The Economic Status and Performance of Plant Biotechnology in 2003:

Adoption, Research and Development in the United States

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The full report can be accessed at www.apec.umn.edu/faculty/frunge/plantbiotech.pdf.

Executive Summary

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. (See Figure 1.) 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 to as much as $60 per acre for corn, on the order of $15 per acre for soybeans and from $15 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, 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 billion in 2002. Biotech soybeans rose from 9 percent of planted soybean acres in 1996 to 81 percent in 2003, worth $11 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, half of the total value of the four crops.

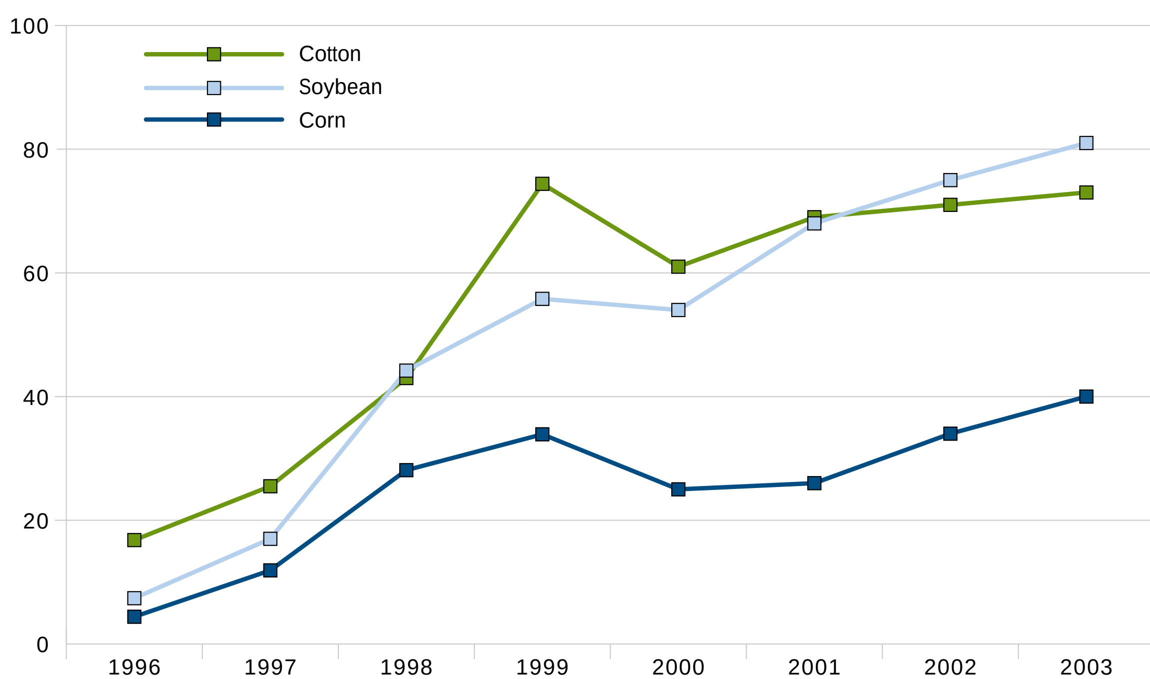
• When evaluated state-by-state, four states (Iowa, Illinois, Minnesota and Nebraska) accounted for 60 percent of the value of biotech corn production. Four states (Iowa, Illinois, Minnesota and Indiana) accounted for 54 percent of the value of biotech soybean production. Four states (Texas, California, 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. (See Figures 2, 3 and 4.)

• 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.

Figure 1

Percent of Crop Acres Planted to Biotech Varieties: 1996-2003



Source: USDA, NASS.

