Tech University. Second is fungal resistance under testing at the Texas Agricultural Experiment Station. Third is herbicide resistance, with further testing by Aventis, its parent Bayer CropScience, Monsanto, Dow and United Agri Products. Last is insect resistance, with trials by Aventis and Bayer CropScience, Dow, Monsanto and Syngenta. It is notable that in cotton, apart from ARS and one state university system, all other permits issued from 2001-2003 were to private sector companies, mostly the six majors.

Rapeseed/Canola

Field testing for biotech traits in rapeseed/canola is divided into six different categories (Table 31). The first is a set of agronomic properties, such as altered nitrogen metabolism, male sterility, cold tolerance and one confidential trait. These are all permits held in the private sector. The second category is fungal resistance, being pursued by Cargill. Third is herbicide tolerance, with work by Monsanto. The fourth is insect resistance, with trials at the University of Georgia. Fifth is marker gene tests at North

Carolina State and the University of Georgia. Finally, a group of output traits are being tested by three private sector companies.

Wheat

Considerable field testing of biotech wheat traits occurred between 2001 and mid-2003, focused on six different categories of these traits (Table 32). The first is a set of agronomic properties such as drought tolerance, starch content, and yield increases. These are being pursued by land grants in wheat regions. The second category is fungal resistance, of particular economic significance to wheat farmers facing persistent infections such as mildew and smut. The federal government (ARS), Syngenta and the University of Minnesota are all engaged in this testing. Third is herbicide tolerance, with tests by ARS and Monsanto. Fourth is virus resistance, with tests at the University of Idaho. Fifth is marker gene testing at Montana State. Finally, a number of output traits are in testing. These include improved wheat digestibility and better bread making characteristics, among others. A number of smaller privates, ARS, and Montana State University have all filed for one or more tests in this category.

Sugar beets

Field trials testing traits in sugar beets focus on herbicide tolerance and virus resistance (Table 33). Herbicide tolerance to glyphosate is being tested by Betaseed of Shakopee, Minnesota, Interstate Payes Seed and Monsanto. Tolerance to a class of broad spectrum herbicides is under testing by Syngenta. Virus resistance is also under testing by Syngenta.

Rice

Field testing for rice spans seven main trait categories (Table 34). The first involves agronomic properties such as male sterility and increased yield, with several privates and two universities active in testing. The second is bacterial resistance, with two land grants engaged in testing. The third is fungal resistance, pursued only by Louisiana State University (LSU). The fourth is herbicide tolerance, with privates Aventis and Monsanto and LSU engaged in testing. Fifth is insect resistance, with Syngenta in testing. The sixth category, marker genes, is being tested by two state universities and ExSeed Genetics. A last category includes several output traits such as rice that can remediate soils of heavy metals, produce novel proteins, alter the manner in which carbohydrates are metabolized or increase starch levels. These are all traits under testing in the private sector.

Potatoes

Ongoing testing in potatoes indicates a focus on six main trait categories (Table 35). The first is bacterial resistance. Here, ARS is testing potatoes resistant to bacterial infections. The second is fungal resistance. Syngenta is the private sector leader, with several land grant institutions and ARS also engaged in field testing. The third category is insect resistance, with two land grants in testing. Fourth is virus resistance, with ARS and two land grants in the Northwest at work. Fifth is testing on marker genes, conducted by ARS, the Boyce Thompson Institute, Syngenta and two other land grants. Finally are trials on product quality output traits conducted by ARS, several privates (J.R. Simplot and Syngenta), and four land grant institutions.

Table 27. Public and Private Sector Institutions Filing for Field Testing Permits for 8 Study Crops Between January, 2001 and July, 2003

PUBLIC SECTOR INSTITUTIONS	PRIVATE SECTOR INSTITUTIONS
ARS - USDA Agricultural Research Service	Abbott and Cobb
Boyce Thompson Institute (Cornell)	AgReliant Genetics
Cold Spring Harbor Lab	Applied PhytoGenetics, Inc.
Colorado State University	Applied Phytologics
Hawaii Agriculture Research Center	Arcadia Biosciences
Iowa State University	Aventis
Kansas State University	BASF
Louisiana State University	Bayer CropScience
Michigan State University	Betaseed
Montana State University	Biogemma
North Carolina State University	Cargill
North Dakota State University	Dow
Ohio State University	Du Pont
Oregon State University	ExSeed Genetics
Pennsylvania State University	Garst
Purdue University	Goertzen Seed Research
Rutgers University	Horan Bros. Agri. Enterprises
Stanford University	Interstate
Texas Agricultural Exp Stn	Interstate Payco Seed
Texas Tech University	J. R. Simplot Company
University of Arizona	Mendel Biotechnology
University of California	Meristem Therapeutics
University of California/Berkeley	Monsanto
University of California/Davis	National Starch & Chemical
University of California/San Diego	Pioneer
University of Connecticut	ProdiGene
University of Florida	Research for Hire
University of Georgia	Shoffner Farm Research, Inc.
University of Hawaii	Stine Biotechnology
University of Idaho	Syngenta
University of Illinois	Targeted Growth Inc.
University of Kentucky	United Agri Products
University of Minnesota	Ventria Bioscience
University of Missouri	
University of Nebraska/Lincoln	
University of Wisconsin	
University of Wisconsin/Madison	
Washington State University	
Virginia Tech	

Source: USDA. APHIS (see Appendix 1).

Table 28. Private and Public Institutions Filing Field Testing Permits for Biotech Corn, 2001-2003

CORN	Institution		
Agronomic Property			
Male sterile	AgReliant Genetics	Biogemma	Garst
Male sterile	Iowa State U	Pennsylvania State U	U of Florida
Fertility altered	Monsanto	Pioneer	
Fertility altered	U of California	Iowa State U	
Altered maturing	Pioneer	U of Wisconsin	
Senescence altered	Monsanto		
Germination increased	Monsanto		
Yield increased	Dow	Monsanto	
Yield increased	Pioneer	Stine Biotechnology	
Altered morphology	Monsanto		
Development altered	Cold Spring Harbor Lab		
Endosperm DNA synthesis altered	U of Arizona		
Seed quality altered	Biogemma		
Storage protein altered	Monsanto	Rutgers U	
Environmental stress reduced	U of California		
Drought tolerant	Monsanto	Syngenta	
Cold tolerant	Monsanto		
Increased stalk strength	Pioneer		
Tryptophan level increased[1/]	Monsanto		
Fungal Resistance			
Fusarium resistant	Aventis	Syngenta	Bayer CropScience
Southern corn leaf blight resistant[2/]	Syngenta	Biogemma	
Rhizoctonia resistant[3/]	Syngenta		
Botrytis resistant[4/]	Aventis		
Herbicide Tolerance			
Phosphinothricin tolerant	Aventis	Bayer CropScience	Dow
Phosphinothricin tolerant	Monsanto	Syngenta	
Phosphinothricin tolerant	U of California/San Diego	U of Illinois	
Imidazolinone tolerant[5/]	BASF	ExSeed Genetics	
Imidazolinone tolerant[5/]	Dow	Stine Biotechnology	
Glyphosate tolerant	Aventis	Bayer CropScience	Monsanto
Isoxazole tolerant[6/]	Aventis		

Table 28 cont.

