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Biotechnology - General Information

Biotechnology : Fundamentally Reshaping the Agriculture, Food and Fiber Industry
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Sparks Companies, Inc.

Biotechnology: Fundamentally Reshaping the Agriculture, Food and Fiber Industry

A Multi-Client Study

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Foreword

Innovation and adaptation long have been a way of life for farmers and the food sectors in most parts of the world. A stream of new technology has brought a myriad of new products and processes leading to persistent gains in productivity throughout this century. Most of these advancements have been incremental, with only a few precipitating abrupt and widespread changes across the entire sector. Most required several years for the adoption to become complete, and most were largely confined to one component of the system, little affecting other components in any direct manner. But, now, a new technology, long in the making, has appeared suddenly and apparently holds the potential to bring both rather abrupt and far-reaching change across the entire food system. If realized, the implications would extend well beyond the food system to supporting and affiliated institutions, public policies, the consuming public and well beyond. And, the changes are not confined to one country or group of countries, but promise to affect the world and in a very short timeframe by historical standards.

The advent of biotechnology comes at a time when the food and agriculture systems already were being strongly affected by a convergence of new forces which were rapidly changing the operating environment. These forces include: a broad set of international trade agreements that included agriculture and food products; new policies that redefined the long-standing role of national governments, reducing both their presence and subsidies; new farming systems built upon application of computers and satellites; and greatly increased globalization and interdependence of economic systems. The addition of biotechnology to the list promises both to hasten the already rapid pace of resulting change and broaden the impacts as all segments of the global system begin to adjust to the new operating environment.

The fast-paced advancement of biotechnology and the rapid reactions it was prompting gave rise to this study. It is an effort to systematically examine the prospects for an emerging technology over a relative short time horizon – the next five years – and to identify and evaluate the likely far-reaching changes it may bring. The study is not intended to produce specific answers, quantitative estimates, or a specific forecast. Rather, its purpose is to assemble and synthesize the relevant information, and organize it in a way to help stimulate thinking and develop informed judgments. The specific purpose is to help clients – from their particular perspective in the food system – identify implications important to them and their business and to develop appropriate strategies and actions to best position themselves for the future.

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Synthesis

For the past four months, SCI has conducted a comprehensive study of one of the most exciting and important technologies ever to be developed – the science of shifting DNA and creating specific traits by modifying the genetic makeup for plants and animals, more commonly known as biotechnology. From the outset of the study, we knew the potential impacts of biotechnology were enormous, especially for agriculture and the food industry. But even our familiarity with this cutting-edge science did not prepare us for the stunning results of the study. Now that the study is complete, we realize more than ever that biotechnology could be the most important development for global food production and the agribusiness industry in history.

Biotechnology has almost unimaginable potential to erase hunger from the world, to stop environmental degradation, and to tailor-design foods for specific health and nutritional purposes. But the science also is accompanied by many unknowns, some of which have been explored in this report.

Now that the study is complete, we took the opportunity to step back and reflect, to identify a few of the factors that were most striking to us. These include:

- ***Biotechnology is unlike any technological advancement seen thus far in agriculture.*** Unlike past technologies that have focused on one aspect of production or of the industry, biotechnology has the potential to change the entire agriculture and food industry.

- ***The acceptance of biotechnology in North America has come early and with little protest.*** The application of lifesaving bioscience in the early 20th century with the "wonder drug" penicillin laid the groundwork for the current environment, causing an appreciation by the US consumer of the technology. It is interesting to note how particular experience and cultural differences have affected consumer acceptance around the world – with great ease in North America, South America, Australia, and Japan, and much less ease in Europe. The implications for the EU are enormous, involving fundamental internal policy and budget issues, geographic expansion, and international policy matters.

- ***The fast pace of adoption of existing products.*** From the first commercial introduction of major products three seasons ago, farmers have eagerly adopted the new crops. Today, almost one-half of two major crops and over one-third of another are planted to new crops.

- ***The industry's response.*** The industry quickly recognized the potential of the technology and that new structures were necessary to make it successful. A major restructuring of the agricultural chemical and seed components of the inputs sector has taken place in less than 36 months. Two major companies are literally reinventing themselves, shedding old traditional businesses and emphasizing new ones, to emerge as leaders in the life sciences field. And, the restructuring now is moving well beyond the inputs sector, extending far across the entire food system.

- ***The enormity of the pipeline.*** While the number of existing products commercially available still is relatively small, the number and breadth of products in the near term (five years) pipeline is impressive. The ability to move quickly from single traits to "stacked" traits has greatly enhanced this. And, this is just what can be expected in five years hence. Speculation about what may come beyond that suggests there are few limits to new product possibilities.

- ***The rapid extension of the successes.*** The early focus has been on cost reducing/yield enhancing crop traits – developing herbicide tolerance and insect resistance – for major field crops (soybeans, corn and cotton). Research now will extend this very quickly to a wide variety of other crops of both major and minor economic importance (canola, potatoes, wheat, sugar beets, rice, vegetables, etc.). Stacked agronomic traits will be available in varieties of these and more crops in five years time. One notable omission, however, is the lack of progress in developing improvements for wheat, a major crop in both North America and the world.

- ***Disparity between crop and livestock products.*** It is striking how few commercial biotech livestock products are available. Moreover, the "murkiness" of the pipeline in terms of specific products with commercial applications is noteworthy, especially given the apparent tremendous economic potential. And, this is even more noteworthy because of the seemingly advanced stage of the basic underlying science. Explanations would seem to involve costs (of research and development), complexity (of animal genetics versus plants, adding to the cost), and expected consumer acceptance (ethics issues). Big stakes would involve not only the cost reducing/yield enhancing and value added for food aspects, but also the enormous potential in developing medicines and compounds for treatment of humans, and perhaps even donor organs, as well.

- ***The potential of nutraceuticals.*** Although likely still some time to come, the ability to tailor-make food for humans that correct conditions, prevent diseases, improve appearance, etc. would seem to have unlimited potential.

- ***The long reach of the implications.*** The new technology produces change from one end of the food system to the other, and well beyond to the supporting and facilitating institutions. Developments introduced in the farm inputs component literally require adjustments throughout the system and beyond.

- ***What's at stake.*** The potential benefits from the new technology – the billions of dollars in savings from improved pest control, the billions created from enhancing commodity products, the billions more from new product developments such as nutraceuticals – are simply enormous from a business perspective. The potential stakes are clearly evident from the huge investments already made for acquisitions and alliances, in only the very beginning stages of development of the new technology. From a broader perspective, the stakes are even greater – reduced hunger and malnutrition, global disease reduction and elimination, reduced or eliminated environmental degradation, and on and on.

- ***Where everyone will fit.*** The business restructuring thus far largely involves the biotech companies – but, what more restructuring must occur? Will biotech companies be successful in a "dirt to dinner" strategy spanning the food chain? How will all the existing players relate to this? Where will they fit? How are corn milling, pasta making, potato processing, oilseed crushing, flour milling, and finished food companies all fit into a new structure?

- ***Restructuring yet to come.*** While the inputs sector restructuring is settling out, and more fundamental restructuring across other components of the food system is being considered, the really serious linkages – those extending beyond the food system to the pharmaceutical, general chemical, and industrial sectors – are hardly being contemplated but very likely in the offing if the biotech success continues.

- ***The farm inputs sector.*** The likely changes coming to the farm sector are enormous, hastening many trends already underway. Biotechnology not only contributes to improvements in successful farmers continuing quest to reduce unit costs, but also offers new revenue opportunities, as well. Cost reduction and expanded revenues should offer wider margins for some farmers.

- ***Environmental impacts.*** While agriculture long has been fingered as a major culprit in environmental degradation, the advent of biotechnology would seem to be a big positive in helping improve its image – reduced pesticide use, less water pollution, less use of fragile lands, less area expansion into rainforest and other ecologically sensitive areas, all the while with higher yields and output to help combat hunger and malnutrition

- ***Public/private sector research.*** Much of the public sector biotech research is "basic research," laying the framework for the more proprietary work that the private sector companies have pursued. The division of labor traces to earlier public sector budget pressures and new legislation enabling patenting of life forms. Alliances between the public/private sector increasingly are evident and likely more necessary in the future.

- ***More international harmonization logical.*** The truly patchwork nature of both national approval processes for new biotech products and the trade and other issues arising from international commerce seems to suggest greater harmonization – both through existing or new bodies at the national and international levels.

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I. Introduction

Background

Today, the food and agriculture sectors of most national economies have advanced to the point of being closely interrelated and collectively forming one of the largest sectors of the economy, contributing more than $1 trillion annually to GDP in the US alone. It is dominated by food and fiber processing, sustained by producers of agricultural genetics, chemicals, machinery and other inputs. And, it is supported heavily by the public, through research and extension, conservation, stabilization and market development and many other programs.

Today, world economies and their food systems have become highly inter-linked. Developments around the world have powerful and immediate impacts on the food sector, as we have seen recently with economic adversities in Asia. This linkage also plainly reflects economic and social trends as well, so that new developments and trends in any part of the world very quickly have implications for everywhere else.

The current degree of world inter-linkage is relatively new, especially for agriculture. And, it comes at a time when new policy and technology developments have appeared suddenly, and are having major impacts on the sector's structure and organization, trends likely to continue for the foreseeable future.

Just as the growing linkage with world markets is a major force for change in the agriculture and food system, the sector's embrace of new technology resulting in dynamic and persistent productivity growth – far stronger than for the rest of the economy – also is a major force for change. This trend has been a proud centerpiece of the food sector since the 18th century (at least). It long has belied its hayseed image, making it among the fastest changing (and volatile) components of the economy.

Food Sector Productivity

The dynamism that characterizes today's food system began to develop in agriculture more than two centuries ago, at the advent of the industrial revolution. Early agriculture offered one of the world's largest potential markets for new machines and new techniques. Steam power was the force behind the industrial revolution and these miraculous new machines quickly found agricultural applications worldwide and changed the sector dramatically. The cotton gin made possible a new level of efficiency in textile production, just as the moldboard plow, the reaper and the threshing machine revolutionized grain production. It is often thought that the 20th century marked the age of revolution in agriculture, but it also is true that many of the implications of this century's new technologies developed from ideas of the 19th century, or before (Tables 1 and 2).

Table 1. Nineteenth Century Farm Machinery Milestones

Year	Inventor	Machine	Remarks
1793	Eli Whitney	Cotton gin	Separated cotton seeds and lint
1797	Charles Newbold	Iron plow	Heavy. Did not scour well.
1826	Patrick Bell	Reaper	European. Not widely adopted.
1837	Cyrus McCormick	Reaper	Not really effective until 1855
1837	Hiram and John Pitts	Thresher	Common use by 1860
1837	John Deere	Steel plow	Widely used
1840	John Gibbons	Grain drill	Simultaneously drilled and seeded
1868	James Oliver	Chilled iron plow	Better scouring and wear
1868	John Lane	Soft-center steel plow	More durable
1878	Combine	Numerous	Combined reaper and thresher
1880	William Deering	Grain binder	Tied bundles
1880	E.W. Quincy	Corn picker	Experiments begun 1820

Source: Bolino (1966), Krooss (1966), and Benedict (1953)

Many key innovations across the sector are well known. The combine, for example, emerged as early as 1878, and initially depended upon horse power. And, agriculture itself changed slowly over the years in spite of the stream of innovations. While a few basic technologies shifted, following development of the steel plow, cultivator, drill and a few other machines for cultivation, and a reaper or binder that basically gathered small grains, power came primarily from horses until well into the 20th century. Most farms continued to be diversified, producing small amounts of grain and livestock, and using huge amounts of resources to supply their own power needs.

Table 2. Farm Power Milestones

Year	Inventor	Machine	Remarks
1678	P.B. Hautefeuille	Engine	French – burned gunpowder
1705	Thomas Newcomen	Steam engine	English – not really practical
1770	James Watt	Steam engine	Improved Newcomen engine
1829	George/Robert Stephenson	Locomotive	English – brought to America
1830	Robert Cooper	Locomotive	"Tom Thumb" – 18 miles per hour
1849	A.L. Archambault	Portable engine	"Forty Niner" threshing engine
1855	Obed Hussy	Steam tractor	Could be used for plowing
1876	Nikolaus Otto	Engine	German – 4-cycle internal combustion
1892	Rudolf Diesel	Engine	High efficiency
1892	John M. Troclich	Tractor	Gasoline engine – John Deere forerunner
1905	C.W. Hart and C.H. Parr	Tractor manufacturers	Oliver forerunner
1920	Competing tractors	Rugged, durable	Efficient, relatively inexpensive
1931	B.F. Goodrich	Rubber tires	Efficient, more comfortable

Source: Bolino (1966), Krooss (1966), Dieffenbach and Gray (1960), Davis, et. al. (1965), and Benedict (1953)

Key sources of 19th and early 20th century farm productivity gains were:

- Machines, especially the plow, reaper, harvester and tractors.
- Plant and animal nutrition, including soil conditioners, and fertilizers and the development of balanced animal rations. By 1965, use of plant nutrients relative to 1939 levels had grown tenfold for nitrogen, fivefold for phosphorous and sixfold for potassium, in response to better information about yield responses, and better, cheaper fertilizers.
- Better genetics, especially the development of hybrids.
- Availability of electricity, and efficient electric motors.
- Pesticides and herbicides.
- The advent of packaged technology, supplemented by numerous information sources to improve management and increase effectiveness of machines, livestock, better genetics and better chemicals.

> The story of the development of hybrids is dramatic, and includes the success of science in spite of opposition from established technologies. Impacts of unusual corn breeding developments were observed as early as the 1870s. However, the initiation of modern corn breeding is considered as occurring about 1920, following the discovery (about 1910) that crossing inbred lines led to increased vigor and higher yields. By 1940, most Corn Belt farmers were using hybrid corn. Merle T. Jenkins, "*Corn Improvement*," USDA Yearbook, 1936. Wayne Rasmussen, USDA, 1960.

The nature of agricultural growth changed fundamentally after about 1930. The industrial revolution had changed the sector dramatically, but productivity actually increased relatively little between 1870 and 1930 and growth came primarily from increased input through 1930. Between 1930 and 1950, agricultural inputs essentially stabilized before peaking in 1950, but output growth was rapid so that productivity increased dramatically (from an index of 53 in 1930 to 92 in 1960 and 113 in 1975).

During the early part of the six-decade period 1920-80, the primary source of productivity growth was from modern farm power. But as important as the shift to tractor power was, yield growth also was important during the early years of the 20th century (Table 3). However, in more modern times, as the impact of the farm power revolution has passed, the primary source of output increases shifted from better power and more land (especially during World War II) to better crop and livestock yields, with most of the increase from crop yields.

Table 3. Sources of Increased Farm Output

Source	1920 to 1940	1940 to 1950	1950 to 1960	1960 to 1980
		percent		
Reduction in Farm Produced Power	51	22	10	0
Yield Growth	34	37	87	73
Cropland Use Shifts	-4	15	-28	-13
Livestock Yields	19	26	31	40
Farm Output Growth	100	100	100	100

Source: Christensen, et al, 1964

The US agricultural production index was 122 in 1994, with gross output 18% higher that year than a decade earlier (Table 4). Crop productivity continues to grow faster than for livestock; labor and energy productivity were both negative during the period, and are stimulating the sector to use less of those inputs. The ratio of output to input for farm labor increased nearly one-third during the decade, more than three-fold the rate of non-farm labor.

Table 4. US Agricultural Production Index, 1985-94
1982 = 100

	1985	1994	Change %
Farm Output	103	122	18
Livestock	104	122	17
Crops	102	121	19
Inputs			
Labor	93	89	-4
Durable Equipment	97	90	-7
Energy	90	95	6
Chemicals	100	111	11
Output/Unit of Input			
Farm Labor	114	152	33
Non-Farm Labor	107	117	9

Source: ERS, USDA, *Agricultural Outlook*, 1998

Without productivity growth, the sector likely would have declined in absolute terms and relative to the rest of the economy over the past 50 years. This trend is quite uneven over time, reflecting both advances in the sector's "knowledge base" and the economic stimuli that lead to their adoption, including, in some cases, government programs that stimulate investment in some areas while retarding it in others. And, the sector's rapid overall productivity growth masks substantial differences among crop and livestock, with a 1.6% average rate recorded for livestock and a faster 2% for crops. The overall rate also masks internal differences in some sectors – for example, dairy productivity growth estimates are relatively small because rapid growth and output increases in the West were largely offset by decreases in other regions. Across the sector, poultry and oilseed crops have been the fastest-growing during the post World War II period (Table 5).

Input productivity reflects both the quantity and quality of inputs used. Thus, the high rates of productivity growth of pesticide use reflect both the amount and quality of product used. By contrast, labor productivity has declined 2.3% annually, and its use has fallen from 7.6 million people in 1948 to 3.4 million in 1994.

Table 5. Agricultural Productivity Growth Compared by Commodity, 1948-94

Farm Outputs/Inputs	Annual Growth
Total	1.88
All Livestock	1.65
Dairy Products	0.60
Poultry	3.55
All Crops	2.00
Food Grains	1.54
Feed Grains	1.67
Oil Crops	4.22
Vegetables	1.67
Fertilizer Use	1.72
Pesticide Use	4.73
Fuels Use	0.83
Feed/Seed	1.24
Labor	-2.27
Capital	0.67

Source: ERS Agricultural Information Bulletin #740, January 1998

In Canada, similar trends are evident:

- Between 1921 and 1996, the number of farms rose gradually from 711,000 in 1921 to a high of 733,000 in 1941, fell steadily to 366,000 in 1971, and decreased gradually to 277,000 farms in 1996.

- Total farm area rose from 141 million acres in 1921 to 168 million acres in 1996. The consolidation of farm operations over the years, coupled with the increase in total farm area, resulted in an increase in the average farm area from 198 acres in 1921 to 608 acres in 1996.

- The total area of land in crops increased 72% to 86 million acres between 1921 and 1996.

- The 3.5 million horses reported on 608,000 farms in 1921 fell below 800,000 on 318,000 farms by 1956. Increased farm mechanization has since eliminated the need for horses as working animals on the farm.

- During this period, the total number of tractors increased nearly fifteen-fold to 711,000 tractors on 246,000 farms. The greatest increase occurred between 1941 and 1951, when total tractor numbers increased by 240,000 units.

- Commercial fertilizer use increased 35% between 1981 and 1996 to 61.6 million acres.

- Herbicide use increased 53% between 1981 and 1996 to 57.5 million acres.

- Total farm capital value increased 174% between 1976 and 1996 to Cdn$156.5 billion. During the same period, the value of land and buildings increased 167% to Cdn$116.2 billion, farm machinery and equipment rose 214% to Cdn$28.4 billion, and livestock and poultry increased 165% to Cdn$11.8 billion.

The food system also has undergone tremendous changes in the last century (Table 6). One hundred years ago, food marketing was vastly different from today. Most food was purchased in bulk in general stores, or directly from the producer. Nearly all preparation was done at home, and there were virtually no "processed foods" on the market. The food system has evolved dramatically, to the point where the commodities involved account for only a small portion of the total product value.

Table 6. Food Industry Milestones

Year	Inventor	Development	Remarks
1860s	Atlantic & Pacific (A&P)	Central Warehouse Distribution	Precursor to modern supermarket
1905	Dewey & Almey	Automated Can Production	Used mechanized application of seaming spray to increase efficiency in can production
1920s	Several developers	Refrigerated Distribution	Benefited meat, dairy product industries
1930	Michael Cullen	Supermarket	The supermarket itself necessitated major developments in transportation, processing, and packaging
1930s	Clarence Birdseye	Freezing	
1930s-1940	W. Edwards Deming	Statistical Quality Control	Deming's methods of quality control using statistical sampling were quickly and widely adopted in the food industry
1940s-1950s	Several developers	Plastic Packaging	Pioneered by US government, expanded by Dow & DuPont
1950s	US Government	Freeze Drying	Developed for troop rations, commercialized soon thereafter
1950s	Hormel	Vacuum Packing	
1970s	IBM	UPC (Bar) Codes	When supermarket scanners were widely installed, bar codes provided a wealth of data for inventory management

Source: Dr. Daniel Farkas, Oregon State University

Productivity responds to both internal and external factors, including weather affecting year-to-year variations. Other external shocks to the economy indirectly affect relative prices and resource allocations – including relative price changes that can stimulate investment in technical innovation. An example is the sharp increases in energy prices during the 1970s which led both public research and private investors to develop new techniques to save on fuel and other expensive petroleum-based inputs.

Productivity growth in agriculture is normally attributed to four major factors[1]:

- Public investment in agricultural research and development;
- Public expenditures on infrastructure;
- Private expenditures in research and development; and
- Technological advances in material inputs such as fertilizer and chemicals.

Why the Study – And, Why Now?

Productivity growth, one of the primary keys to a healthy and growing economy, is among the most closely monitored performance indicators. Increased productivity not only boosts the competitive position of products, but increases our standard of living by passing sector gains to consumers through better products, more output and/or lower prices.

Still, biotechnology is very different from the earlier technology shifts that changed agriculture or food processing – important as they were. Those changes focused on one or a few aspects of production that created shifts that rippled through the system. The current innovations that are the focus of this study have the potential to change food and agricultural products, their characteristics, their performance, and their uses. As a result, they will inevitably change the system itself – its size, its performance, and its control – the first innovation in history with such far-reaching potential.

And, it is just this avalanche of change that is now upon us, after being promised for many decades. It is clear that key economic competitors across the system are well on their way to investing heavily in key positions in the new system. It is just as clear that those who ignore these early signals and shifts could find themselves operating from positions of significant disadvantage as the system changes.

Although still in its relatively early stages, this change is so powerful and broad that it will dramatically alter the sector in each of its dimensions. To gauge its potential impacts all across the agriculture and food industry, SCI is examining recent developments, those likely in the near future and their likely impacts on food and agriculture. It is the vast scope of this just-beginning revolution and the breadth of its implications that have prompted this special study.

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[1] Mary Ahearn, Jet Yee, Eldon Ball, Richard Nehring, *Agricultural Growth and Productivity in the United States,* Economic Research Service, Agricultural Information Bulletin #740, USDA, January 1998, p 12.

Guide for the Remainder of the Report

This review examines the foregoing concerns, and several others in the following sections. It proceeds in six chapters:

- Following this introduction, Chapter II provides a historical perspective on the origins of commercial biotechnology.
- Chapter III reviews the agricultural biotechnology developments that have occurred worldwide to date.
- Chapter IV discusses the biotech pipeline – the products expected to become available in the next five years.
- Chapter V presents an overview of the food and agricultural system – setting the stage to examine the implications of biotechnology.
- Chapter VI analyzes the likely impacts of agricultural biotechnology on the various components of the food system.
- Chapter VII discusses overarching implications that could affect all components of the food system as well as those with broad social implications.
- Chapter VIII presents one suggested view of the food system that will emerge five years hence.
- Chapter IX suggests key indicators and developments to monitor as the biotech revolution unfolds.

II. The Origins of Commercial Biotechnology

What Is Biotechnology?

While we like to think that our current plant and animal science disciplines are relatively modern, many of the same fundamental techniques they use have been applied throughout human history. In fact, the plant and animal improvement process itself is simple B it involves the identification of especially desirable traits, and the selection of individuals that demonstrate Amarkers@ linked with the improvement.

Farmers traditionally understood that they could improve future harvests by selecting seed from the current crop on the basis of key traits (i.e., those plants that gave the highest yield, stayed the healthiest during periods of drought or disease, or were easiest to harvest) because the selected plants tended to produce the same characteristics. The genetic understanding of heredity gave strong support for applied, scientific farming. Subsequent genetic advances have moved far beyond on-farm selection through the introduction of controlled hybridization and the enormous vigor and sustained yield increases of the mid-20th century, but most of this progress continued to depend heavily on selection and more-or-less conventional plant and animal breeding methods.

Modern biotechnology goes beyond traditional selection processes to implant specific genetic information that can enhance desirable traits in an organism that can be passed on to its progeny. For example, scientists now routinely use enzymes to cut and remove individual genetic information from one organism and then transplant or recombine it with another organism.[2] They have successfully identified many specific genetic sequences that are responsible for specific characteristics in different organisms B for example, the specific area of a bacterium=s DNA that makes it toxic to certain insects and yet harmless to humans and animals. And, they have learned to cut and insert key genetic sequences into valuable plants and animals, and thereby control to a degree important characteristics.