Figure 2

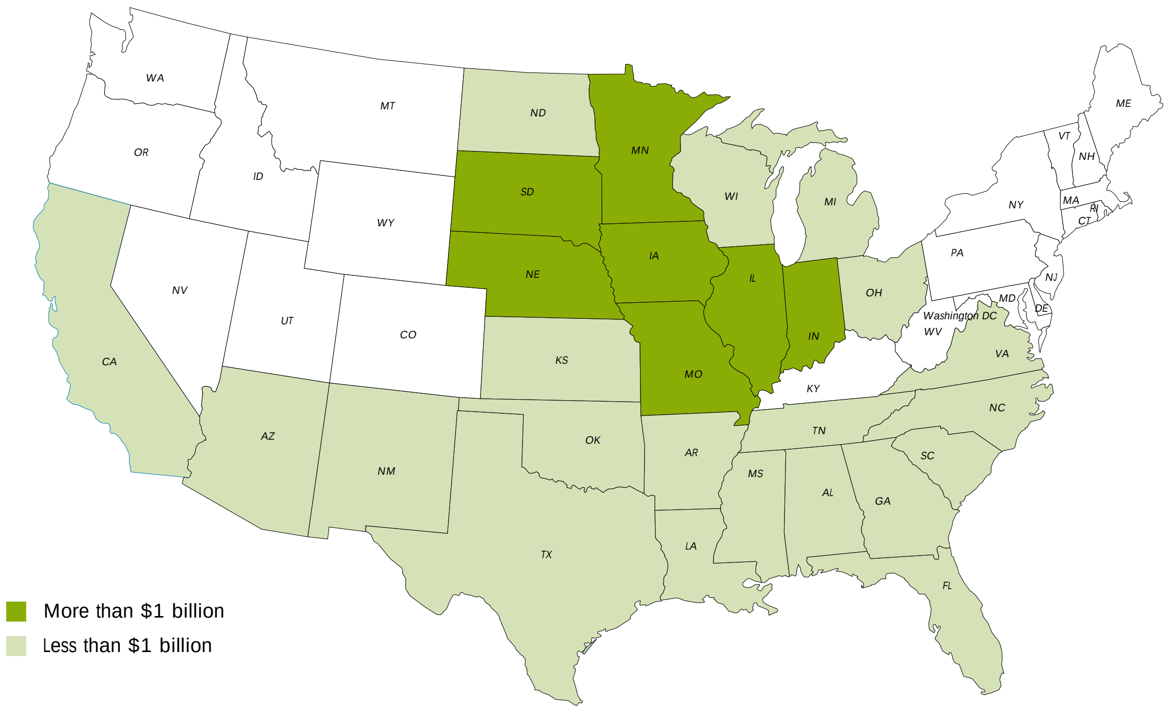
Value of Crops with Biotech Traits by State: 2002 (millions of dollars)*

2002	All Biotech	Soybean	Corn	Cotton	Canola
U.S.	$ 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.

*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.

Figure 3
States with Major Biotech Crop Value: 2002*



*Four biotech crops (corn, soybeans, cotton, rapeseed/canola)

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, 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 dominance 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.