CORN	Institution		
Insect Resistance			
Coleopteran resistant	AgReliant Genetics	Biogemma	Dow
Coleopteran resistant	Monsanto	Syngenta	
Lepidopteran resistant	Monsanto	Syngenta	Dow
Lepidopteran resistant	Pioneer		
Marker Gene			
Visual marker	Dow	Monsanto	Pioneer
Visual marker	Ohio State U	Iowa State U	Stanford U
Visual marker	Rutgers U	Pennsylvania State U	U of Arizona
Visual marker	U of California	U of Connecticut	U of Illinois
Visual marker	U of Wisconsin		
Color sectors in seeds	Kansas State U	Pennsylvania State U	Purdue U
Color sectors in seeds	U of Arizona	U of Florida	
Seed color altered	Rutgers U	Stanford U	U of California
Pigment composition / metabolism altered	U of California/Berkeley	U of Arizona	
Kanamycin resistant	Monsanto		
Product Quality			
Starch metabolism altered	Abbott and Cobb	AgReliant Genetics	Biogemma
Starch metabolism altered	National Starch & Chemical	BASF	
Starch metabolism altered	U of Florida	Iowa State U	
Carbohydrate metabolism altered	Abbott and Cobb	Aventis	Monsanto
Carbohydrate metabolism altered	Iowa State U		
Protein altered	Monsanto	ProdiGene	ARS
Protein altered	Iowa State U		
Altered amino acid composition	Dow	Monsanto	
Seed composition altered	Monsanto	Syngenta	
Carotenoid metabolism altered	Monsanto		
Nitrogen metabolism altered	Monsanto		
Nutritional quality altered	Monsanto		
Animal feed quality improved	Du Pont	Pioneer	
Lysine level increased	Monsanto		
Seed size/weight increase	U of Florida		
Methionine level increased[7/]	Rutgers U		
Phytate reduced[8/]	Dow	Monsanto	

Table 28 cont.

CORN	Institution		
Other			
Gene expression altered	U of Arizona	U of California	U of Illinois
Gene expression altered	U of Missouri	U of Wisconsin	
Anthocyanin produced in seed[9/]	Stanford U	U of Arizona	U of California
Anthocyanin produced in seed[9/]	U of Missouri	U of Wisconsin	
Pharmaceutical proteins produced	Dow	Garst	Horan Bros.
Pharmaceutical proteins produced	Meristem Therapeutics	Monsanto	ProdiGene
Pharmaceutical proteins produced	Iowa State U		
Industrial enzyme produced	ProdiGene		
Novel protein produced	ProdiGene		
Increased transformation frequency	Pioneer		
Polymer produced	U of Hawaii		
Transposon inserted/movement supressed	Stanford U		
Recombinase produced	Monsanto		
Posphinothricin tolerant	Meristem Therapeutics		
Epidermal cells increased on juvenile leaves	U of Illinois		

1/ Tryptophan is an amino acid essential in human nutrition.
2/ Southern leaf blight (*Bipolaris maydis*) is a fungus most notable for an epidemic in 1970 that appeared in corn hybrids with Texas male sterile cytoplasm and caused $1 billion in crop loss.
3/ Rhizoctonia is a fungus that can cause damp-off and root rot of germinating seed and young plants.
4/ Botrytis is a fungus that causes blight or gray mold.
5/ Imidazolinone is a family of herbicides that include Imazethapyr (Pursuit and Arsenal). Also imazaquin and imazapic (Scepter and Cadre). Non-GM imidazolinone tolerant corn is available from Pioneer Hi-Bred and Zeneca Seeds.
6/ Isoxazole herbicide (common name isoxaflutole, trade name Balance) inhibits carotenoid biosynthesis.
7/ Methionine is an amino acid essential in human nutrition. (see article Rutgers)
8/ Low phytate (corn) rations reduce phosphorous secretion in livestock.
9/ Anthocyanin is a natural pigment color purple with potential applications in food processing, medicine, and crop pest control.

Source: USDA, APHIS

Table 29. Private and Public Institutions Filing Field Testing Permits for Biotech Soybeans, 2001-2003

Soybean	Institution		
Agronomic Property			
Growth rate altered	Monsanto		
Yield increased	Monsanto	Pioneer	
Animal feed quality improved	Pioneer		
Fungal Resistance			
Phytophthora resistant	Iowa State U		
Fungal susceptibility	Pioneer		
Sclerotinia resistant	Stine Biotechnology	Syngenta	U of Nebraska/Lincoln
Herbicide Tolerance			
Glyphosate tolerant	Aventis	Monsanto	Bayer CropScience
Isoxazole tolerant	Bayer CropScience		
Lepidopteran resistant	Monsanto		
Phosphinothricin tolerant	U of Illinois		
Cyanamide tolerant	U of Nebraska/Lincoln		
Dicamba tolerant	U of Nebraska/Lincoln		
2,4-D tolerant	United Agri Products		
CBI	Stine Biotechnology		
Insect Resistance			
Lepidopteran resistant	Bayer CropScience	Monsanto	U of Georgia
Virus Resistance			
BPMV resistant[1/]	U of Kentucky		
Marker Gene			
Visual marker	ARS		
Product Quality			
Protein altered	Iowa State U		
Oil profile altered	Monsanto	U of Kentucky	U of Nebraska/Lincoln
Seed composition altered	Monsanto		
Altered amino acid composition	U of Kentucky		
Methionine level increased[2/]	U of Kentucky		
Fatty acid level/metabolism altered	U of Nebraska/Lincoln		
Phytate reduced[3/]	Virginia Tech		
Oleic acid content altered in seed	U of Nebraska/Lincoln		

[1/] Bean pod mottle virus (BPMV); [2/] Methionine is a key feed ingredient currently added to feed from an external source; [3/] Phytates relate to the digestion of soybean meal as feed, lowering the phosphorus levels of animal wastes. Source: USDA, APHIS

Table 30. Private and Public Institutions Filing Field Testing Permits for Biotech Cotton, 2001-2003

Cotton	Institution				
Agronomic Property					
Oleic acid content altered in seed	ARS				
Carbohydrate metabolism altered	Aventis	Bayer CropScience	Texas Tech U		
Environmental stress reduced	Texas Tech U				
Fiber quality altered	Texas Tech U				
Fungal Resistance					
Rhizoctonia solani resistant[1/]	Texas Agricultural Exp Stn				
Herbicide Resistance					
Glyphosate tolerant	Aventis	Bayer CropScience	Monsanto		
Phosphinothricin tolerant	Aventis	Dow			
2,4-D tolerant	United Agri Products				
Insect Resistance					
Lepidopteran resistant	Aventis	Bayer CropScience	Dow	Monsanto	Syngenta