The science of shifting DNA and creating specific traits has been extremely difficult to master. For example, researchers must be able to list the chemical bases in an organism=s DNA in the exact order in which they occur in order to track down particular stretches of DNA devoted to genes,

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[2] The genetic code of every living creature B plant, animal or microorganism B is carried by long, twisting molecules of DNA. A single strand of DNA consists of a long sequence of small molecules called bases, and it is the order of these bases that encodes all genetic information. It is customary to represent the four bases that go into DNA as letters in a sort of chemical alphabet: A for adenine, C for cytosine, G for guanine, and T for thymine. In this way, a strand of DNA is written out as one long Aword@: AATAGCTCCY, and so on for a hundred million or more complementary strands, with an A in one strand always paired side-by-side with a T in the other strand, and similarly for C and G. Sequencing a stretch of DNA means listing the chemical bases in the exact order that they occur. *Board on Biology, Board on Agriculture, National Research Council, National Academy of Sciences.* 1998

identify the sections involved in turning genes on and off, and in general, decode the instructions for assembling and operating that particular creature.

> The major obstacle to sequencing an organism=s genome B the total complement of DNA B is the sheer amount of DNA involved. Even bacteria tend to have genomes that are one or two million base-pairs long, and the genomes of plants and animals are generally hundreds of millions to billions of base-pairs long. Modern sequencing techniques can handle pieces of DNA no more than a thousand base-pairs in length, so researchers must chop up the long strands of DNA into small fragments before sequencing them, and this leaves them with the problem of how to piece together these fragmentary sequences. With various tricks, it is relatively straightforward to assemble sequences that are tens of thousands of base-pairs long, but that is a small part of a chromosome that may be hundreds of millions of base-pairs long. Furthermore, it is difficult to tell where on that chromosome a particular sequence lies. Thus, genetic maps that locate particular genes are used to find markers B links between genes and particular traits B and where they are located on a chromosome. A genetic map of a chromosome may contain hundreds of genes and markers in the order they appear on the chromosome.

The term biotechnology is not new B it was first used by a Hungarian engineer, Karl Ereky, just after World War I, but his concepts were as different from modern biotechnology as the horse and buggy is from the automobile. Ereky included all lines of work by which products are produced from raw materials with the aid of living organisms. Still, Ereky was something of a visionary and described a biochemical age similar to the stone and iron ages B an era in which we are beginning to find ourselves today.

As biotechnology has become more widely used, its meaning has become more specific and less traditional. New understandings of organisms and their cellular structure now permit increasing control of many functions of cells and organisms. Gene splicing and recombinant DNA technology permit scientists to combine the genetic elements of two or more living cells. Functioning lengths of DNA can be taken from one organism and placed into the cells of another. As a result, bacterial cells can be caused to produce molecules identical to those produced by humans or animals. And, we can synthesize therapeutic molecules that did not previously exist. Increasingly, biotechnology has come to mean the use of such processes involving more direct implantation of specific genes into target plants and animals, in contrast to more conventional selection processes.

For any process as dynamic as biotechnology, specific definitions are soon outdated B and, perhaps misleading. In fact, the purpose of this study is a comprehensive examination of agricultural biotechnology and its implications rather than the possible boundaries of this field of science. As a result, a broad definition of biotechnology is used that includes both processes and crop and livestock attributes. The terms Atransgenic@ and Anontransgenic@ are used to describe segments of the biotech product cosmos. Transgenic crops are those that have had a gene inserted from another plant or organism and are the same as Genetically Modified Organisms (GMOs), and the word also encompasses Living Modified Organisms (LMOs), a term used frequently in Canada.

Background B Biotechnology Then and Now

Biotechnology in one form or another has been important since prehistoric times. When man first domesticated crops and livestock, primitive biotechnology approaches were used to improve on what nature first provided. Processes that convert juices into wine, milk into cheese or yogurt, grain into beer, all involve some form of fermentation and other basic biological processes improved by the application of technology B as has the production of breads and other foods made from flour and many, many other products over millennia. Herdsmen, selecting breeding stock on the basis of physical traits that could be either magnified or diminished, were engaged in genetic manipulations B a form of biotechnology.

Not all traditional plant and animal improvement efforts focused on agricultural production B many processing operations depend on biological processes. Controlled fermentation processes have been used since the earliest times to produce foods by allowing living organisms to act on other ingredients. And, it was soon discovered that, by manipulating the conditions under which fermentation takes place, both the quality and the yield of ingredients themselves can be improved. The German scientist, Eduard Buchner, found in 1897 that enzymes extracted from yeast are effective in converting sugar into alcohol, a discovery that has long been important in the development of specific agro-processing operations.

Fermentation depends naturally on microorganisms including bacteria, yeasts, and molds that digest grain and other products. Beer is made using yeast cells to break down starch and sugar (present in cereal grains) to form alcohol; the froth of the beer results from the carbon dioxide gas that the cells produce. Bread rises as a result of gas produced by yeast cells. The digestion process generates alcohol (which contributes to the aroma of the bread) and carbon dioxide gas (which makes the dough rise and forms the honeycomb texture of the baked loaf).

The precursors of modern biotechnology processes ranged increasingly beyond food and agriculture. Early efforts to control disease outbreaks in overcrowded industrial cities led to the introduction, in the early years of the present century, of large-scale sewage purification systems based on microbial activity. By this time, it had proved possible to generate certain key industrial chemicals (glycerol, acetone, and butanol) using bacteria.

Perhaps the most widely known major Awonder drug@ of the early 20th century was Alexander Fleming=s discovery of the bacteria-phage penicillin, derived from the mold Penicillium. Large-scale production of penicillin was achieved during World War II B although the revolution in understanding the chemical basis of cell function that stemmed from the post-war emergence of molecular biology was still to come. This enormously important application of lifesaving bioscience helped lay the groundwork for today=s explosive development of biotechnology. And, as US society has come to know and appreciate these advances and their benefits, the acceptance of biotechnology in the United States has come early and with little protest.

Biotech Regulatory Policy

Today, the US government appears strongly committed to the use of biotechnology in developing increasingly competitive products for domestic and international markets. Two key public policies have been particularly important in support of that commitment for agriculture:

The Plant Variety Protection Act of 1970 permitted genetic traits and transformation methods to be patented (with materials that could be used as parents in another breeding program protected). Before that time, most agricultural genetics was in the public domain B with the exception of work on hybrid corn and a few others. Since then, growing amounts of investment in plant, animal and microbial genetics have been private, contributing significantly to the recent explosion in biotechnology.

In the intervening years, the Congress and a succession of administrations have made clear the public policy of promoting joint public-private investment in basic research on biotechnology, with much of that effort intended to stimulate private investment in the commercial biotech products.

This policy commitment is not exclusively for agriculture B many of the earliest biotech products were medical, and that continues to be the case. However, the public commitment to support the development of private commercial biotech products has become increasingly clear over time.

> An example of government commitment to biotechnology was its support for the *Arabidopsis* Sequencing Program. A small, nondescript member of the mustard family, *Arabidopsis thalia* provided scientists the equivalent of the laboratory mouse B and now is poised to become the first plant to have its entire genome sequenced and made available for study. *Arabidopsis* was chosen for this project because it has a small life cycle, is a prolific seed producer, and has the smallest known genome of any flowering plant B only 100 million base pairs.
>
> In 1996, three US government agencies (USDA, Department of Energy and National Science Foundation) awarded $12.7 million over three years to three sequencing groups at Cold Spring Harbor, Stanford University and The Institute for Genome Research. Other cooperating groups are in Japan and 17 European labs. The project is expected to be complete by 2004. *Board on Biology, Board on Agriculture, National Research Council, National Academy of Sciences.* 1998.

The White House Regulating Framework B *Federal Coordinated Framework for Regulation of Biotechnology*. In the mid-1980s, new medical biotechnology products were appearing rapidly and the Reagan administration was deeply concerned that the bureaucracy would stymie this flow.

The White House Regulatory Framework of 1986 divided responsibility for regulation among three existing agencies, rejected completely the concept of a Asuper agency@ for biotechnology, and clearly established a policy that permitted biotech product testing and approval without undue delay. The United States Department of Agriculture (USDA), the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA) are the three agencies involved in monitoring the development and testing of genetically engineered products.

USDA/APHIS. The USDA regulates genetically engineered food plants through its Animal and Plant Health Inspection Services (APHIS) Division. APHIS administers the Federal Plant Pest Act (FPPA), which authorizes APHIS to regulate interstate movement, importation, and field testing of Aorganisms and products altered or produced through genetic engineering@. This includes such potential products as plants with improved disease resistance and animal vaccines made with genetically-modified bacteria. APHIS also may establish specific rules under which the test must be conducted as a condition of its approval.

APHIS exercises its regulatory authority through a permit system. There are three basic types of permits that an applicant who is developing a genetically engineered plants may be required to obtain. Permit applications are handled by the Biotechnology Permits unit of Biotechnology, Biologics, and Environmental Protection (BBEP) within APHIS. An APHIS permit and approval of individual state departments of agriculture are required to move any genetically-engineered organism that is a potential plant pest into the United States or between states.

APHIS also oversees field testing or Aenvironmental release@ of genetically-engineered crops, requiring information about the plant, all new genes, their origin, the purpose of the test, the experimental design, and precautions to be taken to prevent the escape of pollen, plants, or plant parts from the field test site. Upon evaluation, APHIS prepares an environmental assessment (EA) document that analyzes any possible environmental impacts the field test could have. The EA is required by the National Environmental Policy Act, Council on Environmental Quality regulations, and USDA procedures.

Applicants also may request a courtesy permit from APHIS to move or field test a genetically-engineered plant that is not regulated by the agency. Sometimes a non-regulated plant may be similar to one that is regulated by APHIS, and an APHIS permit may make it easier to move or field test the plant.

Corn, cotton, potato, soybean, tobacco, and tomato crops are considered by APHIS using special criteria. After reviewing many permit requests, APHIS found that 85% of genetically-modified plant field tests involved varieties of these six major crops. Based on the data obtained from these tests, APHIS determined that tests of these crops did not pose a plant pest risk. It therefore issued rules in March 1993 that allow genetically-modified varieties of these crops to undergo field tests with only a 30-day advance notification to APHIS, avoiding the permit application process.

FDA. The Food and Drug Administration has the primary responsibility of regulating food additives and new foods, except meat and poultry products that are regulated by the USDA. However, the genetically-modified animal growth hormones bovine somatotropin (BST) and porcine somatotropin (PST) came under FDA regulation because the agency is required to determine the safety and efficacy of animal drugs. Before allowing drugs for food-producing animals to be marketed, the FDA requires under the Food, Drug, and Cosmetic Act that these drugs are rigorously studied and that residues of the drug in meat, milk, or eggs must be safe to consume.

FDA will require labeling of genetically engineered foods if potential allergens are present. If a gene from a food that commonly causes allergic reactions, like fish or peanuts, is inserted into tomatoes or corn, where people would not expect to find allergens, then the vegetables would have to be labeled to alert consumers. FDA=s policy states that proteins taken from commonly allergenic foods are presumed to be allergens unless demonstrated otherwise.

Labeling also could be required if the nutritional content of the food is changed. Tomatoes are a major source of vitamin C, and if a tomato were developed that no longer contains vitamin C, that then would have to be disclosed. In contrast, FDA does not specify the method by which a plant is developed by a plant breeder to be material information. For example, FDA does not require sweet corn to be labeled Ahybrid sweet corn@ because it was developed through cross-hybridization. Other biotechnological techniques used by plant breeders do not need to be reported for practicality reasons. If, however, genetic engineering changes the composition of a tomato in a way that it is not the same tomato anymore, then it must have a different varietal name, or, if it was a significant difference, it may no longer be called a tomato.

EPA. The Environmental Protection Agency regulates pesticides under the authority of the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). The former holds EPA responsible for regulating the distribution, sale, use, and testing of pesticides in order to protect humans and the environment, while the latter authorizes EPA to set tolerances or establish exemptions from the requirement of a tolerance for pesticide residues in or on food crops.

Producers of biotech products are required to consult with the EPA if the pesticide meets any of the following criteria:

- The pesticide is not derived from a known food source (e.g., *Bacillus thuringiensis* pesticides are derived from a bacteria).
- The pesticide is derived from a known food source and is introduced into a known food source, but the way humans are exposed to it in their diets changes.
- The pesticide has a different structure, function, or composition than its counterpart that already occurs in food (e.g., the structure of a protein pesticide that already occurs in food could be altered significantly).

The regulatory system described above is, in essence, a patchwork of pre-existing regulatory authorities. The issuance of the *Federal Coordinated Framework for Regulation of Biotechnology* in 1986, claiming there would be no new laws to regulate biotechnology, paid off for drug and pharmaceutical research which at the time was already heavily regulated and able to cope with the existing federal regulatory requirements. This was not the case, though, for agricultural biotechnology. USDA=s APHIS permitting system arose to regulate crop plants and comply with the Coordinated Framework.

The current segregated approval process has been considered by some to be burdensome to the agricultural biotechnology research agenda. The early lobbying of the drug and pharmaceutical industry likely drove the decision for no new regulations, but also forced the application of standards from multiple and competing regulatory agencies. As a result, agricultural biotechnology research pays very high transaction costs for regulatory compliance.

Little change has been suggested, however, by agricultural biotechnology companies as it likely is easier to comply with current regulations than risk a tightening of standards even further. For large companies, compliance with regulations is not particularly burdensome and receiving federal government approval of research and products provides a level of >cover= for biosafety questions.

Biotech B Long Term Investments to Pay Off?

In spite of its tremendous promise, the biotech industry has been economically stagnant for much of the past two decades or more B with many of the companies incurring continuing losses and far slower than expected product development. In 1986, FDA identified 155 companies working on significant biotechnology projects with the potential to affect food and agriculture B a large group for a field just evolving. In fact, many of those companies were built around one or a few very strong researchers with a powerful idea for a new commercial product. In many cases, they were retired university professors or retired scientists from public research units betting on exotic new technologies.

For many relatively young companies, techniques developed in university laboratories in the 1970s have opened the possibility of being able to exploit advances in biotechnology in new commercial ways. For instance, scientists realized that they could isolate genes that tell the body how to produce insulin, insert those into a germ or bacteria, grow millions of copies, and get the organisms to produce human insulin. And, the artificial product is both purer and cheaper than insulin from livestock. In the past, drugs had been produced on a hit-or-miss strategy of experimentation in the laboratory, followed by tests on animals. The new methods promised a far more targeted approach, with drugs designed molecule by molecule to achieve their intended effect. Early products, in addition to insulin, included blood-clotting factors that were already known to work as treatments.

The first biotech company is generally acknowledged to have been Genetech Inc., of South San Francisco, founded in 1976. Genetech stock first soared but then faded as it became clear that the science of producing commercial biotechnology was a lot more complicated than laboratory work had suggested. And, since the 1970s, the industry was locked into a series of boom-and-bust cycles on Wall Street.

At the other extreme, the largest biotech company today is Amgen Inc., with 5,300 employees and $2.4 billion in sales from just two products. The first is erythopoetin (Epogen) which signals the bone marrow to produce red blood cells and offsets anemia in people on kidney dialysis. The second product is similar and corrects imbalances in production of white blood cells. Amgen=s market capitalization now has reached $16 billion, making it perhaps the largest biotech company in the world.

Many of today=s biotechnology companies were linked to medical products, in part because the market for human drugs is so large and provides such potentially large payoffs from risky investments, and successful commercial development of new biotech medical products provides powerful success stories. Recent press reports suggest that long periods of heavy losses may be nearing an end for many small biotechnology companies. A handful have finally become profitable, and analysts expect many more to become so over the next few years. For example, Ernst and Young projects the industry as a whole should be operating in the black by the end of the century for the first time in history. Sales and employment are rising by about 20% annually.[3] New treatments, long in the works, have advanced to late stages of testing and reportedly are holding up well B and, a number (especially in the drug field) are winning approval by FDA.

In many cases, these companies still seem to be betting on risky propositions. An example cited in a recent article was of a small company (MedImmune) that developed an antibody to prevent respiratory infections hospitalizing 90,000 babies annually. Its approval by FDA was the first for that type of product, and represents broad potential for such drugs. In response, biotech executives are increasingly predicting many other dramatic results, with Ahigher crop yields, improved manufacturing methods and striking advances in medical care@ seen as a result of the long years of

[3] *Biotech=s Payday Arrives*, Washington Post, July 6, 1998

continued research investment. However, despite this optimism, biotech investing still is seen as perilous. Many companies carry high price tags, still have little cash flowing in, and thus continue to trade on hopes and expectations. And, even if analysts are correct and the industry as a whole becomes much more profitable, individual firms could face continuing disappointments. Ernst and Young suggests an announcement of bad news by one of these companies easily could mean a 35% drop in stock value in a single day.

Still, the prospects for biotech companies in both food and agriculture and the medical fields seem far brighter today than just a few years earlier. For example, MedImmune is now working on a vaccine for the human papilloma virus B responsible for nearly all cases of cervical cancer, which strikes 80,000 women annually and kills nearly 5,000. A safe, effective vaccine, perhaps given to young girls as part of childhood immunization, could stop widespread suffering and would have a huge market, perhaps worth billions of dollars. To an important extent, it is prospects of payoffs of this magnitude that have stimulated the developments B and continuation against adverse conditions and low returns B that are driving the biotechnology revolution today.

Key Events in the Evolution of Biotechnology

Genetic engineering became a reality when a man-made gene was first used to manufacture a human protein in a bacterium. However, it is instructive to review selected key events of the past that led to today=s explosion of biotechnology.

Selected Milestones in the Development of Agricultural Biotechnology

1866	Mendel postulates a set of rules to explain the inheritance of biological characteristics in living organisms.
1953	Watson and Crick discover the double-helix structure of DNA.
1960	Genetic code deciphered.
1970	The Plant Variety Protection Act permits genetic traits and transformation methods in plants to be patented.
1973	First gene (for insulin production) cloned, using rDNA technology.
1976	First new biotechnology firm established to exploit rDNA technology (Genetech in USA).
1977	Genetech, Inc., reported the production of the first human protein manufactured in a bacteria: somatostatin, a human growth hormone-releasing inhibitory factor. For the first time, a synthetic, recombinant gene was used to clone a protein. Many consider this to be the advent of the Age of Biotechnology.
1978	Stanford University scientists successfully transplanted a mammalian gene.
1980	US Supreme Court rules that microorganisms can be patented under existing law (*Diamond v. Chakrabarty*), opening up enormous possibilities for commercially exploiting genetic engineering, which until that point had rested solely on the ability of companies to protect trade secrets. Cohen/Boyer patent issued on the technique for the construction of rDNA.
1981	Scientists at Ohio University produced the first transgenic animals by transferring genes from other animals into mice.
1982	First rDNA animal vaccine approved for sale in Europe (colibacillosis). First rDNA pharmaceutical (insulin) approved for sale in US and UK. First successful transfer of a gene from one animal species to another (a transgenic mouse carrying the gene for growth rate hormone). First transgenic plant produced, using an agrobacterium transformation system.
1983	First successful transfer of a plant gene from on species to another.

1985	US Patent Office extends patent protection to genetically engineered plants.
1986	Transgenic pigs produced carrying the gene for human growth hormone (USDA, Beltsville, Maryland).
1987	First US field trials of transgenic plants (tomatoes with gene for insect resistance). First US field trials of genetically engineered microorganism approved for commercial sales as a biocontrol agent of a plant disease (crown gall of fruit trees in Australia). Calgene, Inc. received a patent for the tomato polygalacturonase DNA sequence, used to produce an antisense RNA sequence that can extend the shelf-life of fruit.
1988	US Patent Office extends patent protection to genetically engineered animals. First genetically modified microorganism approved for commercial sales as biocontrol agen t of plant disease (crown gall of fruit trees in Australia).
1989	UC Davis scientists developed a recombinant vaccine against the deadly rinderpest virus, which had wiped out millions of cattle in developing countries (1989).
1990	The first successful field trial of genetically engineered cotton plants was conducted by Cal gene Inc. The plants had been engineered to withstand use of the herbicide Bromoxynil. The Plant Gene Expression Center reported stable transformation of corn using a high-speed gene gun. GenPharm International, Inc. created the first transgenic dairy cow. The cow was used to produce human milk proteins for infant formula. The Human Genome Project, the international effort to map all of the genes in the human body, was launched. Estimated cost: $13 billion.
1991	Guidelines published for field trials of genetically modified organisms (ABRAC).
1992	FDA announces policy on foods derived from new plant varieties. USDA permission granted to Calgene, Inc., for FlavrSavr tomato.
1993	USDA-APHIS notification procedure to streamline permitting process. FDA approves supplemental BST for commercialization.
1994	Congressional moratorium on supplemental BST ends. FDA considers policy on voluntary labeling for supplemental BST.
1996	FlavrSavr tomatoes pulled from market shelves. Introduction of commercialized herbicide tolerant and insect resistant crops B significant acreage planted in United States.

Source: ERS Agricultural Economic Report #687, *Agricultural Biotechnology: An Economic Perspective*, 1994.

Recent Experiences with Biotechnology

The FlavrSavr Tomato

Calgene developed a genetically engineered tomato variety with a gene that delays softening and reduces spoilage in order to provide vine-ripened tomatoes throughout the year with improved taste. Calgene began talks with FDA in 1989 and submitted the marker gene for approval in 1990. The company opted to forego the confidentiality usually maintained by FDA and requested that all findings and issues be made public. In 1992, USDA deregulated the FlavrSavr tomato, allowing Calgene to grow and ship the new tomatoes in the same manner as conventionally developed tomatoes. In May 1994, in response to Calgene=s request, FDA rendered an advisory opinion that the FlavrSavr tomato was safe to consume and as nutritious as conventional tomatoes. Calgene introduced the FlavrSavr tomato to commercial markets in 1994 under its MacGregor=s brand.

But, the product was pulled from store shelves in mid-1996. The product likely failed not because of concerns over biotechnology but because of the unexpected requirements of a new product. Upon introduction, the tomatoes promised the taste of home-grown tomatoes from the grocer=s cooler. Typical store-bought tomatoes are picked while they are green and hard so that they will not spoil while they are shipped. The tomatoes then have their red color brought out by spraying with the plant hormone ethylene, but still have the lackluster flavor of unripe tomatoes.

FlavrSavr was supposed to change that. Because it had longer shelf-life, it could ripen on the vine and then be shipped to the supermarkets. But, producers continued to use the same equipment to pick and ship the ripe, soft tomato as they had the hard, green tomatoes. This brought losses of as much as 30%, and by the time new packaging equipment was obtained, the company could no longer continue production.

Biotechnology suffered only a modest setback from that experience, but faced further controversy with the introduction of a synthetic growth hormone for livestock, BST.

BST

One of the first genetically engineered products available to farmers was bovine somatotropin (BST), also called bovine growth hormone (BGH). This key hormone is made naturally in the pituitary gland of cattle, and promotes growth in calves and regulates milk production in mature dairy cows. The engineered version of BST is manufactured by bacteria using copies of the cow=s genes and boosts milk yield by up to 20%.

While the product administered to the cow is identical to that made by the cow herself, the use of recombinant BST has been the subject of much controversy. After long study, the hormone was approved for commercial use by US farmers in 1994, but the debate continued for some time over consumer reactions, seeming only in recent years to moderate.

Economics played a large role in the development and adoption of BST. A dairy cow=s normal milk production cycle peaks about 50 days after calving before declining steadily over the following 10 months. The extra energy needed to make more milk comes initially from the cow=s own body fat, but after the peak, the cow relies on feed for that energy. Dairy farmers use BST during the second half of this cycle to boost production, and to reduce the number of cows necessary to achieve a given milk output.

The overall economic effect of BST on farmers depends on the economic structure of each herd. The added costs of medication and veterinary consultations associated with use of BST and the need for increased management related to feeding and housing, make it uneconomical for many small operations. The main focus, however, of the debate that swirled around official approval of BST for commercial use has been animal health and consumer welfare. Arguments were made that BST resulted in increased stress on cows due to the increased production. Companies producing BST included warnings of possible side effects ranging from swelling to a reduced rate of pregnancy. Opponents of the hormone argued considerably more harmful effects.