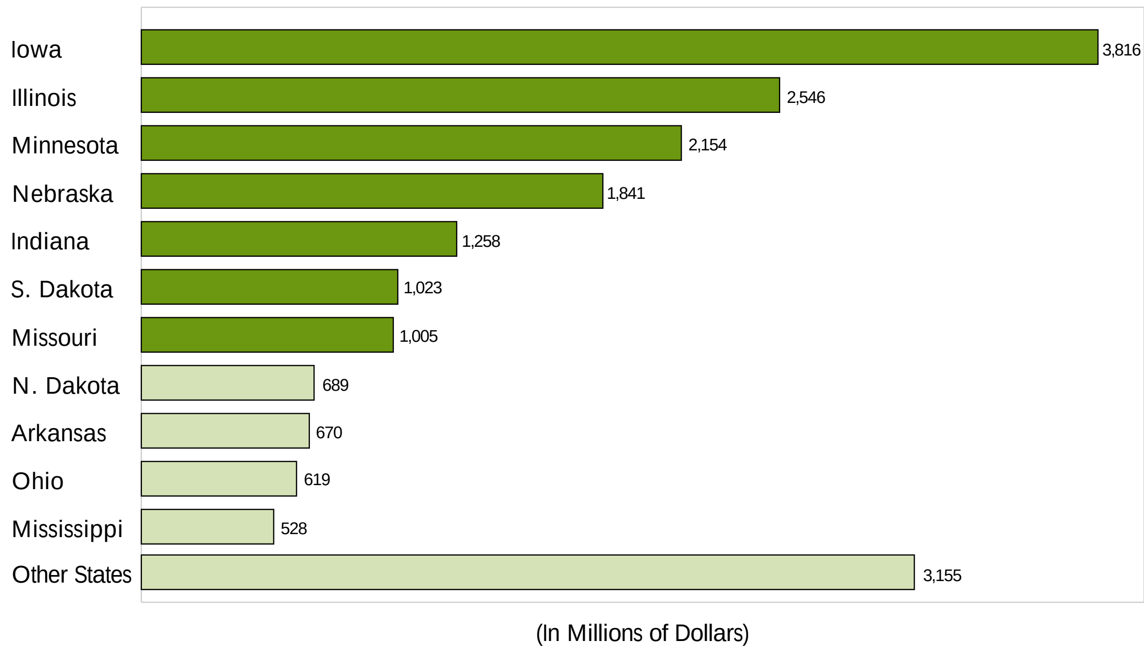
• Plant biotech research rests on a wider platform of genomics, which is the latest episode in a tradition of modern plant breeding going back over a century. The cumulative nature of the research process means that research and development by both private and public plant scientists has accumulated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

Figure 4

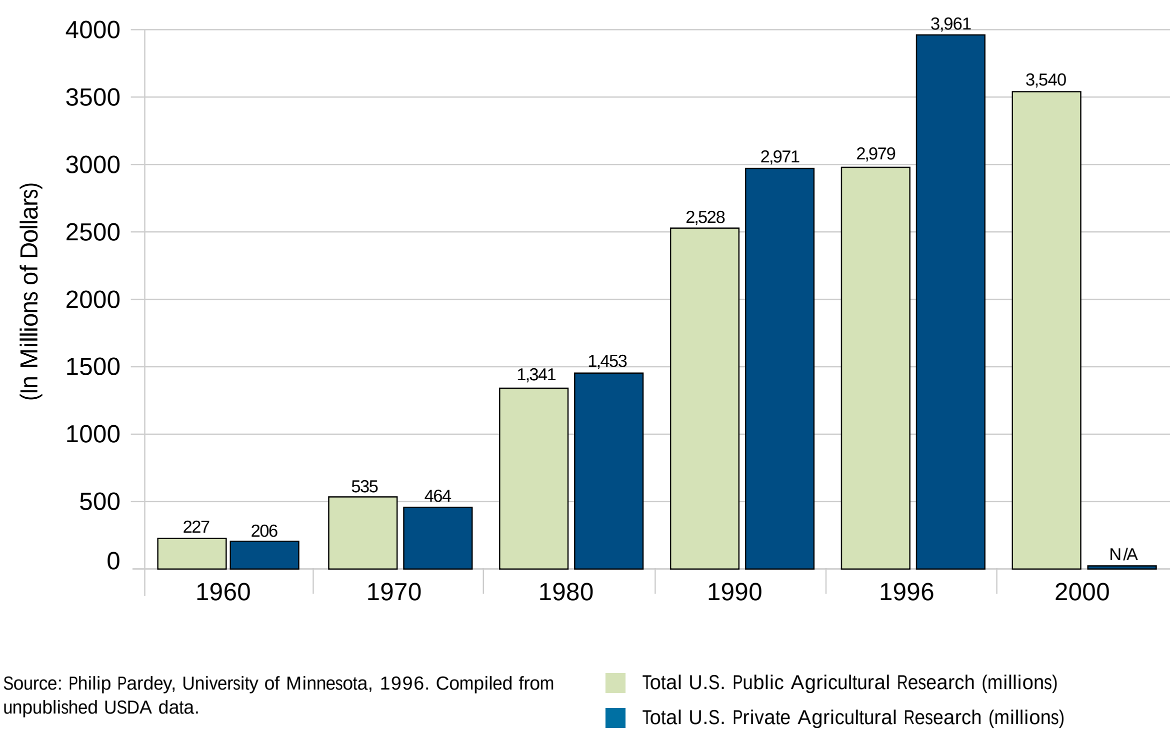
Total Value of Biotech Crops in 2002 in the United States was $20.9 Billion