[1/] Rhizoctonia solani is a fungus that causes seed and root rot

Source: USDA, APHIS

Table 31. Private and Public Institutions Filing Field Testing Permits for Biotech Rapeseed/Canola, 2001-2003

Rapeseed/Canola	Institution	
Agronomic Property		
Nitrogen metabolism altered	Arcadia Biosciences	
Male sterile	Bayer CropScience	
Cold tolerant	Mendel Biotechnology	
CBI[1/]	Targeted Growth, Inc.	
Fungal Resistance		
Cylindrosporium resistant[2/]	Cargill	
Herbicide Tolerance		
Glyphosate tolerant	Monsanto	
Insect Resistance		
Lepidopteran resistant	U of Georgia	
Marker Gene		
Visual marker	North Carolina State U	U of Georgia
Product Quality		
Erucic acid altered	Biogemma	
Fatty acid metabolism altered	Cargill	
Oil profile altered	Monsanto	
Seed composition altered	Monsanto	

[1/] Confidential business information
[2/] Cylindrosporium is the fungus that causes light leaf spot disease

Source: USDA, APHIS

Table 32. Private and Public Institutions Filing Field Testing Permits for Biotech Wheat, 2001-2003

Wheat	Institution		
Agronomic Property			
Drought tolerant	Kansas State U		
Starch level increased	Montana State U		
Yield increased	Montana State U	U of Nebraska/Lincoln	
Fungal Resistance			
Phosphinothricin tolerant[1/]	ARS	U of Minnesota	
Powdery mildew resistant	ARS		
Smut resistant	ARS		
Fusarium resistant	Syngenta	Kansas State U	U of Nebraska/Lincoln
Herbicide Tolerance			
Phosphinothricin tolerant	ARS		
Glyphosate tolerant	Monsanto		
Virus Resistance			
BYDV resistant[2/]	U of Idaho		
WSMV resistant[3/]	U of Idaho		
Marker Gene			
Visual marker	Montana State U		
Product Quality			
Digestibility improved	Applied Phytologics	Ventria Bioscience	
Phosphinothricin tolerant[1/]	ARS		
Starch metabolism altered	Biogemma		
Storage protein altered	Goertzen Seed Research	ARS	
Improved bread making characteristics	Montana State U		

[1/] Phosphinothricin herbicide use is being investigated for increasing the susceptibility to fusarium
[2/] Barley yellow dwarf virus
[3/] Wheat streak mosaic virus

Source: USDA, APHIS

Table 33. Private and Public Institutions Filing Field Testing Permits for Biotech Sugar beets, 2001-2003

Sugar Beets	Institution		
Herbicide Tolerant			
Glyphosate tolerant	Betaseed	Interstate Payco Seed	Monsanto
Protoporphyrinogen oxidase inhibitor tolerant[1/]	Syngenta		
Virus Resistance			
BNYVV resistant[2/]	Syngenta		

[1/] Protoporphyrinogen oxidase (PPO) is a class of broad spectrum herbicides
[2/] Beet necrotic yellow vein virus transmitted by the fungus *Polymyxa betae*

Source: USDA, APHIS

Table 34. Private and Public Institutions Filing Field Testing Permits for Biotech Rice, 2001-2003

Rice	Institution		
Agronomic Property			
Male sterile	Aventis	Bayer CropScience	
Yield increased	Shoffner Farm Research, Inc.	Research for Hire	Louisiana State U Hawaii Agriculture Research Center
Bacterial Resistance			
Burkholderia glumae[1/]	Louisiana State U		
Bacterial leaf blight resistant[2/]	U of California/Davis		
Fungal Resistance			
Rhizoctonia solani resistant[3/]	Louisiana State U		
Herbicide Tolerance			
Phosphinothricin tolerant	Aventis	Louisiana State U	
Glyphosate tolerant	Monsanto		
Insect Resistance			
Lepidopteran resistant	Syngenta		
Marker Gene			
Visual marker	U of California/Davis		
Hygromycin tolerant	ExSeed Genetics	Louisiana State U	
Other			
Heavy metal bioremediation	Applied PhytoGenetics, Inc.		
Novel protein produced	Applied Phytologics		
Carbohydrate metabolism altered	Aventis		
Starch level increased	BASF		

[1/] Burkholderia glumae is a bacterium that causes panicle blight and fusarium sheath rot
[2/] Xanthomonas oryzae causes bacterial leaf blight and leaf streak
[3/] Rhizoctonia solani is a fungus that causes seed and root rot

Source: USDA, APHIS

Table 35. Private and Public Institutions Filing Field Testing Permits for Biotech Potatoes, 2001-2003

Potato	Institution			
Bacterial Resistance				
Erwinia carotovora resistant[1/]	ARS			
Fungal Resistance				
Phytophthora resistant[2/]	Syngenta	Colorado State	ARS	Michigan State
Late blight resistant	U of Minnesota			
Insect Resistance				
Coleopteran resistant	Michigan State U			
Lepidopteran resistant	Michigan State U			
Colorado potato beetle resistant	U of Idaho			
Virus Resistance				
PLRV resistant[3/]	ARS	U of Idaho		
PVY resistant[4/]	ARS	Oregon State	U of Idaho	
PVA resistant[5/]	ARS			
TRV resistant[6/]	U of Idaho			
Gene Marker				
Visual marker	ARS	Michigan State		
Kanamycin resistant	Boyce Thompson Institute	U of Idaho		
Capable of growth on defined synthetic media	Syngenta			
Product Quality				
Steroidal glycoalkaloids reduced[7/]	ARS			
Beta-carotene increased	Boyce Thompson Institute			
Storage protein altered	J. R. Simplot Co.	Washington State		
Starch level increased	Michigan State			
Carbohydrate metabolism altered	Syngenta	North Dakota State		
Bruising reduced	U of Idaho			
Ethylene metabolism altered	U of Idaho			

[1/] Erwinia carotovora is a common bacterium with a widespread host range that causes blackleg, aerial stem rot, and tuber soft rot
[2/] Phytophthora is a soil borne fungi that causes root rot
[3/] Potato leafroll virus (PLRV) is spread by aphids and causes net necrosis.
[4/] Potato virus Y (PVY) is an important virus in potatoes
[5/] Potato virus A (PVA) is a minor potato virus
[6/] TRV (tobacco rattle virus) is transmitted by nematodes and causes the disease corky ringspot (CRS).
[7/] Glycoalkaloids are an important defensive mechanism against plant pathogens but are toxic to humans.