Posilac (Monsanto=s BST product) was approved in the United States on February 1, 1994, and 14 million doses were administered on 13,000 farms that year, representing 11% of US milk producers. Close monitoring by FDA for the next 18 months revealed several hundred Aadverse reactions@ in herds given Posilac, but all of them involved conditions also found in herds not given BST. Biotech advocates thus argue that health problems are caused not by the hormone, but by inadequate management and improper feeding, hygiene or veterinary care.

Anxiety about drinking milk from cows treated with BST also has been a concern. In announcing the approval of the product in 1994, then FDA Commissioner David Kessler observed that, AThis has been one of the most extensively studied animal drug products to be reviewed by the agency. The public can be confident that milk and meat from BST-treated cows is safe to consumers.@ The fear still exists, though, that milk from these cows may contain antibiotics or high levels of hormones, which could be a health risk to humans, especially children.[1]

Caught between industry demands and public concerns, a number of governments opted for extreme caution over BST. By 1996, some 15 countries worldwide had licensed the use of BST. However, the EU placed a moratorium on its use until 2000 and banned the import of milk from BST-treated cows B citing their oversupply of milk, rather than concerns about safety. Due to perceived risks, Canada has to date refused to approve BST.

In spite of the concerns raised, no substantial health threat has developed in nearly five years since the approval of BST. As acceptance of the hormone has grown in additional countries, opponents shifted the terms of the debate to one of Aright to know@ and the question of whether milk should be labeled. Countering this argument, the Food and Nutrition Science Alliance (representing the American Institute of Nutrition, American Society for Clinical Nutrition, Institute of Food Technologies and American Dietetic Association) points out that milk from BST-treated cows is no different from other milk and that the presence of any such label implies some health risk which has not been demonstrated.

The issues that emerged during the development and release of these two products did little to slow the emergence of other agricultural biotech products. The explosion of biotech crops planted in the United States and Canada in 1996 and the exponential growth in acreage over the past three years and around the world well make the case that the biotechnology revolution has begun.

The Players Today

Many companies that have been long involved in biotechnology are making the transition from the chemicals industry into the life sciences, positioning for control of products and global markets. This is illustrated by industry leader Monsanto, long a world leader in chemical products, selling off its entire chemical division in 1997 and anchoring its research, development and marketing in biotech-based technologies and products. Other leaders are consolidating their position, rapidly buying biotech start-up companies, seed companies, agribusiness and agrichemical concerns, pharmaceutical, medical and health businesses, and food and beverage companies, creating broad-scale life-science complexes.

The consolidation of the industry is occurring rapidly. In 1997, the top ten agrochemical companies control 82% of the $31 billion global agrochemical market. Ten life science companies control 40% of the $15 billion per year global seed market. The world=s ten major pharmaceutical companies control 36% of the $251 billion pharmaceutical market. Ten global firms now control 63% of the worldwide veterinary pharmaceutical market. The leading transnational food and beverage companies are extremely diversified and increasingly active in other life science fields.

The life sciences companies are striving to take full advantage of the new biotechnology products and processes, and are devoting significant funds to research and development and licensing agreements. An estimated $7.5 billion annually is currently invested in-house on biotechnology programs.

In the seed industry, too, companies are quickly positioning themselves to gain market access (Table 7). The seed business is clearly the vehicle to deliver the new technology. In 1997, the top ten seed companies accounted for 30% of the $23 billion seed trade worldwide. Pioneer Hi-Bred International currently is the world leader in the seed industry with nearly $1.8 billion in revenues. Monsanto=s interest in acquiring seed companies is clearly driven by its strategy to sell proprietary, genetically engineered traits in the global market. Monsanto now holds an 85% market share for US cotton seed, 33% for soybeans, and 15% for corn seed.

Table 7. World=s Leading Seed Companies

Company	1997 Seed Revenue mil US$
Pioneer Hi-Bred Intl. (US)	1,784
Proposed Monsanto/American Home Products (US) 1/	1,320*
Novartis (Switzerland)	928
Groupe Limagrain (France)	686
Advanta (UK and Netherlands)	437
AgriBiotech, Inc. (US)	425
Grupo Pulsar/Seminis/ELM (Mexico)	375
Sakata (Japan)	349
KWS AG (Germany)	329
Takii (Japan)	300*

1/ Merger canceled. *Estimated.
Source: Various

It is likely that by 2000 virtually all commercial seeds of major crops will contain at least one bioengineered trait, an enormous market potential. The International Seed Federation says that the world market for genetically engineered seeds could reach $2 billion by 2000, and then predicts explosion to $20 billion by 2010.

Some Leading Players

After several decades of investing billions of dollars in agricultural biotech research and strategic mergers and acquisitions, a few leaders in the field have emerged and have been able to quickly bring their products to market. Today=s leaders are three of the largest companies in agricultural biotechnology: DuPont, Monsanto and Novartis.

E.I. DuPont de Nemours

Headquarters:	Wilmington, Delaware
Sales:	$38.3 billion (1996)
Employees:	98,000

The largest chemical company in the world, DuPont conducts business in six major segments: Chemicals, Fibers, Polymers, Petroleum, Life Sciences, and Diversified Businesses. The Life Sciences group, with 1996 sales of $2.5 billion, produces pharmaceuticals and agricultural products (DuPont Agricultural Products), including crop protection (herbicides, insecticides and fungicides), feed, seed, food ingredient and food safety products. In 1997, DuPont formed a research alliance and separate joint venture company, Optimum Quality Grains, with Pioneer Hi-Bred International to speed the discovery, development and delivery of new crops for farmers and livestock producers. DuPont also purchased Protein Technologies International from Ralston Purina in the same year. (PTI is a leading global supplier of soy proteins to the food and paper processing industries.) DuPont recently divested 20% of its ownership in its Conoco petroleum unit through an IPO, resulting in a large surplus of funds to help grow its life sciences business, possibly through the acquisitions of agricultural biotech companies.

Monsanto

Headquarters:	St. Louis, MO
1997 Sales:	$7.5 billion
Employees:	21,900

Monsanto has set a fast pace of strategic acquisitions focused on creating the world=s leading Alife sciences@ company. Monsanto produces agricultural products, food substitutes, and pharmaceuticals. Its products include Roundup, a leading herbicide; several genetically engineered products; artificial sweetener NutraSweet; fat substitute Simplesse; and drugs used to treat insomnia and arthritis. Monsanto is looking to agricultural biotechnology products for growth (1997 agricultural products sales totaled $3.1 billion) B especially seeds, as its purchases of DeKalb Genetics and Delta and Pine Land illustrate. While spinning off its chemicals business (Solutia Inc.) in 1997, Monsanto acquired biotech firms such as Calgene and Agracetus. In addition to developing biotech crops, the company develops and manufactures herbicides, lawn and garden products, and BST, a synthetic growth hormone to boost milk production. Monsanto=s acquisition by drug maker American Home Products recently was called off.

Some of the largest life sciences companies are strategically positioned to control much of the global biotech market. Novartis, a giant new global firm resulting from the $27 billion merger of two Swiss companies, the pharmaceutical company Sandoz and the agrochemical company Ciba-Geigy, is typical of the trend toward corporate consolidation in the life sciences industry. Novartis is the world=s largest agrochemical company, the second largest pharmaceutical company, the third largest seed company, and ranks very high in veterinary medicines. The company also is staking claims in the field of human genetic medicine.

Novartis AG

Headquarters:	Basel, Switzerland
1996 Revenues:	$27.0 billion
Employees:	86,000

Novartis, the result of the $27 billion merger of Ciba-Geigy and Sandoz, is a world leader in Life Sciences with core businesses in healthcare, agribusiness and nutrition. With 1996 sales of $5.7 billion, agribusiness includes crop protection (Ciba and Sandoz Agro merged into Novartis), seeds (Ciba Seeds and Northrup King - a Sandoz company - merged into Novartis Seeds), and animal health. Novartis Seeds develops, produces and markets selected, high-performance seeds and plants based on the most advanced genetics and related technologies. Novartis Seeds, the world=s second largest seed producer, is focused on high value-added products and markets in corn, sugar beets, oilseeds, vegetables and flowers. Novartis Crop Protection discovers, develops, manufactures and markets fungicides, herbicides, insecticides and seed treatment products. In 1997, Novartis acquired Merck & Co., Inc.=s crop protection business (1996 sales of $200 million worldwide).

Other companies (not affiliated with those above) with commercialized biotech products released to date include: AgrEvo, Dow Chemical (Mycogen), Zeneca, DNAP Holding Corporation, and Gist-Brocades. Introductory information on these companies and their business activities follows.

AgrEvo

Headquarters: Berlin, Germany
Sales: $2.0 billion (1996)
Employees: 8,550

AgrEvo, owned by Hoechst (60%) and Schering (40%), is the fourth-largest global agricultural chemical producer and marketer. It has large sales of herbicides (42%), insecticides (23%) and fungicides (16%), and now is in the process of transforming itself into an integrated crop production company. It acquired Plant Genetics Systems in 1996, recently completed construction of a new Liberty herbicide plant in the United States, and plans a broad array of Liberty Link and insect resistant seed products for the US market. Sales of agricultural biotechnology products and seeds accounted for about 3% of total sales in 1997.

The Dow Chemical Company

Headquarters: Midland, Michigan
Annual Sales: $20.1 billion (1996)
Employees: 42,861

Dow Chemical, the No. 2 US chemical company, is a global leader in production of chemicals, plastics, hydrocarbons, and agricultural and specialty products. It has sold noncore pharmaceutical, consumer, and engineering operations to focus on its chemical line and the biotechnology market. Dow AgroSciences, the agricultural chemical/biotech unit, with annual sales of about $2 billion is one of the largest research-based agricultural companies in North America.

Last year, the company formed Dow AgroSciences by acquiring the remaining 40% share of DowElanco, the joint venture between Dow and Eli Lilly. It researches, develops, manufactures, and markets agricultural and specialty products including herbicides, insecticides, fungicides, nitrogen stabilizers, plant growth regulators, fumigants, seeds, and industrial noncrop pest management products. The company has expanded its interests in the agricultural biotech arena by investing in its own R&D programs to find novel genes and by purchasing the biotech seed company Mycogen.

Zeneca

Headquarters: London, UK
Sales: $8.6 billion (1997)
Employees: 31,400

Zeneca Group, spun off from Imperial Chemical Industries in 1993, operates three main business areas: Pharmaceuticals, Agrochemicals and Specialties (leather coatings, resins, and biocides). Zeneca researches, develops, manufactures and markets products to improve human health, nutrition and quality of life. Zeneca offers a range of herbicides, insecticides and fungicides, while its Plant Science business uses biotechnology to enhance crop quality and help improve food production efficiency. Zeneca was the first company to have a genetically modified whole food (an increased pectin tomato) cleared for sale on both sides of the Atlantic.

DNAP Holding Corporation

Headquarters: Oakland, California
Total Revenue: $281.2 million (1997)
Employees: 589

DNAP Holding Corporation is a leading agricultural biotechnology company that develops and applies plant science capabilities to improve the quality and agronomic traits of fruits and vegetables. The creation of DNAP Holding Corporation in 1996 was the result of the merger of DNA Plant Technology, a leader in utilizing biotechnology to produce superior food products, with the Bionova produce growing and distribution subsidiaries of Mexico=s Empresas La Moderna S.A. de C.V. (ELM). The merger brought together science and commerce in one entity. The new corporation consists of three integrated units: Research, Production, and Distribution (FreshWorld Farms, Inc. and Bionova=s group of national and regional distributors). In early 1997, ELM entered into a collaboration agreement with Monsanto to gain access to technology for a large number of fruits and vegetables, including enabling technology, herbicide resistance, insect resistance, virus resistance, and quality traits.

Gist-Brocades N.V.

Headquarters: Delft, the Netherlands
Employees: 23,000

Gist-Brocades N.V. is an international group of companies - whose core business is biotechnology - that develop and manufacture products for the pharmaceuticals market, the bakery market and the food industry. The group is one of the leading global producers of yeast and ingredients for bakery products, antibiotics and foodstuffs and cattle food enzymes. Its most important products emanate from fermentation processes. Its subsidiary, Gist-Brocades/Bio-Intermediair, specializes in large scale animal cell culture and microbial fermentation and product purification. Gist recently merged with DSM, a Netherlands-based chemical company with $6 billion sales worldwide, 18,000 employees, and main activities in life science products, performance materials, polymers and industrial chemicals.

There are many other key players in the agricultural biotechnology field B this is by no means an exhaustive list. But as mergers and acquisitions continue at a rapid pace, it becomes more and more difficult to rank or categorize the industry=s players, and any classification is simply short-lived. Throughout the remainder of the report, there will be many references to the other Aplayers@ in the biotech arena B what has just been outlined is merely a Asnapshot@ of those with widespread recognition and products already available in the marketplace.

A Word on Categories and Concepts

In subsequent sections, the biotech products available today and in the near-term pipeline are identified and described. To facilitate that presentation, we have developed categories into which the products are placed. These categories are delineated below and will be used throughout the presentation.

For purposes of the study, we view the biotech products as belonging in one of four categories:

Crops

Field crops
Vegetables
Fruits

Livestock

Microbes/Enzymes (primarily for use in food processing)

Nutraceuticals

We also categorize them as:

Cost reducing/yield enhancing products B reduce input costs for producers and improve yields either by reducing production losses or improving the products= agronomic or growth properties:

Herbicide tolerance
Insect/disease resistance
Drought/cold/stress tolerance

Special product attributes (some of which can be classified as both cost reducing/yield enhancing and value enhanced):

Delayed ripening
Reduced bruising
Shippability
Longer shelf-life
Enhanced flavor/appearance

Value enhanced products (e.g., high protein corn) B altered composition and/or characteristics to make the product more valuable than a corresponding commodity.

Livestock products (e.g., clones, vaccines and growth promoters).

Processing products (e.g., microbes, enzymes).

Nutraceuticals and industrial products B functional foods designed to prevent diseases, treat conditions, or to prevent diseases and conditions.

[1] Like any new product seeking public approval, it underwent lengthy testing to detemine its safety, quality, purity and stability. Trials to measure its effects on human and animal health involved much larger doses than anything consumers reasonably would be exposed to. In 1994, the US National Academy of Sciences Board on Agriculture reviewed many studies on BST and concluded that there was no disagreement among scientists that Acomposition and nutritional value of milk from BST-treated cows is essentially the same as that of milk from untreated cows.@

III. Biotechnology Today

Agricultural Biotechnology Products Available Today

The "first wave" of biotechnology has been dominated by crops with "input traits," such as herbicide tolerance and insect resistance. Herbicide tolerant crops are attractive to farmers mainly because they reduce costs, and many are "yield neutral" or affect yield only modestly due to less competition from weeds for nutrients and water, so farmers' revenues are largely unaffected. On the other hand, some insect-resistant crops both reduce costs (reducing insecticide applications) and improve yields, since pests such as the European corn borer cause production losses by causing "lodging" and other damage.

Key Developments

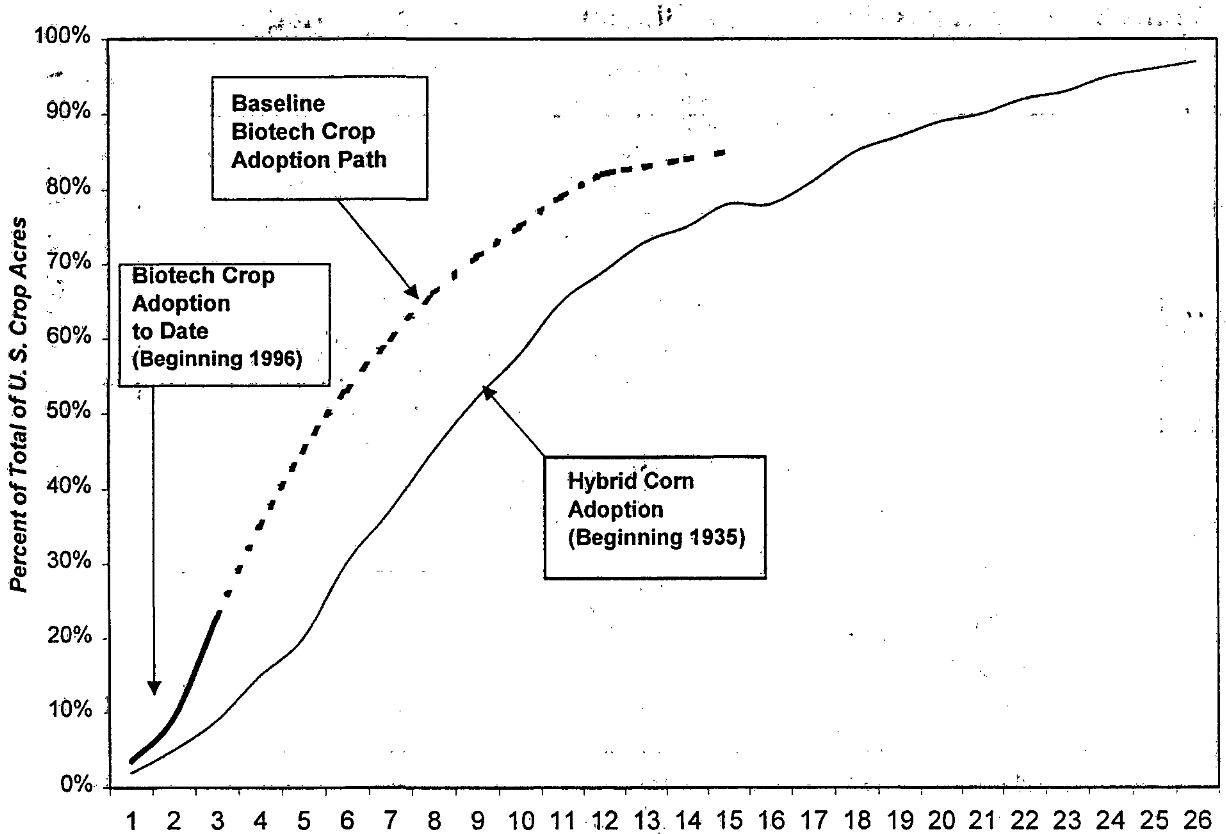
- **Herbicide Tolerance**. Herbicide tolerant crops enable farmers to spray herbicides on their fields, controlling the weeds while leaving crops unharmed. In the past, since nonselective herbicides such as Roundup and Liberty were designed to kill all plants regardless of whether they were valuable crops; the use of such herbicides was generally limited to pre-plant applications or controlled spraying between crop rows. Monsanto's Roundup Ready and AgrEvo's Liberty Link seeds opened new post-emergent markets for both products. Similarly, imidazolinone (i.e., Pursuit) also served as a selective herbicide effective against annual grasses and broadleaf weeds in soybeans and other legumes. But since the early 1990s, corn varieties (nontransgenic) tolerant of the herbicide have been available as IMI corn.

- **Insect Resistance.** By inserting the gene of a common soil microorganism, *Bacillus thuringiensis* (Bt), into plant tissue, scientists have created crops that produce their own insecticide. Commercialized in 1996, Bt cotton combats bollworms and budworms, and Bt corn protects against the European corn borer. Future insect resistant crops promise control of many other economically important pests, such as the cotton boll weevil and the corn rootworm.

Bt…A Versatile Bacterium

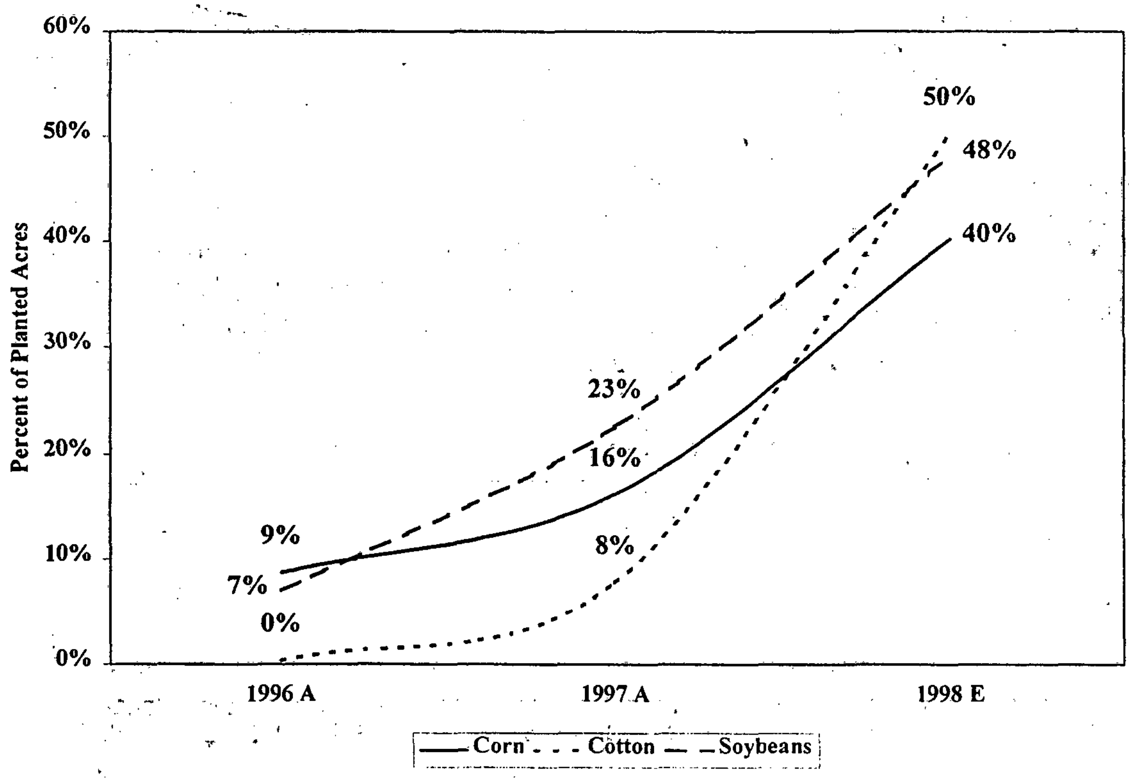
One of the most successful agents of biological control, first discovered in the early 1980s, is *Bacillus thuringiensis* (Bt), a naturally-occurring bacterium that produces insecticidal chemicals. When ingested by insects, the bacterial spores germinate and produce toxins, eventually killing the insect as part of their own life cycle. Different strains of the bacterium produce their own toxins, each of which has its own range of insect targets. Bt has been used in pesticide sprays for many years, but this is both costly and difficult to synthesize in commercial quantities. Today, the Bt gene responsible for producing the toxin is directly inserted into the plant to produce pest resistant varieties.