Source: USDA, NASS.

Figure 5

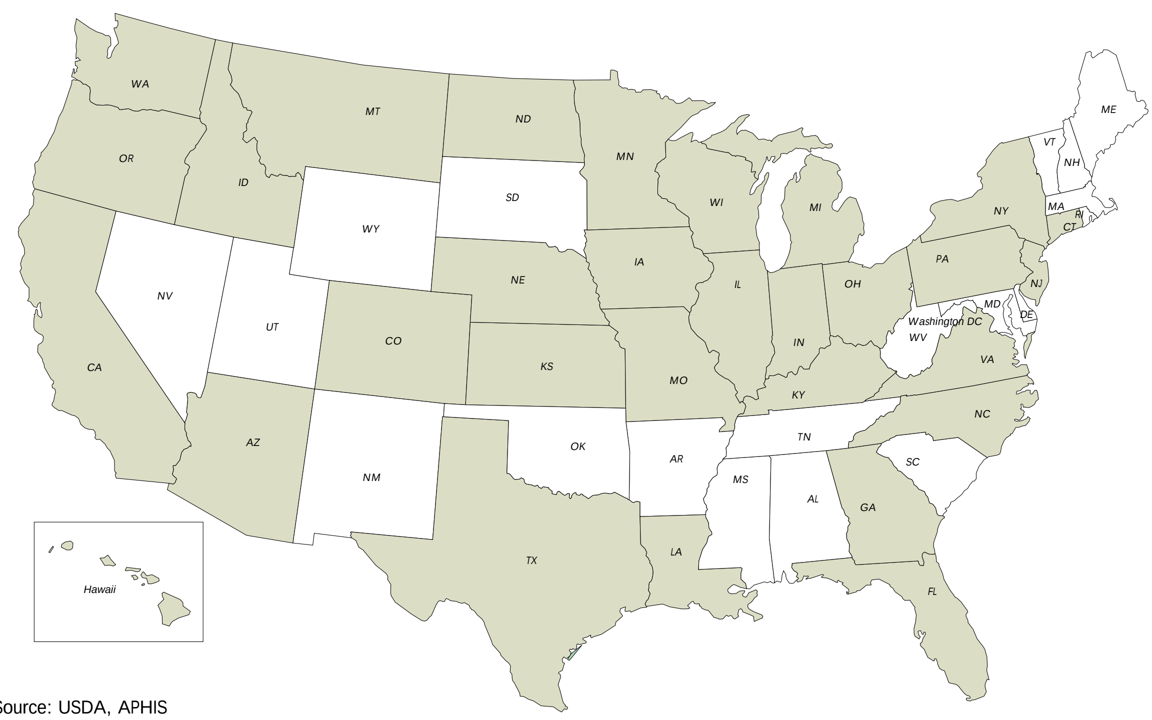
Public and Private U.S. Agricultural Research and Development Spending in Nominal Dollars, Selected Years



Source: Philip Pardey, University of Minnesota, 1996. Compiled from unpublished USDA data.