Source: USDA, APHIS

Plant Biotech: Beyond the Farm Gate

Both public and private sector activity in plant biotechnology are creating new jobs unknown a decade ago. As a result many states have put biotech at the forefront of strategies for economic growth and development. At least 41 of the 50 states had some type of biotech initiative by 2001. Unfortunately, it is very difficult to isolate the particular contributions of agricultural biotech from medical or pharmaceutical activity.[69] Because biotech is both new and cuts across many business lines and academic disciplines, neither private accounting categories nor public sector records offer easily quantifiable estimates of spending. There is no budget category at public universities, for example, called "plant biotech." Instead, we must rely on various proxies and other indirect indicators of economic activity and job creation. Even so, these indicators are very promising.

In the private sector, we have already stated the size and contribution of plant biotech behind the farm gate, by commodity and state. All told, in the crops that have been commercialized (corn, soybeans, cotton and rapeseed/canola), this activity accounted for more than $20 billion in value in 2002, of which $7.0 billion was attributed to corn, $11.0 billion to soybeans, $2.7 billion to cotton and $115 million to rapeseed/canola. Beyond the farm gate, the sales activity of the six largest plant biotech companies has also been reported. Total agricultural sales in 2002 for Syngenta, Bayer, Monsanto, DuPont/Pioneer Hi-Bred, Dow AgroSciences and BASF were $28 billion. Because these companies also sell many non-biotech products, total sales overestimate the economic impact of plant biotech. Their R&D spending, which is heavily oriented to

[69] Ronald A. Wirtz. "Big Bang Biotech." *Fedgazette*. Federal Reserve Bank of Minneapolis. September, 2003.

plant biotech, probably provides a lower-bound estimate, equal to about $3.0 billion in 2002. In addition, there are hundreds of smaller start-up firms, venture capitalists, and financial institutions invested in plant biotech, worth billions of dollars.

In the public sector, we have described the federal spending specifically earmarked by USDA for biotech through its own agencies and the land grant institutions of the states. We also emphasized that the value of the stock of plant-breeding knowledge, as of 1995, was about 10 times that of the value of commodity production in that year. If the same ratio is applied to 2002, for the eight commodities in this study, their combined value of $50.5 billion represented a stock of knowledge worth $550 billion. Of this, only a portion was biotech-related in 1995. If the value of the eight commodities associated with biotech is treated in the same way, its total 2002 value of $20 billion represented a stock of knowledge worth $200 billion. However, there is reason to think that the growth rate of investment, the potential returns, and the share of total R&D dedicated to plant biotech will all increase over time. The trends, and the investments in this stock of knowledge, may easily exceed the 10:1 ratio in years to come.[70]

Most difficult of all is the estimation of future returns to research currently in the pipeline but not yet commercialized. The APHIS data analyzed gives us a picture of investment opportunities to come. It also suggests the growing role of research in the plant biotech sector as a creator of jobs for researchers in the life sciences. New faculty at universities, new laboratories, new testing and trials, all generate jobs. The number of biological sciences degrees, for example, rose dramatically in the 1990s. In the U.S. as a whole, the number of degrees (bachelor's, master's and Ph.D.'s) in the biological

[70] Philip Pardey, University of Minnesota. Personal communication September 24, 2003.

sciences rose from 45,000 in 1990 to 73,000 in 2000, an increase of 62 percent. And in the main, these degrees and the opportunities they create lead to good jobs, with above-average wages.[71]

In a recent analysis by the Federal Reserve Bank of Minneapolis, this biotech sector job activity (including plant-biotech) was estimated using the number of research and development firms in engineering, physical and life sciences, according to the U.S. Census Bureau. In the Minneapolis Federal Reserve District, Minnesota had 178 such firms in 2001, followed by Wisconsin with 128, Montana with 53, North Dakota with 20 and South Dakota with 17. In the five states, there were 396 such firms. About 60 percent (236) had fewer than five employees, and only 25 had more than 50. Yet employment in these firms in Minnesota and Wisconsin grew at least 50 percent from 1998 to 2002, adding 1,000 jobs each.[72]

There is also reason to believe that many estimates of biotech activity, and specific estimates of plant biotech as a subcategory, have been substantially understated, even by industry spokesmen. The Biotechnology Industry Organization (BIO), for example, identified only 64 biotech companies in the Midwest. Other studies estimating the value of the industry have included only firms in the medical and pharmaceutical side of biotech.[73] In a critical assessment, researchers at the Minnesota Department of Employment and Economic Development argue that these estimates overlook many agricultural applications. A 2003 survey of Minnesota firms involved in biotech found

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[71] Ibid. Ronald A. Wirtz. A recent report based on biotech industry surveys conducted by the U.S. Department of Commerce reinforces the finding that agricultural biotech firms "reported one of the highest levels of R&D intensity of any application area." See U.S. Department of Commerce, *A Survey of the Use of Biotechnology in U.S. Industry*. Technology Division, Bureau of Industry and Security. October 2003, p. 32.
[72] Ibid. Ronald A. Wirtz. "Biotech by any other measure."
[73] Eg. Joseph Cortright and Heike Mayer. "Signs of Life: The Growth of Biotechnology Centers in the U.S." Brookings Institution. Washington, D.C. 2002.

170 firms in scientific biotech in Minnesota alone, of which two in five were in the agricultural and industrial sectors.[74] The Wisconsin Association for Biomedical Research and Education (WABRE) in 2001 identified almost 200 Wisconsin bioscience companies, including 56 in the agricultural sector. All told, these companies employed some 21,000 workers in Wisconsin, with an additional 5,000 employed in R&D at Wisconsin universities and private laboratories. The WABRE estimated total industry activity at $5 billion, about 3 percent of gross state product.[75]

In order independently to assess the employment impacts and potential of the plant biotech sector by state, we used data from the U.S. Department of Commerce Bureau of Labor Statistics (BLS) and its Occupational and Employment Survey (OES). These data capture numerous sectors of the U.S. economy that employ skilled plant biotech workers. Since plant biotech does not fit neatly into any government employment statistics, or appear as a separate category, we examined the crop services sector (128,500 U.S. workers in 2001), the agricultural chemicals industry (46,490 in 2001), and the farm products – raw materials sector (97,180 in 2001). Although it is clear that a substantial and growing number of those employed in these sectoral categories are involved in plant biotech, these data cannot be recovered from the larger categories. Apart from these sectors, it should be noted that plant biotechnology firms also employ many of the same skilled workers as other sectors of the economy (managers, computer programmers, legal advisors, etc.). What makes plant biotech different is the reliance on life science workers, including occupations like agricultural and food scientists, microbiologists, biochemists and biophysicists. These workers

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[74] Eugene Goddard. Minnesota Department of Employment and Economic Development. Personal communication, September 23, 2003. See www.positivelyminnesota.com/biosciencesinitiative/industryissuereport.
[75] Op cit., note 69. Ronald Wirtz.

typically require at least a Bachelor's and Master's degree, and many require Ph.D.'s and other advanced training.