Chart 1. Biotech Crop and Hybrid Corn Adoption: "S" Curves Compared



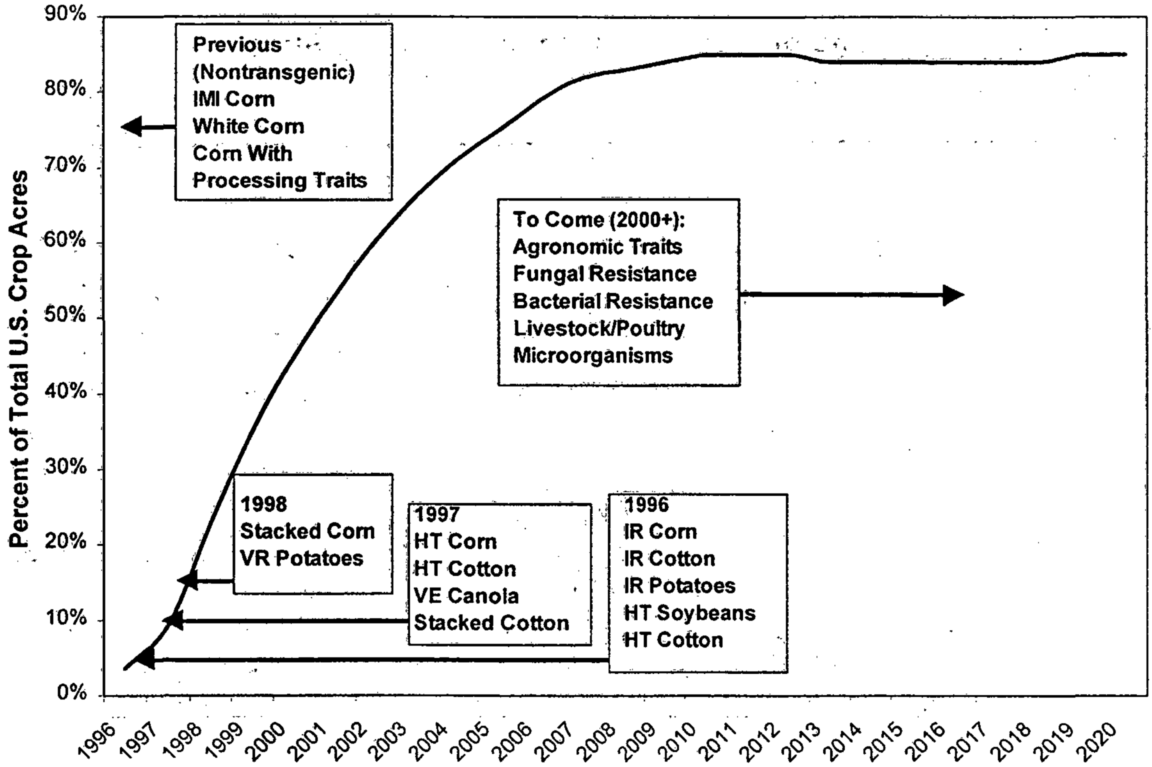
The nature of the biotech crops constituting the successive "waves" likely will be much broader than for the hybrid corn varieties. For example, biotech soybeans have achieved almost 50% market penetration, consisting mostly of Roundup Ready and STS soybeans (Chart 2). These will be followed not only by other herbicide tolerant crops, such as Liberty Link soybeans, but also by value enhanced crops, including nutraceuticals and functional foods. And, in just three years, biotech varieties also account for a significant share of the US corn and cotton acreage.

Chart 2. Adoption Rates of Major Biotech Crops in the United States



It also is plausible to suggest that within the overall biotech "S" curve, there may be several scallop-shaped curves for individual varieties, all occurring within a greatly compressed timeframe from previous adoption rates. Moreover, the biotech adoption process encompasses a greater range of crops and marketing chains than the hybrid corn example, and the impacts reach much further up and down the marketing chains. The "S" curve of biotech crop adoption and the composition of varieties driving adoption are shown in Chart 3.

Chart 3. Varieties Driving Biotech Crop Adoption



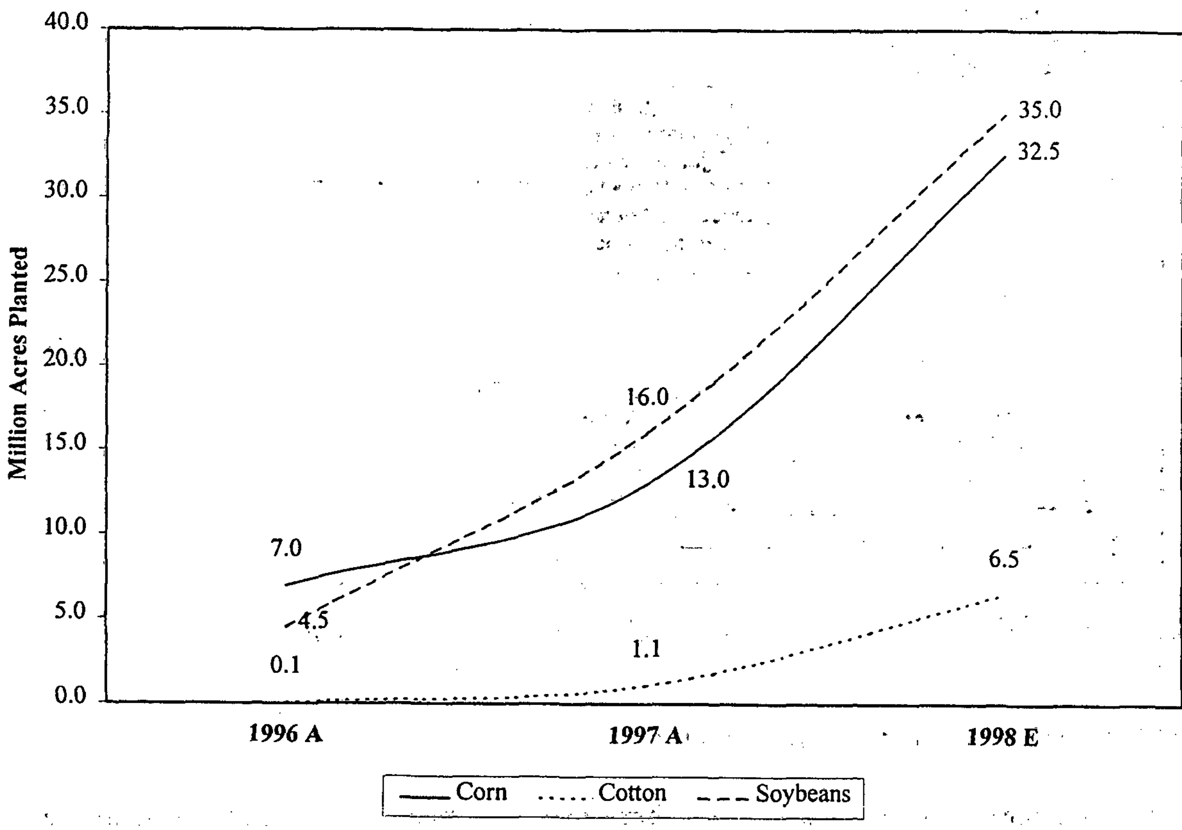
Adoption of Biotech Crops in the United States

A tremendous amount of biotech research has been ongoing, much of it concentrated in the United States. The first commercial agricultural biotech products were introduced in the United States, making it a logical starting point for a discussion of such biotech products available to date.

The first commercial transgenic grains and oilseeds were released in 1996 in the United States – Ciba Seeds' Bt corn and Monsanto's Roundup Ready soybeans and Bollgard (Bt) cotton. For this reason, 1996 is marked as the inaugural year for biotechnology in agriculture. Biotech acreage totaled just over 13 million acres, for both transgenic crops and nontransgenic crops with enhanced attributes (mostly herbicide tolerance) similar to transgenic crops. It is estimated that biotech crop area in 1998 has grown sixfold to nearly 75 million acres, 23% of total planted acreage of all major crops.

Still, biotech acreage is dominated by relatively few crops – soybeans, corn and cotton (Chart 4). This year, nearly 35 million acres of biotech soybeans were planted, an increase of nearly 20 million acres over last year. Biotech corn varieties account for over 32 million acres, including 11 million acres of nontransgenic varieties with enhanced characteristics, primarily used in specialized processing applications (e.g., waxy corn, high-amylose corn). For cotton, over one-half of 1998 plantings were biotech varieties, mostly Monsanto's Bollgard and Roundup Ready.

Chart 4. Acreage of Biotech Crops in the United States



Other crop acreage, such as biotech canola and potatoes, remains small. In 1998, an estimated 80,000 acres were planted to Monsanto/Calgene's Laurate canola, which contains oil high in lauric acid suitable for food processing applications as well as industrial uses such as soaps and detergents. Biotech potato acreage totals only 50,000 acres, all Monsanto's NewLeaf potatoes. These plantings represent 7% of canola and 4% of potato acreage.

Transgenic crops account for more than 70% of the total biotech acreage in the United States (Table 8). Soybean varieties make up the largest portion with 25 million acres, while corn area is 21.4 million acres. Many of the value enhanced corn varieties that are currently on the market have traits which were developed through conventional breeding techniques; these nontransgenic varieties accounted for 11.2 million acres this year. Nontransgenic soybean varieties were planted on just over 10 million acres this year, mostly accounted for by DuPont's STS soybeans, which are tolerant of sulfonylurea herbicides.

Table 8. Transgenic and Nontransgenic Crop Acreage – United States

	Transgenic			Nontransgenic		
	1996	1997	1998	1996	1997	1998
	million acres					
Canola	0.0	0.1	0.1	0.0	0.0	0.0
Corn	1.0	5.6	21.4	6.0	7.4	11.2
Cotton	0.1	1.1	6.5	0.0	0.0	0.0
Potatoes	0.0	0.0	0.1	0.0	0.0	0.0
Soybeans	1.0	9.0	25.0	3.5	7.0	10.0
Total	2.1	15.8	53.0	9.5	14.4	21.2

It is notable that no biotech wheat product yet has been commercialized. This likely results both from scientists getting a late start on research, and the reported greater difficulty in its genetic modification than other crops, especially the oilseeds.

<u>Herbicide Tolerant Crops</u>

The most widely adopted biotech crop is Roundup Ready soybeans – 25 million acres, 34% of total soybean plantings (Table 9). DuPont's STS soybeans have the widest plantings of any nontransgenic biotech crop – 10 million acres this year.

Table 9. Herbicide Tolerant Crops in the United States

Company	Product	USDA Approval Date	Acreage 1996	1997	1998
				million	
AgrEvo	Liberty Link canola	1/29/98	n/c	n/c	n/c
AgrEvo	Liberty Link corn	6/22/95	n/c	0.7	4.2
AgrEvo	Liberty Link soybeans	7/31/97	n/c	n/c	n/c
AgrEvo	Liberty Link sugarbeets	4/28/98	n/c	n/c	n/c
American Cyanamid	IMI (imidazolinone tolerant) corn 1/	Not Transgenic	3.4	4.5	6.6
DeKalb	GR (glufosinate resistant) corn	12/19/95	n/c	0.1	0.2
DuPont	STS (sulfonylurea tolerant) soybeans	Not Transgenic	3.5	7	10
DuPont	STS cotton	1/25/96	n/c	n/c	n/c
Monsanto	Roundup Ready corn	11/18/97	n/c	n/c	0.75
Monsanto	Roundup Ready cotton 2/	7/11/95	n/c	0.8	5.00-
Monsanto	Roundup Ready soybeans	5/19/94	1	9	25
Monsanto/Calgene	BXN cotton	2/15/94	0.05	0.28	1.3
Univ. of Minnesota/BASF	Poast Protected (sethoxydim resistant) corn	Not Transgenic	n/a	n/a	0.3

1/ Estimate based on seed availability, not actual planted acres.
2/ Total 1998 acreage of Roundup Ready and Bollgard cotton is estimated over 5 million acres. Estimate not available for Roundup Ready cotton.
n/c = not commercialized; n/a = not available

Source: Biotech/seed companies, US Grains Council Value Enhanced Corn Quality Report, Furman Selz LLC, NatWest Securities

AgrEvo's Liberty Link corn is estimated to have been planted on 4.2 million acres in 1998. DeKalb also has developed varieties that are tolerant of herbicides containing glufosinate (i.e., Liberty), which are marketed under the name GR Corn, though the area planted to these varieties is thought to be only 20,000 acres. Monsanto's Roundup Ready corn was commercialized in 1998 and planted on an estimated 750,000 acres.

Roundup Ready cotton, introduced only this year, was planted on a significant acreage although no estimate is yet available for it separate from Roundup Ready stacked with Bollgard. Monsanto has reported a total acreage with Bollgard and/or Roundup Ready traits of over 5 million acres in 1998.

Insect Resistant Crops

The insect resistant crops that have been commercialized all contain genetic material from the *Bacillus thuringiensis* (Bt). Thus far, insect resistant varieties have been introduced for corn and cotton, targeted at the bollworm and budworm in cotton and the European corn borer. These include Ciba's Bt corn in 1996 (just under one million acres) and Monsanto's Bollgard cotton (1.8 million acres) (Table 10).

Then came YieldGard corn in 1997, and by the next year it had the second-largest biotech acreage (13 million). It surpasses Novartis' Bt corn (two million acres) by a wide margin. DeKalb introduced a Bt corn (DEKALBt/Bt-Xtra) in 1997, and it accounted for 1.2 million acres this year.

Table 10. Insect Resistant Crops in the United States

Company	Product	USDA Approval Date	Acreage 1996	1997	1998
				million	
DeKalb	DEKALBt/Bt-Xtra corn	3/28/97	n/c	0.2	1.2
Monsanto	Bollgard cotton 1/	6/22/95	1.8	2.5	5-
Monsanto	NewLeaf potatoes	3/2/95	0.01	0.03	0.05
Monsanto	YieldGard corn	8/22/95 & 3/15/96	n/c	2.6	13
Novartis (Ciba/Northrup King)	Maximizer & KnockOut corn	5/17/95 & 1/18/96	1.00-	2	2

1/ Total 1998 acreage of Roundup Ready and Bollgard cotton is estimated over 5 million acres. Estimate not available for Bollgard cotton.
n/c = not commercialized

Stacked Trait Crops

Once a single new trait could be introduced into a crop, it was clear that others would soon follow, producing multiple or "stacked" traits (Table 11). The first of these appeared in 1997 when Monsanto released Roundup Ready and Bollgard cotton. Monsanto then released BXN/Bollgard cotton this year, tolerant of Buctril herbicide and insect resistant. It also released a small amount of corn that combines Roundup Ready tolerance and European corn borer resistance, planted only on some 30,000 acres.

Table 11. Crops With "Stacked" Traits in the United States

Company	Product	USDA Approval Date	Acreage 1996	1997	1998
				million	
Monsanto	Roundup Ready & Bollgard cotton 1/	n/a	n/c	0.06	5
Monsanto/Calgene	BXN & Bollgard cotton	4/30/97	n/c	n/c	0.2
Monsanto	Roundup Ready & YieldGard corn	5/27/97	n/c	n/c	0.03

1/ Total 1998 acreage of Roundup Ready and Bollgard cotton is estimated over 5 million acres. Estimate not available for stacked Bollgard and Roundup Ready cotton.
n/c = not commercialized

Biotechnology and the Food and Feed Industries

Most developments in the current wave of biotechnology have focused on agronomic traits – adding value for the producer, while providing little apparent, direct benefit to the consumer. However, some products with consumer-oriented traits have been developed, and many more can be expected. While not every crop easily lends itself to consumer-oriented traits, fruits and vegetables and other value enhanced products (including modified oilseeds and corn tailored for specific markets) are those where such benefits are obvious.

Fruits and Vegetables

Fruits and vegetables have been a focus of biotech research for more than a decade. Modifications include input traits for the farmer's benefit, but most are clearly intended to add value downstream at the consumer end of the marketing chain.

The first food crop, the FlavrSavr tomato developed by Calgene (now a subsidiary of Monsanto), was commercialized in 1994. It was the first high-profile genetically modified food to reach the consumer marketplace – and still may be the most recognized biotechnology food product among consumers. More recently, DNAP, part of the Empresas La Moderna/Seminis group of companies, has developed two tomatoes marketed under the FreshWorld Farms brand. Each has delayed ripening characteristics (Table 12).

Table 12. Biotech Fruits and Vegetables on the Market in the United States

Name	Manufacturer	Description
FreshWorld FarmsTomato	DNAP/Empresas La Moderna	Developed to have improved color, taste, and texture, and a 10- to 14-day shelf life.
FreshWorld Farms Endless Summer Tomato	DNAP/Empresas La Moderna	Limited production of ethylene, the hormone that causes fruits to ripen – extends shelf life by 30 to 40 days.
Increased Pectin Tomato	Zeneca Plant Sciences	These tomatoes remain firm longer and retain pectin during processing into tomato paste.
Bt Sweetcorn	Novartis	Contains the Bt bacteria, and provides protection against several pests.

Value Enhanced Products

The "first wave" input traits, which reduce costs and/or enhance yields for the farmer, are "substantially equivalent" once harvested and pass the farm gate. The "second wave," however, exhibits consumer-oriented traits, and more are expected in the coming years. Most value enhanced crops thus far have been concentrated among: oilseeds with modified fatty acid composition and corn tailored to specific end-uses (i.e., processing or feed).

Most of the value enhanced corn and oilseed varieties now available are nontransgenic (accounting for 97% of the 3.8 million acres planted in the United States in 1998). The most widely adopted are DuPont/Optimum Quality Grains' high-oil corn used mostly as an enhanced-energy animal feed, and varieties used in specific processing applications. These include waxy and high-amylose corn with starch compositions opposite to each other and standard corn, designed to yield starch for specific food and industrial uses. "Food-grade" corn, technically hard-endosperm corn, is desired for its large grits used in extruded products such as breakfast cereals and snack foods.

The modifications to fatty acids in value enhanced oilseeds thus far have been intended to produce oils more healthful and/or more stable. Enhanced stability can be targeted at shelf-life and/or stability in specific applications, such as producing the shortening used in restaurants.

One product designed specifically to be more healthful is soybean oil with reduced saturated fatty acids (Table 13). Developed by Iowa State University and marketed by Optimum Quality Grains, the oil is marketed as LoSatSoy in Hy-Vee stores in the Midwest.

Table 13. Value Enhanced Crops in the United States

Company	Product	USDA Approval Date	Acreage 1996	1997	1998
				million	
DeKalb	Nutritionally dense corn	Not Transgenic	0.14	0.14	0.14
Monsanto/Calgene	Laurate canola	10/31/94	0.02	0.07	0.08
Multiple	Hard endosperm/food-grade corn	Not Transgenic	1.00-	1.00-	1.00-
Multiple (Main: DeKalb/Custom Farm Seeds)	High amylose corn	Not Transgenic	0.04	0.04	0.04
Multiple	White corn	Not Transgenic	0.58	0.55	0.65
Multiple (Main: DeKalb/Custom Farm Seeds)	Waxy corn	Not Transgenic	0.4	0.42	0.43
Optimum Quality Grains	High protein soybeans	Not Transgenic	n/a	0.01	0.01
Optimum Quality Grains	High sucrose soybeans	Not Transgenic	n/a	0.01	0.01
Optimum Quality Grains (DuPont)	High oil corn	Not Transgenic	0.4	0.75	1.20
Optimum Quality Grains (DuPont)	High oleic soybeans	5/7/97	n/c	0.01	0.03
Optimum Quality Grains (Pioneer Hi-Bred)	High oleic sunflower	Not Transgenic	n/a	n/a	0.11
Optimum Quality Grains (Pioneer Hi-Bred)	Low linolenic soybeans	Not Transgenic	n/a	0.01	0.01
Optimum Quality Grains/ Iowa State University	LoSatSoy (low saturates) soybeans	Not Transgenic	n/c	0.01	0.05

n/c = not commercialized; n/a = not available

High-oleic soybeans and sunflowers also are currently on the market (Table 14). These yield oil that is stable with low or no hydrogenation for use in food applications, thereby reducing or eliminating the presence of trans-fatty acids (associated with heart disease) that result from hydrogenation. This reduces food processors processing costs and results in a healthier oil. The high levels of monounsaturated fatty acids and low levels of trans-fatty acids also are more desirable from a health standpoint. The high-oleic soybeans are transgenic while the high-oleic sunflower is not. Both are marketed by Optimum Quality Grains, which also markets and arranges for the contract-growing of low-linolenic-acid soybeans which yield oil requiring less hydrogenation.

Optimum Quality Grains also has commercialized soybeans with modified components other than oil. High-sucrose soybeans are promoted as having improved flavor and less desirable side-effects (such as gas in humans). Products from these soybeans will enable food processors to include a higher proportion of soy in foods without incurring off-tastes or other undesirable consequences. High-protein soybeans are intended for use in soyfoods, particularly tofu and soymilk.

Table 14. Biotech Edible Oils Currently on the Market in the United States

Type of Oil	Company	Description
High-Oleic Peanut Oil	Mycogen	Developed through mutagenesis, produces oil high in oleic acid, resulting in longer shelf-life for nuts, candy, and peanut butter.
High-Oleic Soybean Oil	Optimum Quality Grains	Contain oil with 10% saturated fat and 80% oleic acid, compared to 15% and 24%, respectively, for standard soybeans. The oil requires low or no hydrogenation, resulting in lower trans-fatty acids.
Low-Linolenic Soybean Oil	Optimum Quality Grains	Oil is lower in linolenic acid and requires less hydrogenation.
Low-Saturate Soybean Oil	Optimum Quality Grains	Oil has a saturated fatty acid content of 8%, which is about half the saturated fatty acid content of standard soyoil and is comparable to canola oil.
High-Oleic Sunflower Oil	Optimum Quality Grains	Oil has improved stability and requires less hydrogenation, resulting in lower trans-fatty acids.

Adoption of Biotech Crops in Canada

While much of the biotech crop acreage is in the United States, several crops also have been commercialized in Canada. The focus there has been on input traits, specifically herbicide tolerance.

Canada's principal crops are wheat, barley and canola, but since wheat and barley have been little affected, canola is the dominant biotech crop. Canola has proven to be one of the most receptive crops to genetic manipulations, including value enhanced traits. Other crops that have been commercialized also are on the market in the United States. And, there is broader adoption of imidazolinone herbicide tolerant crops, mostly under the Pursuit Smart brand developed by Pioneer.

Biotech canola is thought to comprise about half of all canola acreage in 1998 (Table 15). Liberty Link, Roundup Ready and Pursuit Smart varieties have about equal market shares, each accounting for two million acres.

Although the Canadian corn acreage is limited, biotech varieties cover just over one million acres this year, about 40% of the crop. The most prominent varieties are Monsanto's YieldGard (Bt) on 700,000 acres, and AgrEvo's Liberty Link on 300,000 acres.

Besides the Liberty Link, Roundup Ready, YieldGard and Pursuit Smart brands which have gained significant market shares in the canola and corn sectors, other biotech varieties have received approval for planting from the Canadian government (Table 16). Almost all of these are crops with input traits, and many are the same as biotech crops commercialized in the United States.

Table 15. Acreage of Biotech Crops in Canada

Company	Product	Approval Date	Acreage 1996	1997	1998
AgrEvo Canada	Liberty Link canola	Mar-95	370,500	2,100,000	2,100,000
AgrEvo	Liberty Link corn	Apr-97	n/c	n/c	300,000
Monsanto	Roundup Ready canola	Mar-95	50,000	450,000	2,000,000
Monsanto/Calgene	Laurate canola	Apr-96	5,000	5,000	5,000
Monsanto	Roundup Ready soybeans	Apr-96	n/c	6,000	150,000
Monsanto	YieldGard corn	Feb-97	n/c	60,000	700,000
Monsanto	Roundup Ready & YieldGard corn	Sep-97	n/c	n/c	3,000
Monsanto	NewLeaf Potato	Dec-95	1,500	5,000	10,000
Pioneer Hi-Bred	Pursuit Smart (IMI tolerant) corn	Feb-96	n/a	10,000	20,000
Pioneer Hi-Bred	Pursuit Smart (IMI tolerant) canola	Apr-95	n/c	1,600,000	2,100,000
Univ. of Saskatchewan	STS flax	May-96	440	6,000	3,400

n/c = not commercialized

Source: Canadian National Research Council/Plant Biotechnology Institute, Ontario Corn Producers Association, Company Reports, Press Reports

Table 16. Other Biotech Crops Approved in Canada

Company	Product	Approval Date
BASF	Poast Protected corn	Feb-97
DeKalb Genetics	GR corn	Dec-96
DeKalb Genetics	GR & DEKALBt/Bt-Xtra corn	Apr-97
ICI/Zeneca Seeds	IMI corn	Jul-97
Novartis/CIBA & Mycogen	Maximizer & NatureGard corn	Feb-96
Novartis/Northrup King	Maximizer	Aug-96
Pioneer Hi-Bred	Roundup Ready & YieldGard corn 1/	Dec-96
Pioneer Hi-Bred	High oleic/low linolenic acid canola 1/	Aug-96
Rhone-Poulenc	BX-canola (Bromoxynil tolerant)	Jul-97

1/ Pioneer's Roundup Ready & YieldGard corn and high-oleic/low-linolenic acid canola have not been commercialized.

Source: Agriculture Canada, Pioneer Hi-Bred

Although considerable research on value enhanced crops is underway, little acreage is planted to these crops. Monsanto/Calgene's Laurate canola has been planted on some 5,000 acres in 1996-98, and high oleic acid and low linolenic acid canola were approved by the government in August 1996 but have yet to be commercialized.

Adoption of Biotech Crops in the Rest of the World

Mexico and South America

Aside from the United States and Canada, the next largest biotech acreage is in Argentina. Roundup Ready soybeans planted there over the last two years reached 3.75 million acres in 1997, 22% of total acres. Monsanto reported it had sufficient Roundup Ready soybean seed for 10 million acres in 1998, and Bt corn was approved for planting.