Figure 6

States Where Public Research Institutions Conducted Biotech Field Trials: 2001–2003*



Source: USDA, APHIS

*Eight biotech crops (corn, soybeans, cotton, rapeseed/canola, wheat, potato, rice, sugar beets)

• 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) compared to 5 percent on U.S. government bonds in 2002. 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. (See Figure 5.)

• 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.

- Ongoing commercial activity shows a growing list of approvals in corn, soybeans, and cotton through 2001, mainly 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. (See Figures 6, 7 and 8.) 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 from 2001 to mid-2003 by the six major private companies, 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 (now Bayer) 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.

Figure 7

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

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.

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

Source: USDA. APHIS

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

Figure 8

Public and Private Sector Institutions Filing for Field Testing Permits for Eight 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	DuPont
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

*Eight biotech crops (corn, soybeans, cotton, rapeseed/canola, wheat, potato, rice, sugar beets)

• 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. (See Figure 10.)

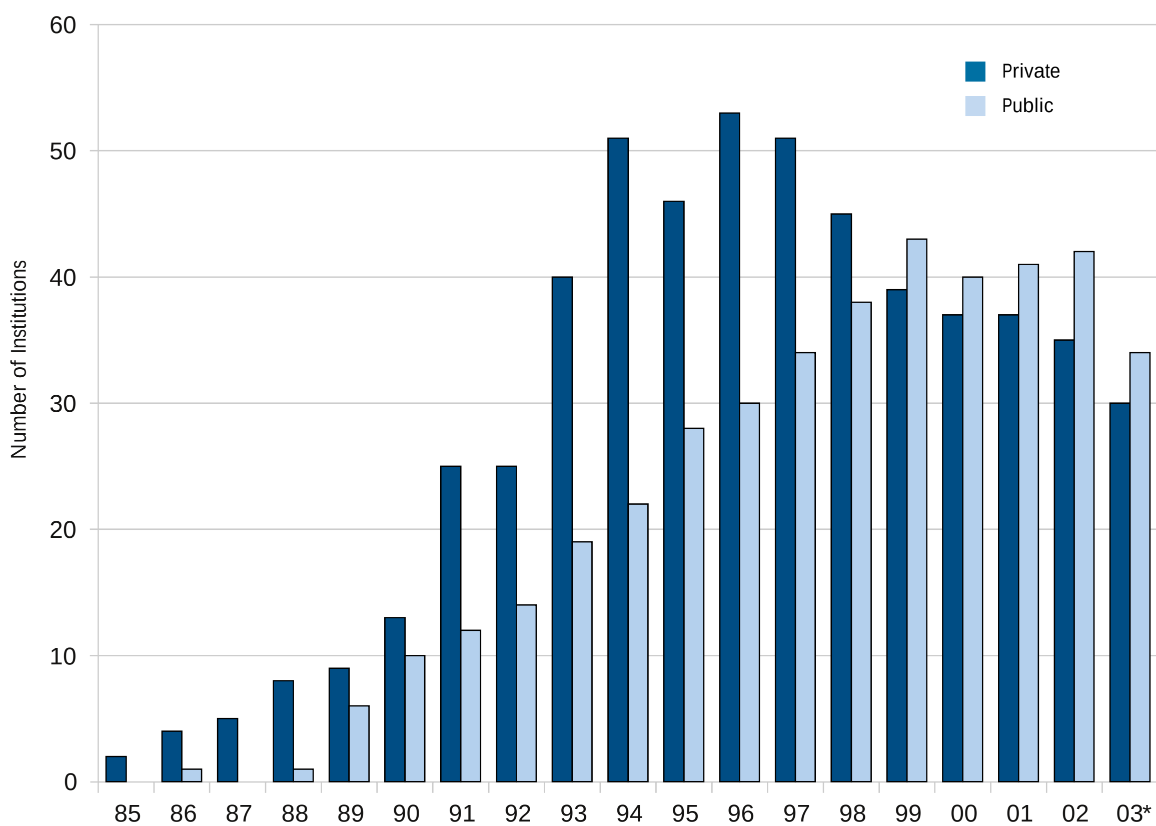
• The distribution of wages in the AFS sector showed that overall, AFS workers in the states with the highest levels of biotech plant adoption made between 1.5 and 2 times the average wage. These wages exceeded averages throughout the career life cycle.