The BLS data also does not reflect all of the rapid and ongoing changes in job categories due to scientific and technological changes in the plant biotech industry, and is limited in its ability to capture confidential or closely held job information. For example, in the new field of bioinformatics or computational biology, workers must have genomics and advanced computer programming skills, which simply do not appear in BLS job classifications. Even so, Burrill and Company reports continue to emphasize that a limiting factor across the entire life sciences industry is the lack of trained bioinformatics workers needed to develop software to analyze huge amounts of genomics data.

In the final analysis, we focused on the BLS category *agricultural and food scientists* (AFS), nearly all of whom are involved in or affected by R&D in plant biotechnology. In 2001, the OES estimated 13,470 such scientists employed in public and private institutions in the U.S. The average salary for these workers was $52,310 a year, more than one and one-half times the U.S. average of $34,020. Government employs about 40 percent of these scientists, many at the federal level.

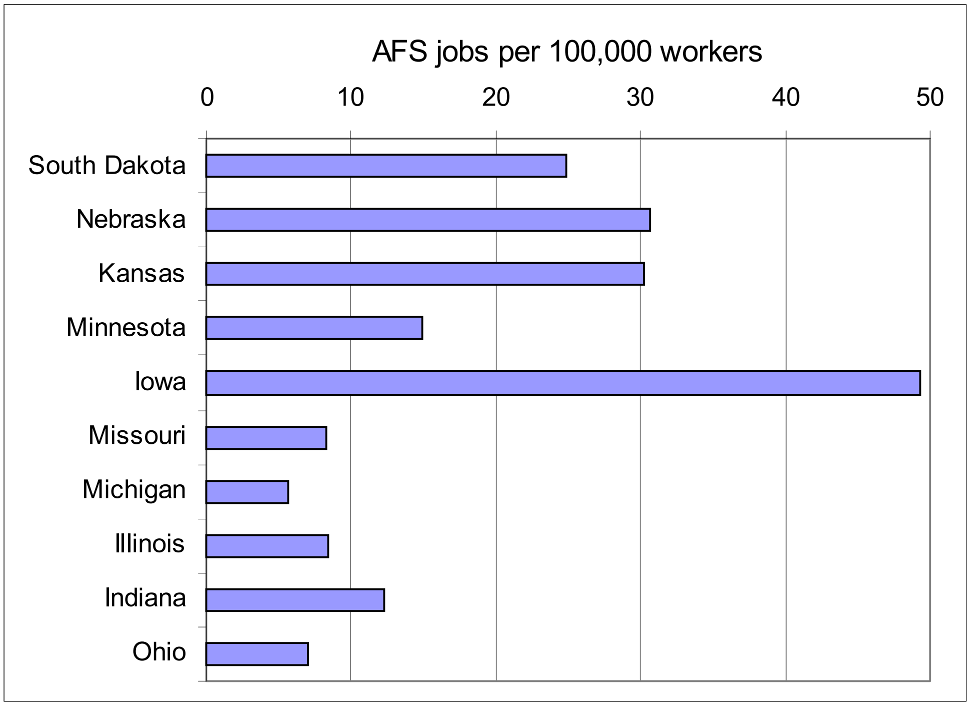
We then looked specifically at the lead producing states discussed earlier in this study, in which biotech corn and soybean varieties were marketed commercially in 2003. We ranked those states by their rate of adoption of biotech varieties,[76] and compared them with the size of the AFS job category in that state. We found that those states that rank highest in biotech crop adoption have more jobs in the AFS category than those states with lower levels of biotech crop adoption (Figure 9). For example, South Dakota

[76] Rankings were based on the 2003 share of total corn and soybeans planted to biotech, subtracted from the U.S. average.

had the highest overall ranking for percentage biotech adoption, with 75 percent of its corn and 91 percent of its soybeans planted to biotech varieties, compared with a national corn average of 40 percent and a national soybean average of 81 percent. South Dakota had 25 AFS workers per 100,000. Iowa, the fifth-ranking state in percentage adoption rates for biotech varieties, had the highest number of AFS workers per 100,000, nearly 50.

We then determined the extent to which these jobs pay above-average wages. Table 34 shows the distribution of wages and the differential for AFS workers relative to average wages in the state as a whole. For example, in North Dakota, AFS workers, even those in the lowest 10 percentile of wages, still made 1.9 times the average wage in that percentile. In Iowa, those in the 50th percentile of wages in the AFS job category made 2.2 times the average wage. Overall, AFS workers made between 1.5 and 2.0 times the average wage in the lead biotech adopting states, and these wages remain above average throughout the career life cycle.

Figure 9. Highest Ranking Plant (Corn and Soybeans) Biotech Adopting States and Agricultural and Food Scientists (AFS) per 100,000 - 2003



Source: Bureau of Labor Statistics, U.S. Department of Commerce

Table 36. Distribution of Wages and Differential for Agricultural and Food Scientists (AFS) by Percentile in Lead Plant (Corn, Soybeans) Biotech Adopting States, 2003

State	10p	25p	50p	75p	90p
South Dakota	1.9	1.9	1.7	1.4	1.3
Nebraska	2.1	1.9	1.9	1.7	1.5
Kansas	2.1	2.1	2.0	1.8	1.8
Minnesota	1.9	1.7	1.5	1.3	1.1
Iowa	1.6	2.0	2.2	1.9	1.7
Missouri	2.1	2.0	1.7	1.5	1.4
Michigan	1.9	2.0	2.0	1.7	1.6
Illinois	2.0	1.9	1.9	1.9	1.6
Indiana	1.9	2.0	1.9	1.6	1.4
Ohio	2.2	2.0	1.9	1.6	1.3

Source: Bureau of Labor Statistics, U.S. Department of Commerce

The States' Roles in Value Creation and Research

A final perspective on the economic activity surrounding plant biotechnology was to view it from the point of view of individual states and their role in value creation and research. Table 37 shows the value of all biotech soybeans, corn, cotton and canola planted in the U.S. by state in 2002. These data appeared separately for each of the commodities (except canola, which was estimated from industry sources) in Tables 5-8. In Table 37, we aggregated and extended these data to all states reporting any of the four crops in 2002. As above, the total value of these biotech varieties in 2002 for the U.S. as a whole was $20.9 billion. The value for each state is shown in the left-hand column of Table 37.

However, USDA data collection practices required care in interpreting the table, which includes 28 states in all. Once the cotton-producing states were factored in, such as Arkansas, Mississippi, Texas or California, the biotech corn and soybeans grown there fell into the "other" category reported as $1.6 billion at the bottom of the table. The reason was that USDA's National Agricultural Statistics Service (NASS) reported biotech varieties of corn and soybeans only for the top 12-14 states, and then allocated the remaining states to an "all other" category. For example, in Table 5 (p. 12), neither California nor Texas was listed as a biotech corn producing state, although both undoubtedly produced biotech corn. The result of these data-collecting practices was to understate the impact of biotech corn and soybean varieties' value to states such as Arkansas, Mississippi, Texas or California in Table 37.