Biotech crops have yet to be approved by Brazil. A major hurdle was cleared in September 1998, when the Brazilian National Bio-security Technical Commission (CNTBio) ruled to allow the sale of Roundup Ready soybeans. However, the Agricultural Ministry still must give formal approval – and this is expected soon. Monsanto is expected to have Roundup Ready seed available for sale next year.

In Mexico, Monsanto's Bollgard/Ingard cotton has been commercially available since 1996, when some 2,000 acres were planted. Acreage rose to 50,000 acres in 1997, 10% of total cotton acres. Monsanto planned to have sufficient seed for 200,000 acres of Bollgard/Ingard cotton seed for 1998, though preliminary reports suggest plantings may not have exceeded 100,000 acres.

Asia and Australia

China has adopted a biotechnology-friendly stance as it seeks ways to feed its massive and growing population. Biotech crops reportedly have been there since the early 1990s, including virus resistant varieties of tomatoes and tobacco.

The International Service for the Acquisition of Agri-biotech Applications (ISAAA) at Cornell University estimates biotech crop acreage of 2.8 million acres in 1996 and 4.5 million acres in 1997. Tobacco resistant to the Cucumber Mosaic Virus accounted for 2.5 million acres of the 1996 acreage and 4.0 million in 1997. Virus resistant tomatoes were planted on 0.3 million acres in 1996 and 0.5 million acres in 1997.

Plantings for 1998 are not yet available, though the ISAAA has added Bt cotton to the list of biotech crops grown. Monsanto reported it would have as much as 375,000 acres worth of Bollgard/Ingard seed available, but ISAAA suggests no more than 100,000 acres.

In Australia, Bollgard/Ingard cotton already has gained significant market share. Monsanto reports 75,000 acres planted in 1996 and 150,000 acres in 1997, 15% of the total crop. Monsanto indicated seed sufficient for 200,000 acres Bollgard/Ingard cotton this year.

Biotech Developments in Livestock

Until two spectacular developments in the mid-1990s, few people realized that biotechnology applications were as far advanced for animals. The first was the February 1994 introduction of bovine somatotropin (BST) (Posilac brand), a protein hormone that increases milk production in cows. The second event was public introduction in February 1997 of Dolly, a sheep, the first mammal cloned from a cell of an adult.

The increase in milk production from Posilac tends to be between five and 15 pounds per cow per day. The product now has a sizable market. Monsanto estimates that of the nearly nine million dairy cows in the United States, 30% are in herds supplemented with Posilac. The volume of Posilac reportedly increased 45% in 1996 and 30% in 1997.

Forms of somatotropin also have been developed for beef cattle ("Beef BST") and hogs (porcine somatotropin, or PST). However, neither has been adopted to the extent of dairy BST. Beef BST has had difficulty for two reasons. First, it must be injected or even placed into the rumen of beef cattle, which can be difficult and adds (significantly) to labor requirements at the feedlot, thus increasing costs. Second, feeding trials have generally indicated Beef BST should be used in combination with a steroid implant in order to be fully effective – a costly combination – and a study by Iowa State University even showed that treating steers with Revalor (a commonly used anabolic steroid implant) alone produced equal or better weight gain and better feed conversion than using a combination of BST and Revalor.[5] Beef BST, however, has a key benefit of significantly increasing the lean percentage of carcasses, which may be desirable as the cattle sector attempts to align production practices closer to consumer demands. Still, the economic and operational constraints of Beef BST have not permitted it to be commercially viable thus far.

Similarly, porcine somatotropin is effective at increasing the average daily gain of hogs and improving feed conversion ratios, and it results in a higher lean percentage. However, hog producers have had remarkable success at achieving these goals by adopting superior genetics (through breeding, not biotechnology), rather than PST, in order to improve the entire structure of the hog, including increased loin-eye depth and reduced backfat.

The birth of Dolly in Scotland was followed by the birth of cloned calves in the United States. One calf, dubbed Mr. Jefferson was produced by PPL Therapeutics, the same company that produced Dolly. Another company, ABS Global, which long has been a provider of cattle breeding products and services, cloned a calf that it named "Gene." Then, Japanese researchers reported in July 1998 they had produced cloned calves, and scientists in Hawaii reportedly have cloned mice – with both teams producing the clones from the cells of adult animals.

Perhaps suggesting things to come, PPL Therapeutics announced in May 1998 that using the same cell-nucleus transferal method as had been used for Dolly, it had produced two transgenic lambs, Molly and Polly, into which human genes had been inserted to "manufacture" blood-clotting factor in the sheep's milk. This leads to the possibility that herds of such sheep can be used as "factories" for the production of the factor (Factor IX) used in the treatment of hemophilia B. PPL also is reported to have a herd of 700 transgenic sheep (not cloned through nuclear transferal) that produce the enzyme alpha-1-antitrypsin, which is in clinical trials for the

5 John Rathmacher, et. al., Iowa State University, *Effects of Bovine Somatotropin and Revalor-S on Growth Performance and Carcass Leanness in Beef Cattle*.

treatment of cystic fibrosis. Similarly, ABS formed a partnership with Pharming Holding NV to develop the blood-clotting proteins Factor VIII, Factor IX and Fibrinogen, to be produced in the milk of transgenic animals.

In a development that has already been commercialized in Canada, researchers have discovered a DNA-based test for Porcine Stress Syndrome (PSS), a genetic condition that contributes to the incidence of pale, soft and exudative pork. Research has shown that PSS is also associated with other problems such as lower conception rate, smaller litter size and higher mortality rate. Subsequent to the identification of the DNA site of the defect, a DNA test was developed that provides a reliable and practical method for detecting the "halothane sensitivity gene" present in animals susceptible to PSS. The test is used to select against breeding animals carrying this recessive gene.

Through an agreement between the Canadian Pork Council and the University of Toronto's Innovations Foundation, swine breeders and hog producers across Canada are now able to become licensed users of this DNA test to determine the presence of the halothane gene and to use the results to control the incidence of PSS. The Canadian Pork Council, which represents the interests of commercial hog producers, has made use of this licensing agreement to distribute the technology as widely as possible throughout Canadian industry. This benefits all segments of the swine and pork industries, with on-farm productivity gains by both breeders and commercial producers, and enhanced pork quality for packers and processors.

Biotech Microorganisms and Enzymes

Biotech developments are not limited to large living organisms. Microorganisms that have improved functional characteristics also are being developed through genetic engineering. These microorganisms are being targeted at agricultural and food processing industries, the animal feed sector, and even crop production.

One of the most prominent areas in which biotechnology has affected the food industry is in cheese production. Traditionally, to augment the curdling of the milk to produce cheese, rennet had to be obtained from calves' stomachs. However, in the late 1980s, products were commercialized that contained the enzyme chymosin that performs this function, after researchers had discovered the means to transfer the DNA responsible for the production of this enzyme in the calf into commercial microorganisms. These microorganisms have the advantage of being more consistent in quality and availability than rennet obtained from calves' stomachs, and they also result in cheese that meets religious regulations and other dietary requirements, such as kosher, halal and/or vegetarian needs, although some groups are averse to the use of genetic engineering. Chymosin-based biotech products are now used in the manufacture of a majority of hard cheese.

Transgenic enzymes, such as alpha-amylase and beta-glucanase, also are used by the grain-processing industry in the conversion of grain into ethanol, beverage alcohol and sweeteners. In the animal feed sector, transgenic forms of the enzyme phytase are added to feed to aid the digestion of phosphorous by monogastric animals (i.e., hogs and poultry). In grains, a substantial portion of the phosphorous tends to be in the form of phytate, which is difficult for monogastrics to digest. When excreted, this phosphorous can contribute to water pollution.

Two of the key companies in the development and commercialization of biotech microorganisms for the commodity processing, food and feed sectors are Gist-Brocades and Genencor International, a joint venture between Eastman Chemical Company and Cultor Ltd. of Finland.

Another focus of biotech efforts related to microorganisms is targeted at crop production. Nitrogen fixation in crops such as corn has been a "Holy Grail" for plant biotech researchers, but is proving to be a very elusive goal. Given that nitrogen fixation by crops results from the interaction between the roots of legumes and bacteria, principally rhizobia, some researchers are starting to focus on enhancement of the role of bacteria through genetic modification. Research Seeds, Inc. has already commercialized transgenic rhizobia for use as an alfalfa seed inoculant, to increase nitrogen fixation and thus yields of alfalfa. As with many biotech developments to date, this is a precursor of products to come that will focus not only on nitrogen fixation in legumes but also enhanced uptake of nutrients by other crops.

Nutraceuticals

The modification of crops to produce foods that influence human health is a natural progression for biotechnology developments. This ability already has been demonstrated in the development of oilseeds with more healthful oil properties (e.g., lower saturated fats). However, products with a specific health function (i.e., nutraceuticals) have yet to be introduced commercially. These products likely will be developed and commercialized more rapidly as linkages between agricultural biotechnology and the pharmaceutical industry are strengthened. Though pharmaceutical production from plants and the ability to create tailored foods for specific health needs may seen futuristic, two major biotech players (Monsanto and AgrEvo) also are significant in the pharmaceutical industry, suggesting development of "farmaceuticals" and "functional farm foods" to be very plausible.

One of the areas in which biotech research is reported to be ongoing is the development of "functional foods," often referred to as "nutraceuticals." While no widely-held definition of these terms yet exists, functional foods generally are regarded as providing a health benefit beyond basic nutrition, either because they have been fortified with added nutrients or genetically modified to contain higher levels of nutrients. Consequently, a soybean genetically modified to have higher levels of vitamin E could be considered a functional food, while a soybean with lower fat content would not.

Examples of functional foods currently on the market, all of which are nontransgenic, include Tropicana's calcium-fortified orange juice, Hain Foods' soups with added St. John's Wort, and Benecol, the margarine made from ingredients derived from pine trees that reduces blood cholesterol levels. However, there are no biotech products with a specific health function that have been commercialized to date.

IV. Biotechnology Tomorrow

While the commercially available biotech products appeared "suddenly" in 1996, they were the products of research and development programs that had been underway for a long time. The products now available are impressive, and lead immediately to the question of what more can we expect and how soon. This section examines the research and development "pipeline" and suggests what may be in the offing in the next few years. It begins with an overview of the research efforts, their structure, and magnitude, to help develop an appreciation for an examination of what the pipeline contains.

Research

Since the 1950s, the world food problem has been widely recognized as the result of poverty – the inability of poor people in developing countries to produce the food they needed or to purchase it on world markets. In fact, those problems included isolation from markets, lack of investment in human resources, badly-designed economic policies, and a host of other constraints. Part of the recent progress in those nations includes imported technology, an end to much of the former economic isolation, more supportive economic and trade policies, and much greater dependence on direct capital investment.

How can biotech help? Biotechnology's contribution will be multi-faceted and complex, and will extend well beyond simple food production. Today's biotechnology already has demonstrated the capacity to increase productivity, and reduce input needs – and tomorrow's advances promise the capacity to deal with many of the key constraints limiting current systems. They promise to provide significantly increased productivity over time, reduced environmental pressures through reduced pesticide use, and increased product values that make commercial users more competitive in growing markets. Potential impacts include:

Boosting yields by producing plants and livestock specifically tailored for climatic conditions in relatively small production regions, and thereby reducing pressure to cultivate marginal and/or fragile land.

Increasing tolerance to stress, perhaps expanding potential production area.

Increasing resistance to diseases and pests, reducing the use of chemicals, and increasing the performance and practicality of no-till or limited-till and other conservation practices.

Increasing commodity quality and uniformity – as well as its storability and many other characteristics that reduce losses and increase value.

Tailoring plant and animal products to specification, increasing value for consumers and reducing production input requirements.

Helping low income, low-technology producers increase their food supply. In the 66 developing countries where 2.3 billion people live, and where current food supplies are inadequate, productivity growth is barely 2% annually (just slightly faster than population growth), constrained by lack of inputs, lack of crop protection products, poor management and numerous other problems. In these nations, imports are increasing as fast as domestic production, and economic aid is falling rapidly.

In just a decade, the world "food gap," the amount required to maintain *current* inadequate nutrition levels, could approach 18 million tons, nearly 3.5% of the total supply available to these consumers. To achieve *minimum* nutrition standards by that time would require even more, some 24 million tons or 4.5% of total availability. Since food aid to these countries also is falling, an improvement in the nutritional level of these people appears to depend heavily on improving their agricultural productivity and their incomes.

Over the longer term, these countries all need large amounts of investment capital in production, infrastructure, and agricultural support systems as well as technical assistance in improving their production and marketing processes. However, they also can benefit very significantly from crops and livestock specifically tailored for local production situations. Crops, especially, that can be produced in poor soil, that tolerate stress, that require minimal fertilization and resist diseases and pests and still produce improved yields would be particularly helpful.

A key feature of biotechnology's future role in increasing productivity of small farmers in developing countries is the capacity of the system to produce new plant and livestock strains specifically tailored to meet specific needs. A major stumbling block to the use of biotechnology in this way is the lack of capacity of these producers to pay the "genetics fee" for private, commercial products. However, it is likely that international philanthropic institutions or one or more governments might consider a special sponsorship role to develop a modest number of demonstration products, and that developing country governments might also support future use of biotechnology in this way.

Helping reduce pressure on the environment. As a practical matter, virtually all of the highly productive land in the world now is cropped, much of it at levels of intensity that are near maximum for sustainability. Pressure on the environment commonly includes, among other forms:

Clearing "new lands" for more intense cropping, frequently resulting in soil loss, stream siltation and rapid fertility loss.

Cultivation of marginal lands, frequently pasture land, with steep slopes, thin topsoil, or other constraints to cultivation, resulting in severe soil loss, damage to streams and rivers and lakes.

Increasing fertilizer and other agricultural chemical use, often to uneconomical levels, again with damage to streams and aquifers.

Increasing cropping intensity by mining aquifers until their use becomes uneconomical, by increasing salinity of irrigated land, or by damaging the natural environment by diverting natural watercourses.

In the future, substantial increases in output, either to meet rapidly growing commercial markets or to increase nutrition levels of the world's poor must depend on increased productivity of crops and livestock. The expected output growth rates under current technology provide little margin for either rapid growth in commercial markets or substantial increases in diets for the poor. While the major part of future productivity growth likely will come from commercial producers, non-commercial producers in developing countries will benefit from productivity increases, as well. For either group to meet the expected needs of the next quarter-century, the support of well designed, biotechnology approaches will be required.

Research Investment

The long-term productivity growth in agriculture and food systems is widely attributed to four major factors:

- Public investment in agricultural research and development;
- Public expenditures on infrastructure;
- Private expenditures in research and development; and
- Technological advances in material-inputs such as fertilizer and chemicals.

Except for direct investment in infrastructure, each of these reflects (with a very long, 15-year or so lead time) investment in research. In addition, the nation's experience indicates that investment in each of these areas means quite high rates of social return – including, surprisingly, private investment in research (Table 17). USDA analysis of research priorities suggests that the greatest return is to basic research to find new approaches and new relationships without regard to their application. However, it also concludes that the social return to private research is very high – nearly as high as for all public research, as high as farmers' education and higher than public extension.

Table 17. Social Rates of Return to Research,

	Social Rate of Return
	percent
All Public Agricultural Research	40-60
Basic Public Research	60-90
Private Research	30-45
Public Extension	20-40

Farmers' Education	30-45

Current research on biotechnology has unlocked some of the deepest secrets of the organisms we depend upon for our food, fiber and medicines. The key to the commercial development – and the distribution of benefits from this knowledge is current and future investment in research. Just as the world food system is facing a revolution from biotechnology, the research and development investment that fuels the revolution has changed dramatically, as well. An example is the focus and importance of private research – a system that has come to dominate the development of productivity.

Today, the vast bulk of US research investment in agriculture is private – about 60%, with 16% from state governments and 24% from the federal government.[6] For public investment in research and development, for example, federal spending increased rapidly during the 1970s and through the mid-1980s, but since that time has declined in real terms. Private research and development spending has grown much faster – an average of 4.5% annually through the 1980s and early 1990s, reaching nearly $2.4 billion in 1993 (in constant 1985 dollars) and substantially exceeding the federal investment.

In the mid-1960s, over two-thirds of private research and development (R&D) in agriculture went into either farm machinery or post-harvest research (food processing and products) (Table 18). Public research, by contrast, concentrated on biological innovations to increase crop and livestock yields, pest control and natural resources research.

Table 18. Private Agricultural Research

Primary Focus Areas	1966	1995
	percent	
Farm Machinery	29	11
Food Products	38	30
Plant Breeding	3	14
Animal Health	8	8
Agricultural Chemicals	22	37

By 1995, the structure of private R&D had changed dramatically. Much of the focus had shifted from farm machinery to agricultural chemicals (now the single largest private investment area), while retaining its strong focus in food products. And, private research had become much more important in the overall US agricultural and food research system – the key investment structure now

[6] Wallace Huffman and Richard Just, *Agricultural Research: Benefits and Beneficiaries of Alternative Funding Mechanisms*, Iowa State University and University of Maryland, December 1997.

driving the biotechnology revolution.

The US public and private investment in research now is about $7 billion and has doubled in real terms since 1970. Since 1982, however, the private sector has invested more in agricultural R&D than the federal and state governments combined. As real federal spending has stagnated, the gap between private and public R&D spending has widened and the private sector has developed significant capacity in areas long dominated by public research, such as plant breeding. And, at the same time, state experiment stations have relied increasingly on private industry, other non-government organizations and product sales to fund their research programs. Between 1970 and 1995, the share of experiment station research funded by private and non-government sources (including private sales) has nearly doubled from under 11% to more than 20%. Key factors that have spurred private sector investing have been key discoveries in biotechnology, growing market opportunities, and stronger intellectual property protections for biotechnology advances.

Several policy shifts have spurred the increased investment in biotechnology research. These include:

Relatively recent changes in US patent and copyright laws that have encouraged the growth of private agricultural research as commercial investors were able to protect their marketing rights for new products for 20 years. Expansion of intellectual property rights to include plants and animals also has contributed to the significant growth of private-sector research in plant breeding and biotechnology in recent years.[7]

The Patent and Trademark Amendments of 1980 that allow institutions to patent technology developed through federally funded research. Most universities now have offices of technology transfer to patent and license inventions developed in their laboratories.

The Federal Technology Transfer Act of 1986 established Cooperative Research and Development Agreements (CRADAs) as formal arrangements between federal laboratories and private companies to develop specific technologies. Key advantages of this cooperation include reductions in research redundancy and increased efficiency in the allocation of research efforts. However, it also raises questions regarding the division of property rights between public and private partners, and possible shifts in research focus toward short-term payoffs rather than longer-term investments. Today, there are 290 active joint projects between USDA and private companies, with about 60% of these related in some way to biotechnology.

The private/public investment partnership continues to be extremely important. Private agricultural research is revenue driven and tends to focus in limited areas including

[7] *Role of Research in Global Food Security and Agricultural Development*, World Food Summit, FAO, 1996.

pesticide and herbicide research, biotechnology and certain types of plant breeding. Public agricultural research is more "broad based," focusing on basic and pre-technology science, and concentrates largely on increasing productivity. Public research continues to be an important part of the foundation support for productivity growth far in the future.

The disparity between public and private research spending has widened significantly since the 1980s. The decrease in public funding, in real terms, has occurred not only in spite of pressures to increase the world's food supply but also as the agricultural research system increased its focus beyond its traditional goals of increasing productivity to include environmental protection and improved food safety.

For example, USDA's research budget in 1985 was just under $1.6 billion, including research in 11 agencies, and $54 million for facilities (Table 19). By FY 1998, this amount had declined modestly to $1.48 billion (in constant, 1986 dollars), a drop of 7% over the period. However, for the two agencies that support the bulk of the productivity-focused research, the Agricultural Research Service (ARS) and the Cooperative State Research, Education & Extension Service (CSREES), the cuts were larger, nearly 11% for ARS and more than 13% for CSREES.

Table 19. USDA Research, Development and Education

USDA Agency	1985	1990	1995	1997	1998	Change 1998/85
	million 1986 dollars					%
Agricultural Research Service	797	738	724	696	711	-10.8
Alternative Agriculture	0	0	5	7	7	
Cooperative State Research, Education	454	400	427	394	393	-13.4
Agricultural Marketing Service	5	3	5	8	8	60.0
Animal & Plant Health	0	16	17	20	19	
Economic Research Service	74	63	55	53	69	-6.8
Foreign Agricultural Service	9	3	1	1	1	-88.9
Forest Service	182	185	198	177	182	0.0
Grain Inspection, Packers	2	0	2	3	3	50.0
National Agricultural Statistics Service	13	3	4	3	3	-76.9
Rural Business-Cooperative Services	5	4	0	0	0	0.0
Research Facilities	54	88	124	138	86	59.3
Total	1595	1503	1562	1500	1482	-7.1

Private sector agricultural research funding, however, is likely to continue to increase to supply profitable markets. Thus, while the private sector could pick up some of the slack left by declines in public funding, the concern remains that declining public research will undercut productivity growth and diminish US competitiveness in the growing world markets.

As the structure of research investment has shifted from public to private, there also has been a shift in the character of public research. Encouraged by the revenue potential, corn breeding, for example, now is being done almost exclusively by the private sector, in contrast to 20 to 30 years ago when a significant portion of it was conducted in the public arena.[8] As private research in the more commercial, patent-protected areas has increased, public research has focused on technologies for which it is difficult to exclude use by others. Research in high-yielding varieties of open-pollinated crops like wheat is now being done mainly by the public sector, as is the bulk of the food safety and environmental research.

Biotechnology research is a good example of the benefits of long-lead time, basic research that subsequently is used by the private sector to boost overall sector productivity. For example, the $40 million national Plant Genome Initiative begun in FY 1998 will focus on deciphering the genetics of corn and other economically significant crops. Thus, while most agricultural biotechnology research now is done in private labs, public and private research 15 to 20 years ago helped create the knowledge base now supporting productivity advances.

Global Trends in Agricultural Research

Long-term trends in support for public and private research in OECD countries through the early 1990s (most recent such data available) are shown in Tables 20 and 21.[9] The United States spends more on agricultural research than any other single country, followed by Japan. The total agricultural research budget for the 22 OECD member countries is estimated to be between $10 billion and $14 billion, with the United States accounting for about $4.5 billion in 1993, likely nearing $6 billion today.

Table 20. Publicly Funded Agriculture Research, Developed Nations

	1971	1976	1981	1986	1990	1991	1992	1993	Growth Rate - 1981-93
	million 1985 dollars								%
USA	1,229.5	1,583.8	1,621.7	1,804.8	1,995.6	2,028.2	2,060.9	2,073.7	2.1
Japan	926.2	1,033.3	1,232.1	1,268.1	1,411.9	1,472.6	1,471.9	1,348.4	0.8
France	295.7	355.2	409.5	433.0	449.2	462.0	493.6	509.7	1.8
Canada	354.7	331.1	451.5	506.3	443.7	471.7	450.2	466.6	0.3
UK	274.4	332.1	372.3	374.6	356.5	364.4	380.3	371.1	0.0
Germany	308.6	326.9	299.8	304.7	311.6	314.4	317.2	320.1	0.5
Rest of OECD	930.7	1,133.4	1,356.7	1,642.6	1,758.7	1,843.2	1,859.9	2,078.9	3.6
Total	4,319.8	5,095.8	5,743.6	6,334.1	6,727.2	6,956.5	7,034.0	7,168.5	1.9

[8] Dr. Wallace Huffman, Department of Economics, Iowa State University, personal interview, March 17, 1998.

[9] These OECD estimates, the most current available, reflect worldwide investment trends for the 1981-93 period.

Source: ISNAR/IFPRI, Agricultural Science and Technology Indicators Database

The trend of stagnating investment for public research is not unique to the United States, but is occurring in almost every country around the globe. Publicly-funded agricultural research in the OECD member countries grew annually by 1.9% (constant dollars) during 1981-93.[10] By contrast, private research funding in these developed countries grew at a 4.8% annual rate during the period.

While developed countries continue to support agricultural research heavily, they are generally reducing the rate of growth. Examples include Canada where research reached a peak in 1985 but has been lower since that time, and the UK where there was essentially no growth between 1981-93.