• 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.

• When private and public institutions involved in field test permits are compared over time as shown in Figure 9, two pictures emerge: first, there has been steady progress in public sector research through the years. Second, it suggests private sector growth expanded rapidly in the early 1990s;

Figure 9
Number of Private and Public Institutions Granted APHIS Field Test Permits, 1985-2003



*Data for 2003 only includes the first 8 months.

however, the apparent decline in activity since 1996 is likely due to rapid consolidation of firms, leading to fewer private company filings.

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.

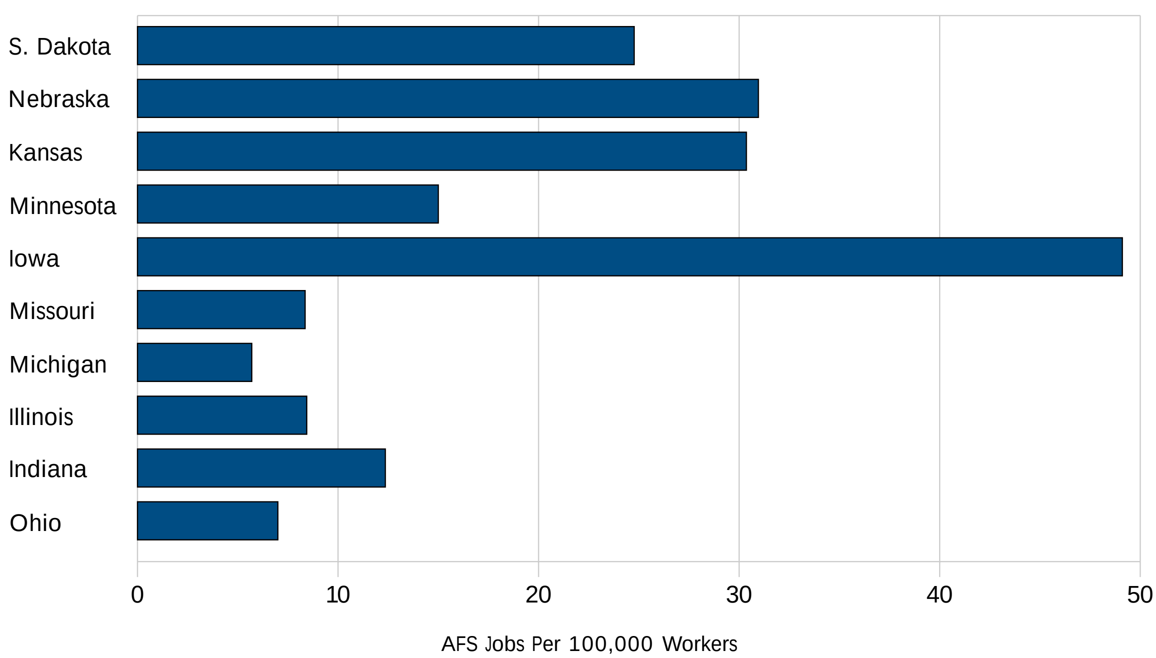
- In the input supply industry, the introduction of biotech varieties has forced changes in the "bundles" of crop protection products, seeds and fertilizers sold to farmers, and promoted rapid consolidation of chemical and seed companies. Biotech varieties have given new impetus to precision agriculture, 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 dominate 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 complementarity between private and public science.

Figure 10

Highest Ranking Plant (Corn and Soybean) Biotech Adopting States and Agricultural and Food Scientists (AFS) per 100,000 — 2003



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

- 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.

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www.apec.umn.edu/faculty/frunge/plantbiotech.pdf