Table 37. Value of crops with biotech traits by state: 2002 ***(millions of dollars)***[1/]

2002	all biotech	soybean	corn	cotton	canola
US	**$ 20,889**	**$ 11,026**	**$ 7,040**	**$ 2,708**	**$ 115**
IA	3,816	2,004	1,811		
IL	2,546	1,756	790		
MN	2,154	1,151	995		8
NE	1,841	802	1,039		
IN	1,258	1,057	201		
SD	1,023	581	441		
MO	1,005	661	236	108	
ND	689	275	312		102
AR	670	371		299	
OH	619	562	57		
MS	528	195		334	
WI	498	274	224		
TX	489			489	
MI	427	309	118		
CA	404			404	
GA	329			329	
KS	274	262		12	
TN	138			138	
NC	137			137	
LA	126			126	
AZ	119			119	
AL	101			101	
OK	31			31	
NM	31			31	
SC	21			21	
VA	17			17	
FL	13			13	
Other	1,588	766	816	-	6

Source: USDA, NASS.

[1/] USDA reports only the top 12-14 corn and soybean growing states for biotech varieties, allocating the rest to the "other" category. When these states are paired with USDA data on biotech cotton, the result is to underestimate biotech corn and soybeans in those states growing biotech cotton.

With these caveats, we can confidently attribute the total economic value in 2002 associated with biotech varieties of the four crops in Iowa ($3.8 billion); Illinois ($2.5 billion); Minnesota ($2.2 billion); Nebraska ($1.8 billion); Indiana ($1.6 billion); South Dakota ($1.0 billion); Missouri ($1.0 billion); North Dakota ($689 million); as well as Ohio ($619 million); Wisconsin ($498 million); and Michigan ($427 million). In all, these 11 states accounted for $15.9 billion in biotech crop value, about three-quarters (76 percent) of the $20.9 billion total. The remaining 17 states in Table 37, most of them cotton-producing states which were not leading corn/soybean producers, showed total economic value associated with biotech crops which were underestimates. These underestimates are due to the absence of corn and soybean data reported.

A second state-level perspective comes from rearranging the APHIS data in Tables 27-35, which showed public and private applications for field permits from 2001 to mid-2003. This is R&D activity beyond the farm gate. In the public sector, these permits are associated with institutions operating in one state, such as the University of Minnesota. However, where private companies filed for permits, it is less clear where the economic and research activity were located, especially since many of these companies are multinationals.

Table 38 shows the states in which this field-testing research was undertaken from 2001 to mid-2003, by crop and by trait tested. It is clear that the states engaged in this plant biotech research include most of those where biotech crop commercialization is concentrated, as shown in Table 37. However, some states that do not appear in data on commercialization are still active in research. For example, research into biotech potatoes and wheat was undertaken in Idaho at the University of Idaho, which does not appear at all, either as a state or in commodity terms, in Table 37. Moreover, the commodities on which field trial research was concentrated does not always correspond to the crops grown most often in the state. Georgia and North Carolina, for example, were involved in research on rapeseed, although they were not leading producers like North Dakota. Arizona had six trials devoted to corn, although it is not a major producer. Finally, some of the states that *are* major producers of biotech crops were not engaged in research based on field trials, such as South Dakota, Arkansas, and Mississippi. Even so, the APHIS data shown in Table 38 reflects the wide participation of research activity at the state level in plant biotechnology.

Table 38. Public Institutions Engaged in Plant Biotech Field Studies by State, Commodity and Trait: 2001-2003.

Public Institution by state	Commodity	Trait in field study
Arizona		
U of Arizona	Corn	Endosperm DNA synthesis altered
U of Arizona	Corn	Visual marker
U of Arizona	Corn	Color sectors in seeds
U of Arizona	Corn	Pigment composition / metabolism altered
U of Arizona	Corn	Gene expression altered
U of Arizona	Corn	Anthocyanin produced in seed
California		
Stanford U	Corn	Visual marker
Stanford U	Corn	Seed color altered
Stanford U	Corn	Anthocyanin produced in seed
Stanford U	Corn	Transposon inserted/movement supressed
U of California	Corn	Fertility altered
U of California	Corn	Environmental stress reduced
U of California	Corn	Visual marker
U of California	Corn	Anthocyanin produced in seed
U of California/Berkeley	Corn	Seed color altered
U of California/Berkeley	Corn	Pigment composition / metabolism altered
U of California/Berkeley	Corn	Gene expression altered
U of California/Davis	Rice	Bacterial leaf blight resistant
U of California/Davis	Rice	Visual marker
U of California/San Diego	Corn	Phosphinothricin tolerant
Colorado		
Colorado State U	Potato	Phytophthora resistant
Connecticut		
U of Connecticut	Corn	Visual marker
Florida		
U of Florida	Corn	Male sterile
U of Florida	Corn	Color sectors in seeds
U of Florida	Corn	Starch metabolism altered
U of Florida	Corn	Seed size/weight increase
Georgia		
U of Georgia	Rapeseed	Lepidopteran resistant
U of Georgia	Rapeseed	Visual marker
U of Georgia	Soybean	Lepidopteran resistant
Hawaii		
Hawaii Agriculture Research Center	Rice	Yield increased
U of Hawaii	Corn	Polymer produced

Public Institution by state	Commodity	Trait in field study
Idaho		
U of Idaho	Potato	Colorado potato beetle resistant
U of Idaho	Potato	PLRV resistant
U of Idaho	Potato	PVY resistant
U of Idaho	Potato	TRV resistant
U of Idaho	Potato	Kanamycin resistant
U of Idaho	Potato	Bruising reduced
U of Idaho	Potato	Ethylene metabolism altered
U of Idaho	Wheat	BYDV resistant
U of Idaho	Wheat	WSMV resistant
Illinois		
U of Illinois	Corn	Phosphinothricin tolerant
U of Illinois	Corn	Visual marker
U of Illinois	Corn	Gene expression altered
U of Illinois	Corn	Epidermal cells increased on juvenile leaves
U of Illinois	Soybean	Phosphinothricin tolerant
Indiana		
Purdue U	Corn	Color sectors in seeds
Iowa		
Iowa State U	Corn	Male sterile
Iowa State U	Corn	Fertility altered
Iowa State U	Corn	Visual marker
Iowa State U	Corn	Starch metabolism altered
Iowa State U	Corn	Carbohydrate metabolism altered
Iowa State U	Corn	Protein altered
Iowa State U	Corn	Pharmaceutical proteins produced
Iowa State U	Soybean	Phytophthora resistant
Iowa State U	Soybean	Protein altered
Kansas		
Kansas State U	Corn	Color sectors in seeds
Kansas State U	Wheat	Drought tolerant
Kansas State U	Wheat	Fusarium resistant
Kentucky		
U of Kentucky	Soybean	BPMV resistant
U of Kentucky	Soybean	Oil profile altered
U of Kentucky	Soybean	Altered amino acid composition
U of Kentucky	Soybean	Methionine level increased
Louisiana		
Louisiana State U	Rice	Yield increased
Louisiana State U	Rice	Burkholderia glumae
Louisiana State U	Rice	Rhizoctonia solani resistant