Table 21. Privately Funded Agriculture Research, Developed Nations

	1981	1985	1990	1991	1992	1993	Growth Rate 1981-93
			million 1985 dollars				%
USA	1417.9	1,863.3	2,223.0	2,261.4	2,391.5	2,391.5	4.5
Japan	801.8	1,082.2	1,610.0	1,559.4	1,587.1	1,639.7	6.1
UK	414.6	465.1	623.0	593.5	641.3	641.8	3.7
France	255.6	352.8	507.3	510.1	540.3	572.4	6.9
Germany	426.1	478.8	522.6	520.2	489.5	458.9	0.6
Netherlands	183.7	206.9	247.5	241.9	237.8	281.3	3.6
Canada	75.5	91.6	98.9	103.2	106.0	118.7	3.8
Australia	25.2	55.5	91.0	112.6	136.9	137.3	15.2
Rest of OECD	414.8	538.2	718.5	739.9	774.3	767.2	5.3
Total	4015.2	5,134.4	6,641.8	6,642.2	6,904.7	7,008.8	4.8

Source: ISNAR/IFPRI, Agricultural Science and Technology Indicators Database

At the same time, private agricultural research funding growth rates in those same countries have been significant. In Canada, private research funding has increased at an annual rate of 3.8% from 1981 to 1993, 3.7% in the United Kingdom, France 6.9%, Australia 15.2%, and Japan 6.1%.

CGIAR

The Consultative Group on International Agricultural Research (CGIAR), perhaps the world's preeminent public agricultural research body, is cosponsored by FAO, the UN Development Program, the UN Environment Program and the World Bank. Its research is primarily conducted

[10] ISNAR/IFPRI, Agricultural Science and Technology Indicators Database, The Hague/Washington, DC, 1997. Also *Paying for Agricultural Productivity: Financing Agricultural R&D in Rich Countries,* edited by J.M. Alston, P.G. Pardey, M. Philips and V.H. Smith, John Hopkins University Press, 1998.

in its 16 centers located around the world, including:

CIAT Centro Internacional dê Agricultura Tripical in Cali, Columbia.
CIFOR Center for International Forestry Research, Bogor Barat, Indonesia.
CIMMYT Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico D.F., Mexico.
CIP Centro Internacional de la Papa, Lima, Peru.
ICARDA International Center for Agricultural Research in Dry Areas, Aleppo, Syria.
ICLARM International Center for Living Aquatic Resources, Makati City, The Philippines.
ICRAF International Center for Research in Agroforestry, Nairobi, Kenya.
ICRISAT International Crops Institute for the Semi-Arid Tropics, Andhra Pradesh, India.
IFPRI International Food Policy Research Institute, Washington, D.C.
IIMI International Irrigation Management Institute, Colombo, Sri Lanka.
IITA International Institute of Tropical Agriculture, Abadan, Nigeria.
ILRI International Livestock Research Institute, Nairobi, Kenya.
IPGRI International Plant Genetics Research Institute, Rome, Italy.
IRRI International Rice Research Institute, Manila, the Philippines.
ISNAR International Service for National Agricultural Research, The Hague, Netherlands.
WARDA West African Rice Development Association, Bouake, Cote d'Ivoire.

The CGIAR centers have been extremely active in the development of new agricultural technologies since their establishment, and were instrumental in the discovery of many "Green Revolution" plants and varieties. Today, their stated objectives are much broader than simply the development of new crops and livestock, and include both poverty alleviation and natural resources management.

CGIAR now is planning research expenditures for the coming fiscal year of about $355 million, with about 10% of that amount going to biotechnology research.[11] However, in spite of this support, these research centers have major concerns regarding some of the directions biotechnology has taken in recent years, especially about the availability of advance genetics for the poor. The system strongly supports many biotechnology projects, including those focused on biotechnology safety, those focused on greater understanding of biotechnology generally and the concept of a biotechnology service center to help each of the centers increase the effectiveness of their biotechnology research. For example, they also are concerned about:

[11] *Mobilizing Science for Global Food Security*, CGIAR 1998 mid-term meeting, Brasilia, Brazil, May 1998.

The extent to which CGIAR mandated crops already are affected by proprietary claims.

The extent to which owners of proprietary agricultural biotechnology (private companies and universities) make their proprietary science available. The organization has concluded, for example, that intellectual property owners generally agree that their property should be used to help the poor, but only if they do not face technical or financial damage from such assistance subsequently.

The impacts and consequences of new biotechnologies. At a World Bank meeting held just last month, the CGIAR adopted a resolution banning the "Terminator" and related genetic seed sterilization technology from its crop breeding programs worldwide. The CGIAR cited the potential for the Terminator to have negative consequences for food security, genetic diversity, biosafety, sustainable agriculture, and plant breeding. It did note, however, that CGIAR scientists might retain the option to study the technology in the laboratory – without aims to release it to farmers.

Research Investment in Biotechnology

It is difficult to estimate directly public expenditures for biotechnology research since most research expenditure records do not permit that level of direct detail. However, in a number of interviews with research administrators, estimates of these amounts were requested and are reflected below. These include:

USDA – Agricultural Research Service – biotech estimated to be 15% of $711 million research expenditure.

USDA – Cooperative State Research and Extension – biotech estimated at 15% of $393 million.

USDA – Other (e.g., APHIS, FS) – biotech estimated to be 5% of $378 million.

Other Public – State, Foundation – biotech could be 3% of $1,500 million.

CGIAR – International Centers – biotech estimated to be 10% of $355 million.

Other Developed/Developing Countries – biotech estimated to be 1.0% of over $8 billion.

Summary

Based on interviews with research administrators, public budget documents and other research reports, the following amounts are estimated for public spending on biotechnology – a very small share of the public/private R&D budget for agriculture and food. The largest individual amounts appear to be spent by public institutions in the United States which account for well over one-half of the world total (Table 22). Research spending in other developed and developing countries, and by the World Bank appears to be a much smaller share of total research than in the United States.

Table 22. Public Spending on Biotechnology

Institution	Research	Biotech Share	Biotech Spending
	mil $	%	mil $
USDA – ARS	711	15	107
USDA – CSREES	393	15	59
USDA – Other	378	5	19
Other US State/Foundations	1,500	3	45
CGIAR	355	10	36
Other Developed/Developing	8,000	1	80
Total	11,337		346

The Pipeline

While the extent of biotech products already in use and the fast pace of their adoption has been spectacular, available evidence suggests that many more products with wide-ranging characteristics will continue to emerge in the marketplace. Given the rapid adoption of the new products in just the past three years, it seems reasonable that the appearance of new products could be expanded to be even more rapid in the next few years. This section identifies the new products that are being developed for regulatory approval, and thus can be expected to become commercially available in the next five years.

The Biotechnology Pipeline

The biotechnology pipeline is a "flow" concept – public agencies and private companies continually fund research and development, test products, submit them for governmental regulatory approvals, and eventually some reach the marketplace. The return on the research investment typically is not built on one successful product or trait, but on the anticipation of an ongoing sequence of commercial products in several areas.

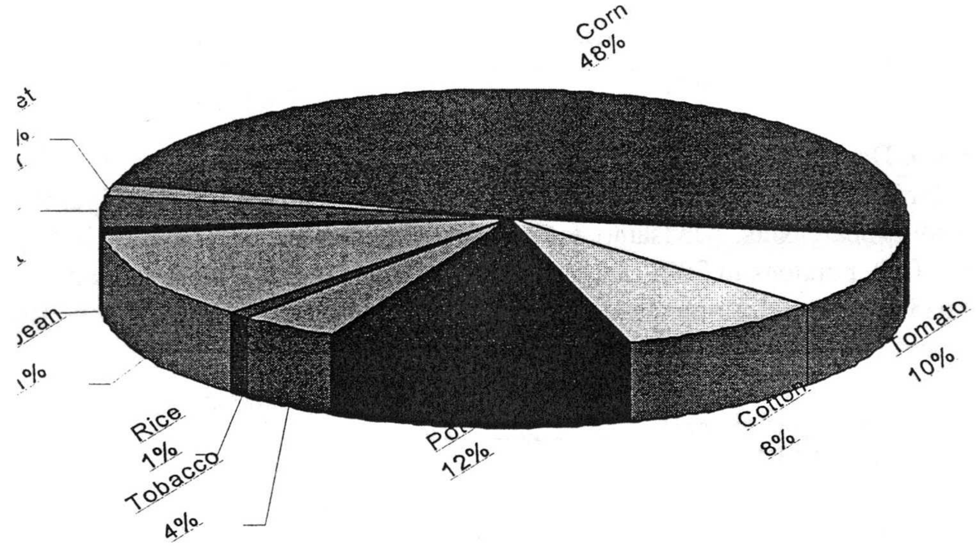
The identification of what is in the biotech product pipeline was compiled from a wide variety of sources. Many of the major biotech companies – seed, chemical, animal veterinary, food, etc. – were contacted over the course of the study period. Interviews and phone conversations were conducted with the appropriate company representatives. Publicly available databases from APHIS of US field trial notifications and OECD (global field trials) were thoroughly reviewed and analyzed to determine those products currently in field trials that likely will reach the market in the next several years. Other sources included company annual reports and Securities Exchange Commission filings (10Ks and 10Qs), other reports, seminars and conferences. Public sector sources included USDA/ARS, World Bank and many land grant universities research programs.

These and other sources served as our "crystal ball" on the biotechnology pipeline. And the pipeline is truly enormous – billions of research dollars are being devoted to expanding existing commercial traits to new commodities, to develop new value enhanced crops and livestock products, and to add wide-ranging nutritional and industrial attributes to plants and livestock. Over the next five years, the biotech pipeline will release many new products to commercial markets, and even more and different products will be released over the longer term as agriculture becomes more closely linked with pharmaceutical and industrial applications.

Field trials for biotech crops have been underway for more than ten years in the United States. Between 1993 and August 1998, APHIS has received nearly 5,600 notifications of field trials for biotech crops. Of that total, nearly one-half have been genetically modified corn varieties (Chart 5). Potatoes follow with 12% of the field trials while soybeans and tomatoes are next with 11% and 10%, respectively. Cotton varieties account for 8% of the APHIS field trials conducted since 1993, while wheat represents a low 1%. Other crops that have been tested (to demonstrate the extensiveness of research) include alfalfa, eggplants, walnut trees, melons, barley and carrots.

In the first quarter of 1998, the USDA approved 870 requests to field test genetically engineered crops, almost double the approvals made during the same period in 1997.

Chart 5. APHIS Field Trials by Crop – 1993 to Present



APHIS Regulations For Genetically Engineered Organisms

Developing and commercializing new genetically engineered plant varieties most often involves field testing under APHIS oversight, followed by submission of a petition for determination of "nonregulated status" by the agency. APHIS grants nonregulated status to a new plant variety when it determines the new variety has no potential to pose a plant pest risk and is as safe to grow as any other variety of the same plant.

USDA has the responsibility to ensure that, in releasing any bioengineered plant, no plant pest risk is presented. APHIS reviewers focus on the biology, propagation, and cultivation of the plant. The reviewers also consider the source of the engineered genes, the vector used to transfer them, and the stability of the insertion.

Recently amended regulations will allow a broader application of existing simplified procedures for requests for movement or field testing of genetically engineered plants. They also will streamline the determination of nonregulated status for plant varieties that closely resemble other varieties that have already been through the determination process. For example, once DeKalb's Roundup Ready corn was approved by APHIS, other companies testing similar varieties will not have to start at the beginning of the extensive, nonregulated-status determination process. This will enable APHIS to extend the existing determination of nonregulated status for new products that do not raise new risk issues.

The following subsections identify and describe from all the many sources the various products found to be in the pipeline with a reasonable expectation of being commercially released within the next five years.

Crops

Herbicide Tolerance Developments. As one of the first commercially successful biotech product traits, herbicide tolerance will continue to be a key trait of many products in the pipeline as it is extended to many additional plants. Monsanto, for example, plans to release Roundup Ready alfalfa and sugar beets in 2000, potatoes in 2001, and rice and wheat around 2002. American Cyanamid expects to extend its IMI system for resistance to imidazolinone (LIGHTNING) herbicide from corn to sugar beets, rice and wheat. A summary of the herbicide tolerant crops in the pipeline is presented in Table 23.[12]

Table 23. Summary of Herbicide Tolerant Crops in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Alfalfa	Monsanto	Glyphosate tolerant
Corn	Cargill Limagrain Pioneer DeKalb Monsanto Pioneer Garst Mycogen Pioneer Rogers Southern Illinois University Zeneca	Glyphosate tolerant Glyphosate tolerant/ Imidazolinone tolerant Phosphinothricin tolerant Chloroacetanilide tolerant
Cotton	Chembred United Agri Products AgrEvo Boswell	2,4-D tolerant Glufosinate tolerant Imidazolinone tolerant
Creeping Bentgrass	Rutgers University	Phosphinothricin tolerant
Lettuce	Seminis Vegetable Seeds	Glyphosate tolerant

[12] The chemical names for the active ingredient in the herbicides are referenced. The brand names that correspond to these chemicals include:

Sulfonylurea – Synchrony, Merit
Glyphosate – Roundup
Glufosinate – Liberty
Phosphinothricin – Liberty
Imidazolinone – Pursuit, Odyssey, LIGHTNING (IMI)
Bromoxynil – BXN

Poplar Trees	Monsanto Oregon State University Weyerhaeuser	Glyphosate tolerant
Potato	University of Idaho	Bromoxynil tolerant
Rapeseed 1/	Calgene Cargill Pioneer Western Ag Research	Glyphosate tolerant Glufosinate tolerant
Rice	Monsanto American Cyanamid AgrEvo ARS/USDA Louisiana State University	Glyphosate tolerant Imidazolinone tolerant Glufosinate tolerant
Soybean	AgrEvo Asgrow Pioneer University of Illinois Limagrain	Glufosinate tolerant Isoxazole tolerant
Sugar Beet	Monsanto Novartis Seeds American Cyanamid AgrEvo Betaseed	Glyphosate tolerant Imidazolinone tolerant Glufosinate tolerant
Sugarcane	Thermo Trilogy	Phosphinothricin tolerant
Sweetgum	Union Camp	2,4-D tolerant
Tomato	Seminis Vegetable Seeds	Glyphosate tolerant
Wheat	Monsanto American Cyanamid	Glyphosate tolerant Imidazolinone tolerant

1/ The USDA/APHIS database term "rapeseed" refers to canola varieties.
Source: APHIS field trials database and biotech/seed company reports

Key observations include:

A significant amount of research continues on developing herbicide tolerance for the high-value, high-volume crops (e.g., corn and soybeans). But, herbicide tolerant varieties of alfalfa, lettuce, rice, sugarcane and wheat are likely to appear in the next five years. Herbicide tolerant varieties of wheat have yet to appear in commercial markets, owing to its complex genetic make-up, but Monsanto appears likely to release Roundup Ready wheat near 2002. Once achieved in wheat, it likely can then be extended to other complex small grains such as barley, sorghum and oats.

Biotechnology is being used on trees as well as field crops, making it possible to make them faster-growing and disease resistant. Scientists are working on techniques for mass-cloning from tissues for reforestation purposes, and new genetic characteristics are being introduced into the breeding stock. For example, researchers at Monsanto, Weyerhauser and Oregon State University are working to develop herbicide resistance in hybrid poplars.

Herbicide tolerant crops are under development both by universities and private companies. The university research appears to be focused in product areas that have yet to reach commercialization, including potatoes, rice, poplar trees, and wheat.

Insect Resistance Developments. By inserting the gene of a common soil microorganism into plant tissue, scientists have created crops that produce their own internal insecticide. Most of these products thwart lepidoptera or caterpillar-type insects – Bt corn wards off the European corn borer, for example. Future generations of insect resistant crops promise control of other damaging types of insects - sucking insects in cotton using cholesterol oxidase and control of corn rootworm. Several other crop varieties are in development that will control many different damaging insects (Table 24).

Key observations include:

Monsanto has been working on the development of in-plant protection against corn rootworm since 1989. Field trials conducted this year demonstrated control of the insect, and commercial introduction is expected by 2001 or 2002. In 1997, Monsanto introduced YieldGard insect-protected corn which provides resistance to the European and Southwestern corn borers. Management of both corn borers and rootworms could save US farmers nearly $2 billion annually.

Several new developments are expected in cotton over the next five years. Monsanto plans to release a Second-generation Bollgard Insect protected cotton in 2001 that contains a Bt protein that fatally damages the second generation of bollworms. Monsanto also is expected to release a cotton variety resistant to the boll weevil around the same time.

Insect protection against lepidoptera will be extended to several crops, including rapeseed, soybeans and tomatoes.

There is little evidence of likely release of insect resistant varieties for wheat, rice and soybeans. Bacterial toxins in Bt are very specific to a few insect species, and its widespread use requires both comprehensive understanding of the crops' genetic mapping as well as the genetic coding of Bt insecticides.

University involvement in the research on insect resistance appears to be significantly greater than in herbicide tolerance research. Universities appear focused on extending insect resistance to eggplants, peanuts, potatoes, poplar trees, soybeans and sugarcane.

Table 24. Summary of Insect Resistant Crops in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Corn	Many companies. Monsanto Pioneer DeKalb	European corn borer resistant Corn rootworm resistant European corn borer/Corn rootworm
Cotton	Monsanto Mycogen	Boll weevil resistant Bollworm resistant (second generation) Boll weevil resistant
Eggplant	Rutgers University	Colorado potato beetle resistant
Peanut	University of Georgia	Lesser cornstalk borer resistant
Potato	Michigan State University New Mexico State University Plant Genetics	Colorado potato beetle resistant
Poplar	Oregon State University	Cottonwood leaf beetle/Phratora leaf
Rapeseed	University of Chicago	Lepidopteran resistant
Soybean	Monsanto University of Georgia	Lepidopteran resistant
Sugarcane	Texas A&M University	Mexican rice borer resistant
Tomato	BHN Research Monsanto	Lepidopteran resistant

Source: APHIS field trials database and biotech/seed company reports

A New Insecticidal Toxin to Rival Bt

A new insecticidal toxin was recently discovered at the University of Wisconsin-Madison. The bacterium, *Photorhabdus luminescens,* contains toxins, antibiotics, antifungal compounds, lipases, proteases, and light-producing genes. The bacteria thrive in the gut of an insect-attacking nematode. When the nematode invades an insect host, it releases the bacteria into the insect. The bacteria then kill the insect, leaving a cadaver that glows in the dark! This toxin may challenge the current monopoly of Bt for insect resistant crops. Photorhabdus toxins may eventually help manage resistance to Bt toxins, but that may require ten or more years to develop. Dow AgroSciences has licensed the Photorhabdus technology.

Disease Resistance Developments. Considerable research is underway to control many of the deadly diseases that damage or ruin crops each year. Most of the focus is on viruses, but attention also is being given to fungi and bacteria (Table 25). Traditionally, disease resistance was developed in crop strains through selective breeding of naturally resistant individuals. The process now is made quicker by cloning the genes responsible for resistance and inserting them into other plants, reducing the time needed to develop new strains from perhaps 12 years to only two or three. Once a resistant strain is established, the genes will persist in future generations through normal breeding methods. This technique has been used to culture oat plants with resistance to yellow dwarf virus, for example.

Table 25. Summary of Virus Resistant Crops in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Cucumber	Seminis Vegetable Seeds	Cucumber Mosaic Virus

		Papaya Ringspot Virus Watermelon Mosaic Virus Zucchini Yellow Mosaic Virus (all stacked)
Grape	GenApps	Nepovirus
Melon	Seminis Vegetable Seeds Harris Moran	Cucumber Mosaic Virus Papaya Ringspot Virus Squash Mosaic Virus Watermelon Mosaic Virus Zucchini Yellow Mosaic Virus (individual traits/combination stacked/all
Oat	Iowa State University	Barley Yellow Dwarf Virus
Papaya	ARS/USDA New York Experiment Station	Papaya Ringspot Virus
Pea	University of Idaho	Bean Leafroll Virus Bean Yellow Mosaic Virus Pea Enation Mosaic Virus Pea Seed-borne Mosaic Virus (individual traits/combination stacked/all
Peanut	University of Georgia	Tomato Spotted Wilt Virus
Pepper	Seminis Vegetable Seeds	Cucumber Mosaic Virus
Potato	ARS/USDA Monsanto Cornell University of Idaho	Potato Leafroll Virus Potato Virus Y Tobacco Rattle Virus (individual traits/combination of traits stacked/all
Soybean	Iowa State University	Soybean Mosaic Virus

Table 25. Summary of Virus Resistant Crops in the Pipeline—continued

Crop	Developing Company/Institution	Specific Trait
Squash	Seminis Vegetable Seeds	Cucumber Mosaic Virus Papaya Ringspot Virus Watermelon Mosaic Virus Zucchini Yellow Mosaic Virus (all stacked)
Sugar Beet	Betaseed	Beet Necrotic Yellow Vein Virus
Tobacco	University of Kentucky North Carolina State University ARS/USDA	Potato Virus Y Tobacco Spot Virus Tobacco Yellow Mosaic Virus Tomato Spotted Wilt Virus (individual traits/combination stacked/all
Tomato	Agritope Calgene Cornell University Harris Moran Seminis Vegetable Seeds	Beet Curly Top Virus Cucumber Mosaic Virus Gemini Virus Potato Virus Y Cucumber Mosaic Virus Gemini Virus Potato Virus Y
Watermelon	Seminis Vegetable Seeds	Watermelon Mosaic Virus Zucchini Yellow Mosaic Virus (all stacked)
Wheat	University of Idaho	Barley Yellow Dwarf Virus Wheat Streak Mosaic Virus (individual traits/both

Source: APHIS field trials database and biotech/seed company reports

Key observations include:

Significant research is underway to combat a large number of viruses, reflecting the severe damage and even ruination of crops caused by these viruses. In many crops, viruses typically carried by aphids tend to cause tissue necrosis, yellowing, reduced root growth, and premature death.

A central focus of the research is minor crops, primarily fruits and vegetables, more at risk from attack by aphids and other carriers. Management of viruses is especially important in maintaining the high value associated with these crops.

Private sector leaders in development of virus resistance include Seminis Vegetable Seeds and Harris Moran. Prominent public institutions are the University of Idaho and Iowa State University.

Much attention is being focused on products with "stacked" virus resistant traits. For example, Seminis and Harris Moran are both testing melon varieties with resistance to Cucumber Mosaic Virus, Papaya Ringspot Virus, Squash Mosaic Virus, Watermelon Mosaic Virus, and Zucchini Yellow Mosaic Virus. Other multiple virus resistant crops in the pipeline include cucumbers, potatoes, peas, and wheat, among others.

Researchers have learned that the difference between resistance and susceptibility to fungal diseases is simply the rate of the plant's response. If a plant can respond to a first fungi attack rapidly, then it likely can resist further damage. This enables farmers to inoculate crops against some fungal diseases. Slow-responding plants are given a head start by being deliberately infected with the disarmed fungi – the same principle used to vaccinate children against infectious diseases.

Fungal diseases of fruits, vegetables and grains can cost farmers billions of dollars annually. New fungal resistant genes can be inserted into many of these vulnerable crops, resulting in a significant number of resistant crops to be released in the next few years (Table 26).

Table 26. Summary of Fungus Resistant Crops in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Apple	Cornell University	Apple scab resistant
Carrot	Seminis Vegetable Seeds	Alternaria daucii resistant
Corn	DeKalb	Leaf blight resistant Northern corn leaf blight resistant
	Northrup King	Northern corn leaf blight resistant
	Novartis Seeds	Helminthosporium resistant
	Pioneer	Leaf spot resistant Ear mold resistant/Gray leaf spot resistant Fusarium ear rot resistant/Gray leaf spot Gray leaf spot resistant/Northern corn leaf Mycotoxin degradation Smut resistant
Cotton	Texas Tech University	Verticillium resistant
Creeping Bentgrass	Rutgers University Scotts	Dollar spot resistant Rhizoctonia solani resistant
Eggplant	Rutgers University	Phytophthora resistant/Verticillium resistant
Grape	Cornell University	Botrytis cinerea resistant/Powdery mildew
Kentucky Bluegrass	Scotts	Rhizoctonia solani resistant
Poplar	Oregon State University	Marssonina resistant/Melamtsora
Potato	ARS/USDA Boyce Thompson Institute Michigan State University	Phytophthora resistant
	Monsanto	Phytophthora resistant Verticillium resistant
	Washington State University	Phytophthora resistant Verticillium dahlae resistant
Rapeseed	Cargill	Cylindrosporium resistant/Phoma resistant/
Red Raspberry	ARS/USDA	Fruit rot resistant

Table 26. Summary of Fungus Resistant Crops in the Pipeline—continued

Crop	Developing Company/Institution	Specific Trait
Soybean	University of Illinois Michigan State University	Fusarium rot resistant Sclerotinia resistant
Strawberry	DNAP Holding Corporation	Verticillium dahlae resistant
Sunflower	Pioneer	Sclerotinia resistant
Tobacco	University of Kentucky	Black shank resistant
Tomato	Calgene Seminis Vegetable Seeds	Fusarium wilt resistant/Verticillium dahlae Fusarium wilt resistant Powdery mildew resistant
Wheat	Monsanto Novartis Seeds	Fusarium head blight resistant Septoria resistant

Source: APHIS field trials database and biotech/seed company reports

Key observations include:

Several varieties of major crops are in the pipeline for fungus-resistance. Corn varieties likely to be released focus on ear mold, gray leaf spot, northern corn leaf blight and smut, among others. Resistance to fusarium rot and wilt diseases, caused by the fusarium oxysporum fungus, also is being built into corn, soybeans, tomatoes, and wheat.

Pioneer Hi-Bred is focusing on development of fungal resistant corn varieties, while few other private companies appear to be focusing efforts in this area. Monsanto plans to release a fusarium wilt resistant wheat variety in the next few years, and is doing similar work in potatoes. Other companies are focused more on developing fungus resistant varieties of fruits and vegetables. Pebble Ridge Vineyards, a producer and processor of grapes – not a technology or input supplier – is testing grape varieties with fungal-resistance.

Universities also are prominent in this area. Washington State is developing potato varieties resistant to phytophtora and verticillium. Oregon State is developing a poplar tree variety that would resist four different fungi. Others are testing crops that are important in their particular geographic areas.

Many insect pests, such as whiteflies, aphids and leafhoppers, not only transmit viruses but also bacteria that can cause devastating plant diseases while also causing billions' of dollars worth of direct damage to crops by feeding on them. Several varieties with resistance to these bacteria are in the product pipeline (Table 27).

Table 27. Summary of Bacteria Resistant Crops in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Apple	Cornell University	Fire blight resistant
Poplar	Iowa State University	Crown gall resistant
Potato	ARS/USDA	Erwinia carotovora resistant
Rice	University of California/Davis	Bacterial leaf blight resistant
Sugarcane	Texas A&M University United States Sugar Corp.	Clavibacter resistant
Tomato	Ohio State University Purdue University	Bacterial speck resistant
Walnut	University of California/Davis	Bacterial leaf blight resistant

Source: APHIS field trials database and biotech/seed company reports

UC Davis (Sept. 98) has cloned genes that protect tomato plants from root-knot nematodes and also confer resistance against aphids. This represents a major discovery that a single-resistance gene is effective against a plant parasite and an insect pest from a different phylum.

Key observations include:

Virtually all research on bacteria resistant crops is being done in the public sector (ARS or universities), except a sugarcane variety resistant to clavibacter by the United States Sugar Corporation.

The research effort on bacteria-resistance is focused mostly in minor crops and in trees (poplar and walnut).

Yield Effects – Agronomic Property Developments. World grain production since 1950 has increased at an astonishing rate, due to the combination of improved crop varieties, irrigation, fertilizers and chemical pest control. During that time, world population has more than doubled, and today nearly 90 million new people are added each year. Biotechnology is being viewed as a means to avoiding the adverse environmental consequences that accompany the quest to expand food supplies to meet that growth.

Genetic engineering now can be used to modify crop production at stages, from speeding up early growth of food plants to increasing yields to slowing ripening or wilting. Since the form and function of a plant depends a great deal on its genetic composition, the ultimate goal is to engineer plants optimal for every growing condition and market niche.

Changing a crop's agronomic properties not only affects yields but also the production process itself, as crops can be stylized for specific climates and soil types. Some specific alterations in development include increased stalk strength (standability), yield increases, altered growth rate, drought tolerance, and stress tolerance (Table 28).

Table 28. Summary of Crops with Altered Agronomic Properties in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Apple	University of California	Flowering time altered
Corn	Cargill	Male sterile
	DeKalb	Carbohydrate level increased
		Carbohydrate metabolism altered
		Stress tolerant
	ICI Garst	Modified growth characteristics
	Iowa State University	Male sterile
	Limagrain	Lipase expressed in seeds
	Monsanto	Development altered
		Photosynthesis enhanced
	New York State University/Albany	Male sterile
	Pioneer	Fertility altered
		Growth rate increased
		Increased stalk strength
		Altered maturing
		Yield increased
	University of Arizona	Anthocyanin produced in seed
	University of Minnesota	Vivipary increased
Cotton	Monsanto	Altered maturing
		Ethylene metabolism altered
	Texas Tech University	Carbohydrate metabolism altered
		Oxidative stress tolerant
Creeping Bentgrass	Rutgers University	Aluminum tolerant
		Drought tolerant
		Salt tolerance increased
Poplar	Michigan Technological University	Altered lignin biosynthesis
Rapeseed	Calgene	Yield increased
Rice	Monsanto	Yield increased
Soybean	Monsanto	Altered plant development
Tobacco	Southern Illinois University	Ammonium assimilation increased
	University of Hawaii/Manoa	Growth rate altered
	University of Kentucky	Senescence altered
	University of Wisconsin/Madison	Senescence altered
Walnut	University of California/Davis	Cutting rootability increased
		Flowering altered
Wheat	Monsanto	Carbohydrate metabolism altered
		Nitrogen metabolism altered
		Photosynthesis enhanced
		Yield increased
	Montana State University	Drought tolerant

Key observations include:

Many of the trait modifications for some crops appear rather vague or non-descriptive. This likely is for proprietary reasons, but may well suggest significant yield impacts for crops.[13]

Many of these traits including drought tolerance, stress tolerance, and enhanced photosynthesis would have direct impacts on yield, but it is notable that many groups are working to develop "increased yield" varieties of crops including corn, rice, soybeans and wheat.

The work being done in this area covers a wide range of crops, including the major crops of corn, cotton, soybeans and wheat to the more minor crops such as apples, grasses, trees and tobacco. In the United States, there does not appear to be considerable work underway in the traditional developing country crops – a potentially huge market.

Gene Mapping of Cassava Developed by the International Center for Tropical Agriculture (CIAT)

Researchers at CIAT have been working to find the genes that control agronomic traits in cassava. This knowledge could be used to enhance cassava's traditional role as provider of food security in Africa, and future role as an industrial crop worldwide. The search has spurred researchers to develop a molecular genetic map for cassava, the first such map for a major food crop generated outside of an industrialized country.

The gene map is expected to accelerate the study of economically important genetic traits in cassava, particularly root quality traits. The erratic supply of cassava roots typically prevents new marketing and post-harvest opportunities – gene mapping success likely will lead to better root quality as well as resistance to disease and bacterial blight.

Monsanto continues research on agronomic properties in crops in which it has already altered traits. Additional work also is underway by several universities since development of these traits likely requires more "basic" research and understanding of the crops' genomics.

[13] Applications for field trials are not required to make available details of the specific trait modifications being sought to the public. A firm can claim in a permit application that some scientific data is confidential business information (CBI). APHIS can, however, use that information in its safety deliberations, but may not divulge the information to the public.

Engineering Cold Tolerance in Plants ...

Cold injury to crops often causes billions of dollars in losses. Traditional plant breeding has enjoyed little success in improving cold tolerance of crops. Recent research by Michigan State University reveals that cold tolerant genes can be activated in the plant by introducing a key regulatory gene, thus helping them defend against a cold snap.

The research focuses on "cold acclimation," where plants exposed to gradual low, non-freezing temperatures tolerate subsequent freezing temperatures by expressing a series of "cold regulated" genes. Thus, a gradual cooling can help the plants better prepare for icy weather while a sudden freeze could kill them. When one such gene was "over expressed" in the *Arabidopsis* plant, test plants survived exposure to lethal low temperatures (-5 degrees Celsius).

The research clearly shows the potential of genetic modification of plants to confer cold hardiness and suggests that crops in the future may be redesigned to brave an occasional arctic chill. Even a small increment in cold tolerance would prevent substantial crop losses in the face of frigid weather. Further, since the defense response of the plants against cold and drought are similar, there is potential also to protect the crops against water stress. The Michigan State researchers have filed patents for the cold-fighting gene and are finalizing a licensing agreement with Mendel Biotechnology, Inc. to commercialize their work.

Fruits and Vegetables. Among the many products in the fruit and vegetable pipeline are insect resistant and virus resistant produce, improved-texture peppers, enhanced-taste vegetables, and ripening-altered fruits with longer shelf life (Table 29). There also are fruits and vegetables with "stacked" (multiple) traits, combining agronomic and consumer-oriented traits. Major players in this industry include DNAP (formerly known as DNA Plant Technologies), Calgene, and Agritope, as well as Monsanto and Zeneca.

Table 29. Biotech Fruit and Vegetable Crops in Development

Trait	Product	Description
Insect/Disease	Insect Protected Tomatoes – Calgene Virus Resistant Tomatoes – Calgene	Plants require less insecticide to achieve Resistant to certain plant viruses.
Improved Texture	Firmer Peppers – DNAP	Remains firmer after harvest
Improved Taste	High Sweetness Tomato – Calgene Sweeter Peppers – DNAP Fresh Market Tomato – Zeneca	Enhanced flavor. Made sweeter by overexpressing a gene Enhanced flavor, color, and increased

Table 29. Biotech Fruit and Vegetable Crops in Development—continued

Trait	Product	Description
Ripening Altered	Ripening-Controlled Tomatoes – Ripening-Controlled Cantaloupe – Ripening-Controlled Cherry Tomatoes – Ripening-Controlled Bananas and	Extended shelf life Extended shelf life Longer market life, improved flavor, and Extended shelf life
Improved	High Solids Potato – Monsanto Quantum Tubers Seed Potatoes –	Contains less water, so less oil is absorbed Seed-potato-producing plants have higher
Multiple Traits	Transwitch Strawberries – DNAP NewLeaf Insect and Y Virus-Protected Corn w/Monoclonal Antibodies in its Fungus Resistant Banana – Zeneca	Modified to keep fruit firmer after harvest Better protected against the Colorado Resistant to several plant diseases. Resistant to Black Sigatoka, and will have

What? No Seeds ...

In the wake of the recent development of a seedless eggplant by an Italian research team, Kansas State University scientists now report development of a seedless tomato. The research approach was similar – seedlessness was achieved by genetically engineering overproduction of hormones necessary for fruit development.

While the small seeds in a tomato are not bothersome for consumers, the ability to produce tomato fruits without seeds may afford considerable advantages for the grower. Normally, pollination and subsequent seed production are required for good fruit development in most plants. Bad weather during flowering can interfere with pollination, resulting in a bad tomato harvest. Thus genetic modification of the crop to reduce its dependency on pollination for fruit development could reduce the constraints of weather, insect pollinators, and growing season.

Scientists developed seedless tomatoes by expressing two genes that are present in developing ovaries and fruit. An unexpected bonus in the engineered tomatoes was the high solids content in the fruits, suggesting that the seedless tomato may funnel its resources towards higher solids that would otherwise have gone into producing seeds.

Both seedlessness and high solids are valuable traits for the tomato processing industry, where most of the tomato harvest ends up. Processors routinely remove the seeds and reduce the water content of tomatoes before cooking up ketchup or pasta sauce. Currently, the tomatoes need to be emasculated (pollen sacs removed) to obtain completely seedless fruits, a laborious process. A Dutch biotechnology company, field testing the transgenic tomatoes, is working to introduce a female sterility gene into these lines. The Kansas State researchers also are developing seedless watermelons they hope will result in better tasting fruits with extended shelf life.

Edible Oils. Oil crops in the product development pipeline include traits described above, as well as new ones that could add value in processing (Table 30). Monsanto is attempting to develop both low-stearate canola and soybeans, whose oil would require no hydrogenation. Not to be outdone by the introduction of LoSatSoy (the reduced saturated fatty acid oil already marketed by Optimum Quality Grains), canola varieties with even lower levels of saturated fat are being developed by Calgene and Cargill.

Table 30. Oilseed/Edible Oil Crops in Development

Trait	Product	Description
Less Hydrogenation	High-Stearate Canola Oil – High-Stearate Soybean Oil –	Does not require hydrogenation, thus reducing Requires no hydrogenation.
Less Saturated Fat	Very Low Saturated Fatty Very Low Saturated Fatty	Lower in fat and healthier. In development for its more healthy, lower-fat
High	High Monoun-Saturated Fatty	Will have various food applications.
Making Industrial Oils	Edible Flax Oil – DuPont	Will have a wide range of applications in deep-fat
Processing	Enhanced Medium Chain Low Stachyose Soybeans –	Less-expensive sources of raw materials for Useful in the production of meat extenders, and
Multiple Traits	Altered Fatty Acid High Oil and High Oleic Corn	Lower saturated fats, higher monounsaturated Produce an oil that is lower in monounsaturated

Key observations include:

The major players in oilseed development thus far have been Monsanto (or its subsidiary, Calgene), DuPont, and Optimum Quality Grains.

Most of the development to date has centered on the two major oilseeds in North America – soybeans and canola.

The new traits in development are broadly-based, although the two most widely-developed traits are lower-fat oils and reduced-hydrogenation oils.

Value Enhanced Crops

While the initial focus in biotechnology has been on cost reducing and yield enhancing characteristics, value enhanced traits in field crops hold significant potential in the next few years and beyond. This class of innovations includes, for example, corn with higher amino acid content or methionine levels, cotton with increased fiber quality, rapeseed and soybeans with altered oil profiles, and potatoes, tomatoes and vegetables with improved shipping qualities and ripening attributes. These new traits create value for animal feeders (reduced feed costs due to increased energy value and amino acid content in grain), for food companies (healthier oils and tailor-made components for food ingredients), and personal care companies (oils for soaps and gels). These are but the first of what promise to be a series of value enhanced products for crops (Table 31).

Table 31. Summary of Product Quality Developments in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Alfalfa	W-L Research	Altered lignin biosynthesis
Barley	Coors Brewing	Disulfides reduced in endosperm
	Washington State University	Heat stable glucanase produced
Corn	DeKalb	Altered amino acid composition
		Lysine level increased
		Methionine level increased
		Tryptophan level increased
	DuPont	Carbohydrate metabolism altered
		Increased phosphorus
		Protein quality altered
		Oil profile altered and lysine and methionine
	Monsanto	Carbohydrate metabolism altered
		Nitrogen metabolism altered
	Pioneer	Carbohydrate metabolism altered
		Increased phosphorus
		Lysine level increased
		Methionine level increased
		Mycotoxin production inhibited

		Protein lysine level increased

Table 31. Summary of Product Quality Developments in the Pipeline—continued

Crop	Developing Company/Institution	Specific Trait
Corn	University of Arizona	Nutritional quality altered
		Anthocyanin produced in seed
	University of Minnesota	Oil profile altered
		Lysine level increased
	Rutgers University	Methionine level increased
Cotton	Agracetus	Fiber strength altered
	Calgene	Melanin produced in cotton fibers
	Monsanto	Fiber strength altered
		Natural pigments altered
	Texas Tech University	Fiber quality altered
Melon	Agritope	Fruit ripening altered
	Harris Moran	
Pepper	DNAP Holding Corp.	Prolonged shelf life
Potato	ARS/USDA	Blackspot bruise resistant
		Nutritional quality altered
		Steroidal glycoalkaloids reduced
	Frito Lay	Carbohydrate metabolism altered
	Monsanto	Bruising reduced/Carbohydrate metabolism
		Carbohydrate metabolism altered
		Solids increased
	North Dakota State University	Carbohydrate metabolism altered
	Rutgers University	Bruising reduced
Rapeseed	Cargill	Amino acid composition altered
		Fatty acid metabolism altered
	Limagrain	Nutritional quality altered
Red Raspberry	Agritope	Fruit ripening altered
Soybean	DeKalb	Protein quality altered
		Lysine level increased
	DuPont	Protein quality altered
		Carbohydrate metabolism altered
		Lysine level increased
		Oil profile altered/Seed composition altered
		Lysine and methionine levels increased
		Oil quality altered/Protein altered
	Monsanto	Protein altered
		Seed composition altered
		Nitrogen metabolism altered
	Pioneer	Methionine level increased
		Seed methionine storage increased
	University of Illinois	Protein altered
Strawberry	Agritope	Fruit ripening altered
	DNAP Holding Corp.	

Table 31. Summary of Product Quality Developments in the Pipeline—continued

Crop	Developing Company/Institution	Specific Trait
Tomato	ARS/USDA	Polyamine metabolism altered
	Agritope	Fruit ripening altered
	BHN Research	Solids increased
		Fruit sugar profile altered
	Calgene	Yield increased
		Carbohydrate metabolism altered
	Campbell Soup Company	Fruit sugar profile altered
		Improved fruit quality
	DNAP Holding Corp.	Fruit ripening altered
	Gargiulo	Solids increased
	Harris Moran	Carbohydrate metabolism altered
	Hunt-Wesson	Pectin esterase level reduced
	Lipton	Antioxidant enzyme increased
	Monsanto	Fruit ripening altered
	Purdue University	Pectin esterase level reduced
		Polyamine metabolism altered
	Seminis Vegetable Seeds	Pigment metabolism altered
	Sunseeds	Fruit sugar profile altered
	University of Florida	Fruit ripening altered
		Fruit ripening altered
	University of Georgia	Fruit solids increased/Seed set reduced
	University of Wisconsin/Madison	Carbohydrate metabolism altered
	Zeneca	Carotenoid content altered
		Dry matter content increased/Yield
		Ethylene metabolism altered
		Fruit solids increased
		Solids soluble increased
Wheat	ARS/USDA	Storage protein altered

Key observations include:

Significant research is underway to develop valuable food properties – high starch corn, high solids potatoes and tomatoes, and "flavor genes" for strawberries and other fruits and vegetables.

Research in this area is being conducted by food processing companies, such as Frito Lay, Hunt-Wesson and Campbell as well as by universities and biotechnology/seed companies.

Product development is a focus of both universities and private companies.

The major and minor crop focus is well balanced, with corn, potatoes, soybeans and tomatoes prominent. ARS/USDA is developing a wheat variety with an altered protein composition – apparently the only value enhanced wheat variety currently in testing.

Many companies are working to develop crop varieties with increased lysine and other amino acid concentrations. Since lysine is one of the amino acids in low concentration in corn, animal feeders (especially poultry) often add lysine supplements to their feed mix to increase its competitive value.

Wheat apparently has been much less studied than other crops because of its complexity. The limit may be partly of imagination and partly of funding – the science and return on investment. But, many advancements likely will prove possible over the next several years as research continues. Some possibilities that wheat millers and processors have in mind include:

- Creaseless wheat kernel – simplifies mill diagrams and requires less machinery
- Whiter endosperm – allows longer extraction
- Larger germ – facilitate marketability of germ oil
- Uniform kernel size – reduction in numbers and types of machines
- High starch/gluten content – allow for dry process for starch extraction plus creation of specialty products
- Fiber increases – nutritional gains

New Low-Phytate Corns Ready for Spring 1999 ...

The first two low-phytate corn varieties are NutriDense LP and Yellow Dent LP, available for planting in 1999 from ExSeed Genetics LLC (Owensboro, Kentucky) which will license the new technology from USDA's Agricultural Research Service. NutriDense LP and Yellow Dent LP will be available through Thurston Genetics, the exclusive agent for ExSeed Genetics.

This latest line of specialized grains, designed specifically for the addition to swine and poultry rations, is naturally high in digestible phosphorus, unlike generic corn. Phytic acid (referred to as phytate), a naturally occurring plant compound used to store phosphorus, can inhibit an animal's phosphorus absorption, which means producers must add expensive phosphorous supplements or phytase enzymes to feed.

But, working with the new genetic materials provided by ExSeed Genetics, University of Illinois research shows that low-phytate corn contains 84% digestible phosphorous – three times the level in conventional corn. Where high levels of phosphorous excreted in animal manure are a concern, the low-phytate approach may be revolutionary, especially for swine and poultry producers facing increased environmental monitoring and potential regulation.Earlier, the seed industry expected introduction of such products no sooner than 2000 or 2001. Now, that timetable has been speeded up.

Sugar Beets...Genetic Engineering Yields Low-Cal Sweetener

Dutch researchers say they have genetically engineered sugar beets to make a natural low-calorie sweetener, adding a gene from the Jerusalem artichoke to make beets produce fructan, a type of sugar that is hard to digest and which thus inflicts fewer calories.

Jerusalem artichokes – small, knotty roots, irregularly shaped and hard to process – are not good sources for commercial sugar makers. But beets have been used for many years to make sugar. The Jerusalem artichoke gene causes the plant to convert sucrose – which becomes table sugar – into fructans, which taste sweet but are not digested as easily. The Dutch team suggests their approach could offer an easier way to produce fructan.

Stacked Traits

With the resources to actually "stack" traits, one on top of the other, in a plant, the possibilities for crop characteristics become endless. And, the "stacking" is not limited to similar traits (i.e., all traits must be herbicide tolerant). There are products being tested that have five or more different traits – to provide insect resistance, herbicide tolerance, multiple virus resistance and increased proteins or amino acids, thus combining the cost reducing/yield enhancing traits and value enhanced traits (Table 32). The ability to "stack" these traits has obvious potential for greatly enhancing the value of what once was merely commodities.

Table 32. Summary of Stacked Trait Crops in the Pipeline

Crop	Developing Company/Institution	Specific Trait
Brassica oleracea	American Takii	Male sterile/Phosphinothricin tolerant
Corn	AgrEvo	Male sterile/Phosphinothricin tolerant
		Phosphinothricin tolerant/Carbohydrate
		Alternaria resistant/Botrytis resistant/Rhizoctonia
		Aspergillus resistant/Leaf blight resistant/Leaf
	Asgrow	Male sterile/Phosphinothricin tolerant
	Cargill	Male sterile/Phosphinothricin tolerant
	DeKalb	Carbohydrate metabolism
		Glyphosate tolerant/European corn borer

Table 32. Summary of Stacked Trait Crops in the Pipeline—continued

Crop	Developing Company/Institution	Specific Trait
Corn	DeKalb	Methionine level increased/Phosphinothricin
		Phosphinothricin tolerant/Altered amino acid
		Phosphinothricin tolerant/Increased lysine level
		Phosphinothricin tolerant/Increased methionine
		Phosphinothricin tolerant/Seed methionine
		Phosphinothricin tolerant/Storage protein altered
		Phosphinothricin tolerant/Tryptophan level
		Northern corn leaf blight resistant/Southwestern
	Limagrain	Glyphosate tolerant/European corn borer
		Phosphinothricin tolerant/Lipase expressed in
		Phosphinothricin tolerant/Starch metabolism
	Holdens	Anthracnose resistant/Cercospora
		Anthracnose resistant/Cercospora
		Leaf blight resistant/Phosphinothricin tolerant
	Monsanto	Glyphosate tolerant/European corn borer
	Pioneer	Fertility altered/Phosphinothricin tolerant
	Plant Genetic Systems	Phosphinothricin tolerant/Stress tolerant
		Male sterile/Phosphinothricin tolerant
	Stine Biotechnology	Growth rate increased/Phosphinothricin
		Imidazolinone tolerant/Phosphinothricin
		Phosphinothricin tolerant/European corn borer
	U of Illinois	Aspergillus resistant/Phosphinothricin tolerant
	Many companies	Phosphinothricin tolerant/European corn borer
Cotton	Calgene	Bromoxynil tolerant/Lepidopteran resistant
	Monsanto	Glyphosate tolerant/Coleopteran resistant
Peanut	AgraTech Seeds	Visual marker/Tomato Spotted Wilt Virus
Pineapple	University of Hawaii	Flower and fruit set altered/Root-knot nematode

Table 32. Summary of Stacked Trait Crops in the Pipeline—continued

Crop	Developing Company/Institution	Specific Trait
Potato	Boyce Thompson Institute	Phytophthora resistant/Kanamycin resistant
	Michigan State University	Phytophthora resistant/Coleopteran
	Monsanto	Glyphosate tolerant/Bruising reduced
		Glyphosate tolerant/Carbohydrate metabolism
		Glyphosate tolerant/Colorado potato beetle
		Glyphosate tolerant/Colorado potato beetle
		Glyphosate tolerant/Potato Leafroll Virus
		Verticillium resistant/Colorado potato beetle
		Verticillium resistant/Colorado potato beetle
		Verticillium resistant/Glyphosate
		Colorado potato beetle resistant/Bruising
		Colorado potato beetle resistant/Bruising
		Colorado potato beetle resistant/Potato Leafroll
		Colorado potato beetle resistant/Potato Virus Y
	University of Idaho	Late blight resistant/Potato Leafroll Virus
Rapeseed	AgrEvo	Fertility altered/Phosphinothricin tolerant
		Male sterile/Fertility altered
		Phosphinothricin tolerant/Lepidopteran resistant
	Calgene	Glyphosate tolerant/Oil profile altered
Soybean	DeKalb	Phosphinothricin tolerant/Lysine level increased
Tobacco	Southern Illinois U	Ammonium assimilation increased/Visual marker

Key observations include:

Potato and corn varieties appear to be the focus for stacked products in the pipeline. Companies such as DeKalb, Pioneer, AgrEvo and others are working to develop corn varieties that are herbicide tolerant, insect tolerant, fungus resistant and contain increased levels of lysine, methionine and protein. Monsanto is leading in potato development, combining in a variety of ways, traits to resist the Colorado potato beetle, Potato viruses Y and X, reduce bruising, tolerate glyphosate, and alter the carbohydrate profile.