Public Institution by state	Commodity	Trait in field study
Louisiana State U	Rice	Phosphinothricin tolerant
Louisiana State U	Rice	Hygromycin tolerant
Michigan		
Michigan State U	Potato	Phytophthora resistant
Michigan State U	Potato	Coleopteran resistant
Michigan State U	Potato	Lepidopteran resistant
Michigan State U	Potato	Visual marker
Michigan State U	Potato	Starch level increased
Minnesota		
U of Minnesota	Potato	Late blight resistant
U of Minnesota	Wheat	Phosphinothricin tolerant
Missouri		
U of Missouri	Corn	Gene expression altered
U of Missouri	Corn	Anthocyanin produced in seed
Montana		
Montana State U	Wheat	Starch level increased
Montana State U	Wheat	Yield increased
Montana State U	Wheat	Visual marker
Montana State U	Wheat	Improved bread making characteristics
Nebraska		
U of Nebraska/Lincoln	Soybean	Sclerotinia resistant
U of Nebraska/Lincoln	Soybean	Cyanamide tolerant
U of Nebraska/Lincoln	Soybean	Dicamba tolerant
U of Nebraska/Lincoln	Soybean	Oil profile altered
U of Nebraska/Lincoln	Soybean	Fatty acid level/metabolism altered
U of Nebraska/Lincoln	Soybean	Oleic acid content altered in seed
U of Nebraska/Lincoln	Wheat	Yield increased
U of Nebraska/Lincoln	Wheat	Fusarium resistant
New Jersey		
Rutgers U	Corn	Storage protein altered
Rutgers U	Corn	Visual marker
Rutgers U	Corn	Seed color altered
Rutgers U	Corn	Methionine level increased
New York		
Boyce Thompson Institute	Potato	Kanamycin resistant
Boyce Thompson Institute	Potato	Beta-carotene increased
Cold Spring Harbor Lab	Corn	Development altered
North Carolina		
North Carolina State U	Rapeseed	Visual marker

Public Institution by state	Commodity	Trait in field study
North Dakota		
North Dakota State U	Potato	Carbohydrate metabolism altered
Ohio		
Ohio State U	Corn	Visual marker
Oregon		
Oregon State U	Potato	PVY resistant
Pennsylvania		
Pennsylvania State U	Corn	Male sterile
Pennsylvania State U	Corn	Visual marker
Pennsylvania State U	Corn	Color sectors in seeds
Texas		
Texas Agricultural Exp Stn	Cotton	Rhizoctonia solani resistant
Texas Tech	Cotton	Carbohydrate metabolism altered
Texas Tech U	Cotton	Environmental stress reduced
Texas Tech U	Cotton	Fiber quality altered
Virginia		
Virginia Tech	Soybean	Phytate reduced
Washington		
Washington State U	Potato	Storage protein altered
Wisconsin		
U of Wisconsin	Corn	Altered maturing
U of Wisconsin	Corn	Visual marker
U of Wisconsin	Corn	Gene expression altered
U of Wisconsin	Corn	Anthocyanin produced in seed
USDA		
ARS	Cotton	Oleic acid content altered in seed
ARS	Potato	Erwinia carotovora resistant
ARS	Potato	Phytophthora resistant
ARS	Potato	PLRV resistant
ARS	Potato	PVY resistant
ARS	Potato	PVA resistant
ARS	Potato	Visual marker
ARS	Potato	Steroidal glycoalkaloids reduced
ARS	Soybean	Visual marker
ARS	Wheat	Phosphinothricin tolerant
ARS	Wheat	Powdery mildew resistant
ARS	Wheat	Smut resistant
ARS	Wheat	Storage protein altered

Source: USDA, APHIS.

Conclusion: Future Directions for Plant Biotechnology

Despite the importance of plant biotechnology – to producers, to the input supply industry, to private research and development investors, to educational and research institutions, to the federal government and increasingly to consumers – it is still hard to capture its distinct and separable contributions to economic activity. Neither private nor public data allow a concentrated light to shine on the sector. In this study, we sought to bring plant biotech into sharper focus, to evaluate its current status and performance, and to provide data-based assessments, whenever possible, of both current and future directions. We conclude with a summary of these directions for each of the aforementioned groups: producers, input suppliers, private research and development investors, the federal government and consumers. In general, we conclude that the plant biotech sector will grow wider and deeper in its activities and applications in the years to come.

For producers, the evidence of valuable benefits conferred by plant biotech in the seven years since its commercial introduction in 1996 is strong. Using the basic value of biotech varieties for the nation and individual states, biotech corn, soybeans, cotton and rapeseed/canola were associated with over $20 billion in crop value in 2002. Apart from this direct value, survey data suggests that the management advantages of new biotech varieties, such as rootworm resistant corn, confer not only benefits on the order of $23.00 per acre, but added management efficiencies worth as much as $15.00 per acre, adding another 65 percent in economic value. Multiplied times the growing number of acres in biotech varieties nationally, these advantages are significant contributors to increased farm income. We have also shown these results by state, suggesting that in the Corn Belt, producers of corn, soybeans and rapeseed/canola are reaping hundreds of millions and in some cases (such as Iowa, Illinois, Minnesota, Indiana and Nebraska), billions of dollars in revenues associated with planting biotech crops. Outside the Corn Belt, cotton producing states such as Texas, California, Mississippi, Georgia, and Arkansas have also benefited from planting biotech varieties at levels in the hundreds of millions of dollars. As more biotech plants and new varieties with superior traits become available, this value will increase in size and scope.

In the input supply industry, the introduction of biotech varieties has forced companies to reevaluate their product offerings, and to redesign the "bundles" of crop protection products, seeds and fertilizers sold to farmers. This has put pressure on sales of herbicides and pesticides that compete directly with biotech varieties resistant to weeds and insects. It has also driven the rapid consolidation of traditional chemical manufacturers and seed companies. But it has enhanced the attraction of those products designed to complement the biotech varieties – glyphosate is the leading example – and led to the search for more complementary crop protection offerings. In general, biotech varieties have provided new tools in pursuit of precision agriculture, and promise to offer traits that will yield social rewards not only in productivity but also for soil and water conservation, environmental remediation of damaged soils, drought tolerance and many other areas.

Investors have found that the research inputs to plant biotech cost real money, and yield real returns, but that the lags connecting initial costs and subsequent benefits can be long. This is due in part to the long regulatory process required for approvals, but also to the inherent nature of agricultural research, testing, and the adaptation of new and improved crop varieties to different agroecological zones. The result has been to concentrate increasing R&D investment in the major companies, notably the six outlined above: Syngenta, Bayer, Monsanto, DuPont/Pioneer Hi-Bred, Dow AgroSciences and BASF. These companies are now spending billions each year on research, and possess the complementary assets which allow them to deal with regulatory delays, intellectual property protection, and large front-end costs. Private sector research in general exceeds public by about a third, and this difference is likely to continue to grow. While many opportunities exist for smaller companies seeking niche markets, exemplified by some of the smaller science-based start-ups, big research dollars are unlikely to flow from venture capitalists to these firms, and they will often need to attach themselves in some way to the major companies, as suggested by Mendel Biotechnology's partnership with Monsanto in 2002.

Due to the leads and lags in agricultural research, including plant biotech, there remains a clear role for public educational and research institutions. These institutions can work on projects that may be slower to mature than is acceptable in the earnings-oriented private sector. Research in the life sciences, both at universities and in private companies, has boomed in the last decade. NSF funding, nearly all to universities, increased 70 percent in biological sciences from 1996 to 2002. The value of the knowledge and expertise held in the public sector is suggested by studies that show a 10:1 ratio linking the value of the stock of knowledge in agricultural research and the present value of commodity production. The conclusion is that public research institutions are repositories of knowledge stocks worth hundreds of billions of dollars per year. The erosion of the funding base for these institutions – especially land grant institutions subject to state and federal budget cuts – has direct and negative implications for the pace of scientific progress in plant biotechnology. These institutions are found in nearly every state, but research in the plant biotech sector is affected especially by major land grants such as Cornell University, the University of California, and the University of Wisconsin. The overall conclusion is not that private sector research will replace public, or that the private sector's interests are opposed to those of the public. Instead, new directions must be charted to maximize the complementarity and share the huge financial burdens of a science-based society, including food and fiber production.

The federal government's role in this process has also been central and will remain so. Indeed, because of the regulatory scope relating to new traits designed to affect consumers' health or the environment, federal involvement in plant biotech will become more, not less, important to its acceptance and growth. Apart from USDA and its sub-agencies, including the ARS, CSREES, ERS, NASS and APHIS, plant biotech must also withstand scrutiny from regulators at FDA and EPA, and will deserve the attention of agencies such as the Small Business Administration or the export-promotion arms of the Department of Commerce. The research base represented by USDA's network of connections to the land grant institutions, as well as more basic research funded under NSF or NIH grants, is also critical and should be expanded, not contracted, if plant biotech is to grow and prosper. Whether this will be possible given current fiscal policy directions is highly doubtful.

The last, and perhaps most fundamental, question concerns the ultimate arbiter of market growth and development: the consumer. American consumers remain largely unaware that they are already benefiting from productivity enhancing and environmentally superior plant biotech traits. However, more effort must be made to explain how the process of research and development is leading to these new output traits, and to give consumers reasons for well-justified hope and confidence in the technology. As consumer confidence grows, it will feed the demand for new biotech varieties, increase the advantages of those willing and able to supply them, and indirectly establish a base of support for continued public investments in plant biotech with high social rates of return in the form of educational and job opportunities.

APPENDIX I

APHIS Field Test Database for Biotech Plants

The U.S. Department of Agriculture (USDA) Agricultural Plant Health Inspection Service (APHIS) regulates the movement, importation, and field testing of transgenic plants and microorganisms under the Federal Plant Protection Act.

These organisms are assumed to be a risk to other plants and ecosystems until it is demonstrated otherwise. Field testing or the environmental release of a regulated organism, typically a plant, requires a permit. Certain plants (corn, soybeans, cotton, potatoes, tomatoes, and tobacco) only require a notification permit, while other organisms must follow a more rigorous permitting procedure. The growers of transgenic plants can be relieved of the field test permitting requirements by petitioning that the organism no longer be subject to regulation.

USDA field release data is available from the Information Systems for Biotechnology (ISB) provided by Virginia Tech Agricultural Experiment Station.

The APHIS field test dataset has more than 9,200 records of permit requests dating back to 1985. Each record identifies the public or private institution making the request, the organism or crop involved in the test, and the phenotype or trait being examined. In addition, each permit identifies the donor organism from which the trait is derived, the state or states in which the test will be conducted, and the time period of the trial.

This study focuses on four factors related to this APHIS dataset:

1) The *year* in which the permit application was made. Although it is typically not the case, the actual field test may not begin in that year and/or trial may run longer than one year. Since the intent of this assessment was to spotlight current and forward-looking research efforts, only those permits from January 2001 through July 2003 are included in the tables.

2) The *institution* conducting the field test. Over the 18 years of data in the full set, 226 individual organizations have applied for permits. Twice as many private institutions have applied as have public institutions. For both groups there are institutions that appear to be listed more than once, for example, ICI and ICI Garst, or the University of Wisconsin and University of Wisconsin/Madison. There are also examples, such as the University of California or New York State University, where permits were issued to multiple campuses of the same institution. From 1985 through 1998, more field test permits were requested by private institutions than public institutions, but in the last five years more public institutions have made such applications. In the most recent complete year of data (2002), 42 public institutions and 35 private institutions applied for one or more field test permits. For the eight crops in this study, 28 public institutions and 21 private institutions applied for at least one permit in 2002.

3) <u>The *plant* or regulated organism used as the transgenic host</u>. Only the eight crops (corn, cotton, soybeans, wheat, rapeseed, rice, sugar beets and potatoes) in this study are examined in detail. However, over the 18 years of data some 76 plant species have been field tested. These are listed in Appendix Table 1. Some additional organisms have also been field tested under the APHIS permit process, from bacteria and fungus to nematodes and spider mite predators.

4) <u>The *trait* or phenotype the trial hopes to express</u>. The number of traits tested is hard to estimate since applicants can state the same objective in different ways. For example, *phosphinothricin resistant* and *phosphinothricin tolerant* may represent the same research goals. Similarly, bacterial leaf blight resistant and *xanthomonas oryzae* resistant are the common and Latin names for the same disease in rice. These issues are explained on a case-by-case basis as the eight study crops are examined. Field test traits are also categorized in the APHIS dataset by a broader characterization of potential benefit. These may include agronomic properties, product quality traits, herbicide tolerance, marker genes, four disease resistance traits (bacterial, viral, fungal, and insect) plus a category for "other" phenotypic traits.

No attempt is made to rank institutions by number of permits requested. In the tables for individual crops, private companies are listed before public institutions, and both are ordered alphabetically. No assessment is made of the number of acres in the trial or the (state) location. Only those records that have complete information identifying the institution, crop, and trait under study are included in the analysis. A small number of the records under study have one or more field trials coded as "confidential business information" (CBI). Most of these were eliminated from the dataset. Finally, it should be noted that a field test permit gives the applicant the right, not the obligation, to conduct a field trial.