Many companies and institutions are building on traits already successful in commercial markets and are either joining traits together or "stacking" them with others still in the pipeline.

Livestock

While few biotech livestock products are yet in the commercial arena, it is apparent that significant research is well underway that potentially will result in revolutionary changes in the livestock sector in the not-too-distant future. Researchers are developing genetically engineered "super animals" with enhanced characteristics for food production, novel transgenic animals to serve as "chemical factories" to produce drugs and medicines, and animals to serve as organ donors for human transplants.

This section provides an overview of several possible applications of biotechnology in the livestock sector, including:

Embryo transfer and in-vitro fertilization;
DNA and gene markers;
Cloning;
Vaccines;
Pharmaceutical product, medicines and nutrient production; and
Product improvement.

Embryo Transfer and In-Vitro Fertilization. Embryo transfer is not a new technology, having been routinely practiced in cattle for more than 20 years. Initially, it was expected to revolutionize genetic progress by its ability to increase the number of offspring from elite breeding animals. However, it proved to be quite costly.

With in-vitro fertilization, immature oocytes (eggs) are obtained from the female animal's ovaries, matured and fertilized in a culture environment, and either implanted into recipients or frozen at an early stage. During fertilization, the embryo's DNA can be examined to determine its genetic attributes. For example, some qualitative traits controlled by a single gene pair (i.e., coat color, horns) can be determined. More complex traits, controlled by multiple gene pairs (quantitative traits), such as growth rates and birthing ease also can be determined. The DNA also can be used to determine the sex of the embryo..

Research is underway to develop efficient collection methods for oocytes from females. The variability of superovulation and low rates of development of the embryos have limited the offspring produced. Oocytes collection from heifers offers the best method for decreasing the generation interval in cattle reproduction. Researchers are tying to gain a more complete understanding of the changes occurring in the nucleus during oocyte growth, maturation, fertilization and early development – all essential to the complete development of in-vitro fertilization.

DNA and Gene Markers. The current biotechnology emphasis in animal agriculture stresses the need to integrate new molecular technologies into the identification of major genes affecting growth and development, reproductive performance, lactation and disease resistance characteristics. Basic research is underway to identify those genetic variants which affect growth traits, either positively or negatively. By constructing a well-based genomic map of the animal, genetic improvement of livestock can be accelerated with the general knowledge of genetic markers with beneficial economic traits.

There is a great deal of similarity between the gene maps of humans and other mammals, so genes mapped in humans or even mice may lead to discoveries in livestock. Gene mapping of livestock has lagged behind the human effort due mostly to funding constraints. But even if specific genes are not known, genetic markers can be used to identify certain regions of a chromosome and then to trace the inheritance of that region related to a particular trait. More importantly, researchers not only have to locate the specific gene on a chromosome, but also need to determine its functionality or association with a given biological or physiological characteristic. Presently, researchers are further along in mapping the genomes of livestock than in determining their functions.

Cloning. In the past few years, cloning has received enormous attention, not just from within the livestock industry but also from the general public. The births of "Dolly" and "Gene" raised the issue of the potential for cloning in livestock production and also began a debate over the control and use of cloning technology that likely will continue for quite some time.

The current approach to cloning involves the use of primordial germ cells as the base cloning material taken from a developing fetus, the foundation genetic material. This technology was used by researchers at ABS Global, Inc. to produce "Gene" the calf in 1997.

A new cloning approach for development of transgenic cows has proven successful and is being investigated. The approach, developed by researchers at the University of Massachusetts and Advanced Cell Technology involves transfer of nuclei from genetically modified cultured cells, a strategy similar to that used to produce the transgenic sheep "Dolly."

In contrast to the sheep experiment, the bovine experiment involved transfer of nuclei from an actively dividing population of cells, seeming to be more efficient than the classical microinjection method. This method of nuclear transfer produced three transgenic calves from 276 embryos. Typically, about 500 embryos are needed to obtain one transgenic cow. The three surviving calves were phenotypically and genetically identical. A family portrait of the three calves showed that the calves had the same pattern of black and white coloration. Researchers also expect that the sex of the transgenic cow can be predetermined using this new method.

Advanced cloning techniques offer significant potential to improve the quality and consistency of the animal. Producing multiple copies of animals with known meat characteristics (flavor, tenderness and color) is possible. However, extensive cloning in the near term is unlikely given the high costs of the technology – breeding operations would have to completely switch from natural service or artificial insemination to use of cloned embryo transfers. And, public acceptance of cloning procedures remains a huge unknown – ethical issues related to animal and human cloning have been brought to the forefront of public debate by last year's major developments.

Vaccines. Many companies are focusing on development of technology and/or product opportunities that improve animal health and production efficiency in poultry, dairy cattle, beef cattle, swine, and sheep. This includes therapeutics used in animal health and biologicals for diagnosis and prevention of disease in production animals.

Significant work on livestock vaccines is underway by ARS in conjunction with several major companies. Some of these projects include:

Vaccine for Ovine Lentiviral Infection – researchers are examining the feasibility of transfecting sheep with the ovine lentivirus (OvLV) genes to determine the immune system responses and the possibility of inducing protection to the virus.

Relationships among IBDV, IBV, CAV And E Coli in the Development of Respiratory Disease Complex in Chickens – researchers are studying the interrelationships of infectious bursal disease virus (IBDV), chicken anemia virus (CAV), infectious bronchitis virus (IBV), and E. coli in the development of respiratory disease complex (RDC) in chickens. New control measures for RDC using recombinant DNA techniques are being examined, and researchers are using biotechnology to develop techniques for rapidly identifying new pathotypes of the disease agents. Testing of this research has resulted in a vaccine for IBV.

Natural Resistance to Salmonella: Detection of Susceptible and Resistant Pigs – the National Animal Disease Center in conjunction with Pig Improvement Center (PIC) is working to develop an in-vitro bactericidal test to identify Salmonella-susceptible and resistant pigs. A large population of PIC pigs will be screened and designated "resistant" and "susceptible" based on their ability to kill Salmonella. Preselected pigs will be exposed to Salmonella in containment facilities to validate the in-vitro test. The ability to separate the pigs into two groups, resistant and susceptible, will allow for better screening of genetically defined breeding stock for altered genes that may predispose them to Salmonella or other pathogens.

Pharmaceutical Product, Medicines and Nutrient Production. Much of the cutting edge research in livestock is occurring in the pharmaceutical industry. Researchers are transforming livestock into bio-factories to produce pharmaceutical products, medicines and nutrients. This approach has several advantages over standard chemical means of production, including relatively low operating costs and unlimited ability to multiply. As an added benefit, bioengineers can ensure that the protein products expressed by added genes are deposited in the milk of mammals or the eggs of hens, making the chemicals easy to harvest and process. Some of the products already developed include:

Lysozome is an antibacterial agent that makes up three to four percent of a normal egg white. Researchers are manipulating the lysozome gene to increase the volume of antibiotic produced and make lysozome effective against a wider range of bacteria.

Egg yolk normally contains antibodies that are deposited by the hen to protect the embryo from infection before its own immune system develops. The variety of antibodies can be customized by first immunizing hens with particular antigens. This strategy can be taken one step further by creating transgenic hens. Given genes from other species, these hens will lay eggs with antibodies specific to diseases of pigs, cattle or humans, among others.

In April 1996, Genzyme Transgenics announced the birth of Grace, a transgenic goat carrying a gene that produces BR-96, a monoclonal antibody being developed and tested by Bristol-Myers Squibb to deliver conjugated anti-cancer drugs. Reportedly, by the time Grace turned one year old, she was expected to produce more than a kilogram of the experimental anti-cancer drug. Genzyme Transgenics also plans on testing a goat to produce anti-thrombin, an anti-clotting drug. Genzyme's relatively new $10 million facility which produces drugs for Gaucher disease reportedly could be replaced in the near future by a herd of only twelve goats!

Other work in this area includes research at PPL Therapeutics, whose transgenic calf Rosie produces milk that contains alpha-lactalbumin, a human protein that provides essential amino acids, making the milk nutritious for premature infants. And, another company, Somatogen, recently has created transgenic pigs that produce human hemoglobin.

Scientists are conducting more research to modify milk content by giving the animals added genes encoding various therapeutic proteins. Female mammals regularly produce large quantities of protein in their milk, and research is underway to designate the type and amount of certain protein production. After the milk is collected, the desired proteins are isolated and purified. Human milk proteins including human lactoferrin (a source of iron for infants), human protein C (needed for proper blood coagulation), collagen (for tissue repair) and fibrinogen (a tissue adhesive) soon will be produced in the milk of transgenic animals. These proteins may subsequently may be added to milk-based infant diets and other products.

Product Improvement. Research is ongoing to define the optimum and maximum potentials for use of recombinant derived growth factors (or promoters) under current livestock production systems in the United States. New techniques are being evaluated which would promote more efficient muscle growth and aid in the identification of animals with superior genetic potential for reduced fat and muscle protein synthesis. Other evaluation criteria include growth performance, carcass traits, and quality and sensory evaluation of meat.

Some key research underway includes:

University of Adelaide (Australia) scientists have developed a novel breed of genetically engineered pigs that are 30% more efficient and brought to market seven weeks earlier than normal pigs. The Australian Commonwealth Scientific and Industrial Organization also has produced genetically engineered sheep that grow 30% faster than normal and are currently transplanting genes into sheep to increase wool growth.

University of Wisconsin scientists genetically altered brooding turkey hens to increase their productivity to lay one-quarter to one-third fewer eggs than nonbrooding hens. Brooding hens make up nearly 20% of an average flock, so researchers wanted to curtail the "brooding instinct" that tends to disrupt production and increase costs. By blocking the gene that produces the prolactin hormone, biologists were able to limit the natural brooding instinct, resulting in increased egg production.

USDA/ARS researchers are attempting to use genetic technology to produce a domestic dairy sheep strain productive under US southern region and third world conditions. A major limiting factor to dairy sheep production is availability of dairy genetics. Another limiting factor for the US southern region is inadequate use of tropically-adapted sheep breeds that tolerate heat and humidity, and possess high feed conversion efficiency and parasite resistance. In Europe, a dairy sheep breed – the East Friesian dairy sheep – has unsurpassed production traits and has been successfully used in cross breeding programs in the Middle East and Europe. Scientists are attempting to import East Friesian embryos while at the same time performing lactation and metabolism studies on two tropically-adapted breeds: the St. Croix and the Gulf Coast Native. The ultimate goal of the research is to develop new synthetic strains of sheep that possess both the excellent production traits of the East Friesian and the hardiness and adaptable qualities of the St.

Croix or Gulf Coast Native.

Microbes and Enzymes

Biotech enzymes now are used primarily for cheese production and animal feeds. Considerable work is under way to develop new enzymes with a much broader range of applications in the food and related industries. Applications under development include:

Enzymes used for the liquefaction and saccharification of starch into glucose and isomerization into fructose, thus allowing corn and other grains to be converted into sweeteners such as high-fructose corn syrup and maltose syrup through the application of enzymes. Most of the major players in the industrial enzyme industry (Genencor International, Novo Nordisk, and Gist-Brocades International B.V.) are working on such products.

Similar technology can be used to produce ethanol by use of enzymes rather than conventional means. Genencor and Novo Nordisk are developing products aimed at this market.

The brewing process could be accelerated and/or made more efficient through use of biotech enzymes. Genencor and Gist-Brocades are developing enzymes that will improve brewing efficiency and reduce filtration needs. Novo Nordisk, meanwhile, is developing a wide range of enzymes for brewing that could allow for reduced use of malt, boost fermentability, ease filtration, reduce calories, and speed maturation.

Baking applications for enzymes include flour supplementation, increased crust color, preserving chilled and frozen dough, longer shelf life (prevents staling), dough improvement, and gluten strengthening. Several firms are developing a wide range of enzymes for this market.

Novo Nordisk is developing several enzymes for the wine and fruit juice industries, including products aimed at removing starch from juice, enhancing aroma, and enzymatic peeling of fruit.

Gist-Brocades and Novo Nordisk are developing enzymes for the edible oil industry, including enzymes that will degum oil or produce lyso-lecithin.

The Plant That Creates the Enzyme ...

The University of Wisconsin and the USDA-ARS Dairy Forage Research Center have genetically engineered alfalfa to produce the industrially valuable enzyme phytase. This special alfalfa may eliminate the need for phosphorus supplements in swine and poultry rations, resulting in reduced excretion of the mineral in their manure. The end result could be a reduction in environmental pollution.

Phosphorus is an essential nutrient for animals, critical for bone formation and body growth. But unlike cows and sheep, monogastric animals (hogs and poultry) cannot fully utilize the phosphorus in their feed because of the high phytic acid content, so hog and poultry farmers must add supplements to feed. Some of this passes through the animals' digestive tract unused, along with essentially all of the phytic acid. The resulting phosphorus-rich and odorous manure increasingly is an environmental problem as run-off results in water pollution and promotes the growth of algae in lakes and streams. As rapidly multiplying algae use up oxygen in the water, fish populations dwindle.

Reducing the potential for these types of waste problems would certainly be welcomed by the livestock industry. The poultry industry also should welcome the new alfalfa because of its high protein content and xanthophyll, a pigment that gives egg yolks and poultry skin the yellow color that consumers prefer.

Nutraceuticals and Industrial Products

Nutraceuticals or functional foods are considered by many food industry analysts to be the major product innovation of the next decade. Thus far, much of the product development in this area has focused more on conventional methods than on biotech, such as the use of additives and fortification. The key to biotech development of functional foods is in finding products that can be produced more cost-effectively through biotech than through conventional means. Some of the products in development likely to reach the market in the next five years include:

A tomato with enhanced beta carotene, developed by Zeneca. USDA's Agricultural Research Service is developing (with no apparent private-sector involvement) carrots and cucumbers with added beta carotene.

Potatoes and bananas with vaccines genetically added at the Boyce Thompson Institute for Plant Research. The Institute has developed potatoes with vaccines for hepatitis B and cholera. However, the vaccines do not yet survive the cooking process, which renders them inactive. They also have developed bananas with a genetically built-in malarial vaccine.

- A rice-based food that would allow diabetes sufferers to avoid insulin injections. Monsanto hopes to have this product on the market in three to four years.

- A lycopene-enhanced tomato in development by Zeneca in conjunction with the Royal Holloway Hospital. This tomato, which has attracted interest from major food companies, could be used to create lycopene-rich ketchup, pasta sauce, and other foods. (Lycopene is an antioxidant carotenoid which may reduce the risk of cancer.)

- Milk-derived products that prevent travelers' diarrhea. ImmuCell Corporation is developing these products using bovine anti-E. coli immunoglobulins.

The industry still is very much in the formative stages, with small companies forming alliances with larger partners while continuing basic research. The next five years may see only a trickle of GMO functional foods, but the long-term impacts on the food industry of such new products are enormous. Foods could be tailored to achieve specific medical benefits, targeted for people with certain medical conditions, and designed to prevent food-borne illness. In tropical areas where widespread diseases still are prevalent, foods genetically modified to contain vaccines could control preventable diseases that have plagued humans for centuries.

Human clinical trials already have demonstrated the effectiveness of transgenic plant-derived pharmaceuticals. In the past decade, intensive research has been focused on expanding the use of plants as pharmaceutical production systems through genetic engineering. It now is clear that plants can be manipulated to produce a wide variety of such compounds, from vaccine antigens and monoclonal antibodies to pharmaceutically valuable secondary metabolites.

A Potato A Day Keeps The Doctor Away...An Edible Vaccine In Transgenic Potatoes

Research in the Plants and Human Health group at the Boyce Thompson Institute for Plant Research at Cornell University, led by Drs. Charles Arntzen and Hugh Mason, is focused on developing both production and delivery systems for protein vaccines. They have reported that transgenic plants can express a variety of antigenic proteins, such as hepatitis B virus antigen, Norwalk virus capsid protein, and the B subunit of the E. coli enterotoxin. In 1995, this group showed that not only could transgenic potato plants express the E. coli protein, but also that potatoes expressing this protein could induce a specific immune response when fed to mice as part of their normal diet. These results suggested that transgenic plant tissues expressing vaccine antigens could be used for immunization against a myriad of diseases, and raised hopes that this technology might solve many of the problems associated with delivery of safe, effective vaccines to people in developing countries. Production of recombinant vaccines could be as low-cost as agriculture, distribution as convenient as marketing fresh produce, and administration as simple and as safe as feeding a baby a banana! The report describing the results of the first human clinical trial of a plant-derived vaccine provides further important evidence that transgenic plants likely will be used as "edible vaccines."

Four Out Of Five Dentists Surveyed Recommended Tobacco...A Plant-Derived Antibody Reduces Tooth Decay

In 1995, researchers at Guy's Hospital in London, UK demonstrated that transgenic tobacco plants could express and assemble recombinant secretory antibodies to fight against bacterial colonization in the mouth and subsequent development of tooth decay. The scientists expressed each of the proteins in separate tobacco lines, and created a separate line which expressed all of the lines by sexually crossing them.

For the human trials, the mouths of adult volunteers were sterilized with a bacteriocidal mouthwash, and the tobacco-derived antibody solution applied to the teeth. Overall, the results of this trial were spectacular. The plant-derived antibody survived for longer periods of time than the synthetic antibody (three days compared with one day) in the human mouth.

In the human trials, no major side effects were observed. These reports suggest significant advances in plant biotechnology, and have shown that transgenic plants may indeed be cost-effective, efficient and effective production system for protein pharmaceuticals.

A Potato To Prevent Diabetes

A recent report describes development of a potato-based insulin vaccine that is almost 100 times more powerful than the existing vaccine in preventing insulin-dependent diabetes mellitus (IDDM). IDDM, which affects nearly a million Americans, is the leading cause of non-congenital blindness and accounts for 25% of cardiac surgery and 40% of kidney failures. It is an autoimmune disease in which the insulin-producing cells of the pancreas are destroyed by the cytotoxic T lymphocytes.

Insulin and pancreatic glutamic acid decarboxylase (GAD), a protein linked to the onset of IDDM, are candidates for use as oral vaccines. Plants such as potatoes can be engineered to supply the needed antigenic proteins easily and inexpensively. Recently, Canadian scientists engineered potatoes to produce GAD, and by feeding the transgenic potatoes to diabetes-prone mice, were able to reduce both the incidence of diabetes and severity of the immune response.

A team from the University of California attached an insulin protein directly to their site of action cells using a non-toxic subunit of cholera toxin. Researchers knew that the cholera toxin gene had an affinity for the cell surface receptor on the site of action cells. The team linked the cholera toxin gene with that of human proinsulin and then transformed potato plants to express the appropriate protein. When transformed potato tubers with microgram quantities of the protein were fed to diabetic mice, they showed reduced pancreatic inflammation and delayed progression of the disease. Thus, the conjugated cholera subunit-proinsulin protein was effectively delivered directly to the intestinal immune system tissues. The research represents another advancement in edible vaccine technology development by using a precisely targeted drug-delivery system.

As agricultural biotechnology develops, it increasingly will find applications in non-agricultural industries. Plants are efficient producers of proteins, and since biotechnology gives scientists the tools to introduce code for proteins into plant DNA, plants eventually will be transformed into a delivery mechanism for a broad variety of commercially attractive proteins. The first of the value enhanced products already offers a glimpse of what the future could bring. Monsanto already has demonstrated that specialty oils from its canola work could have application as industrial lubricants and as ingredients in soaps and other personal care products. The key to the concept of plants as factories is economics. The plant-derived product must be less costly to produce than with traditional (chemical or other) means.

Agriculture's traditional role in providing food, feed and fiber is being expanded by biotechnology into entirely new forms of production. Some farms of the future very likely will be living factories churning out industrial chemicals from genetically engineered plants. Research projects in Sweden, Australia and England, for example, have developed plants producing unusual oils used in the production of polymers, plasticizers, lubricants, and other industrial products, thus potentially providing a renewable alternative to petrochemical oil.

Acetylenic and epoxy fatty acids are critical raw materials used in production of polymers such as plastics and certain chemicals. These fatty acids, which are modified forms of those present in edible oils, are currently derived from either non-renewable petroleum or chemically processed vegetable oils. A paper in the journal *Science* describes the cloning and expression in transgenic plants of genes involved in the synthesis of acetylenic and epoxy fatty acids. The chemical modifications of oil are done within the plant, obviating the need for expensive industrial processing and also eliminating waste.

The possibilities include components of detergents, nylon, glue, paints, lubricants, and plastics. Researchers believe that specialty oils eventually will be produced in flax (linseed) to minimize the risk of contaminating edible oils through gene flow (it is better to target self-pollinating oil crops such as flax rather than outcrossing ones such as canola or sunflower). But it may be beyond our five year horizon before crop "mini-factories" are producing high value industrial compounds.

The Plant That Grew The Golden Leaves...Phytomining For Gold

Plants are being proposed as biological extractors of metals, particularly gold. However, under normal circumstances plants take up only very low levels. For gold, this level does not usually exceed 10 nanograms per gram of dry tissue or 10 parts per billion, which is not an economically viable level. Recently, researchers at Massey University in New Zealand reported a method for inducing the hyperaccumulation of gold into plants. The trick is conversion of the normally insoluble gold to a soluble form using ammonium thiocyanate, a gold-solubilizing chemical commonly used in mining operations.

The plants tested in these studies (chicory, impatiens, and Brassica juncea, the latter chosen for its rapid growth rate and high biomass) accumulated gold under laboratory conditions. These plants were grown in the presence of crushed natural gold ore from different mines or a synthetic gold ore prepared from gold powder. Ammonium thiocyanate was added and after seven days, stems and leaves were harvested, dried, and analyzed for the presence of gold. The yield of gold ranged from 0.07 to 57 micrograms per gram of dry plant weight. Concentrations were comparable to natural mine ore and synthetic powdered ore.

The authors claim that this process could be profitable by comparing the estimated gross value of the gold extracted with the chemical cost of the ammonium thiocyanate. They estimated that the cost of the ammonium thiocyanate would be $3,627 per hectare, assuming that ammonium thiocyanate costs $3 per kilogram and was spread to a depth of 15 centimeters at a rate of 0.64 grams per kilogram. With gold currently selling at $300 per ounce, a gold concentration of 17 micrograms per gram of dry weight would be needed for a plant that produces a biomass of 20 tons per hectare. This theoretical concentration is comparable to the concentrations of 19 and 57 micrograms per gram of dry weight achieved under laboratory conditions.

The demonstration of significant gold uptake by plants of different species illustrates the feasibility of phytomining. The next logical step will be the application of these studies to field tests around mines. Obviously, the phytomining process becomes more economically favorable as the price of gold increases or as the accumulation of gold is enhanced.

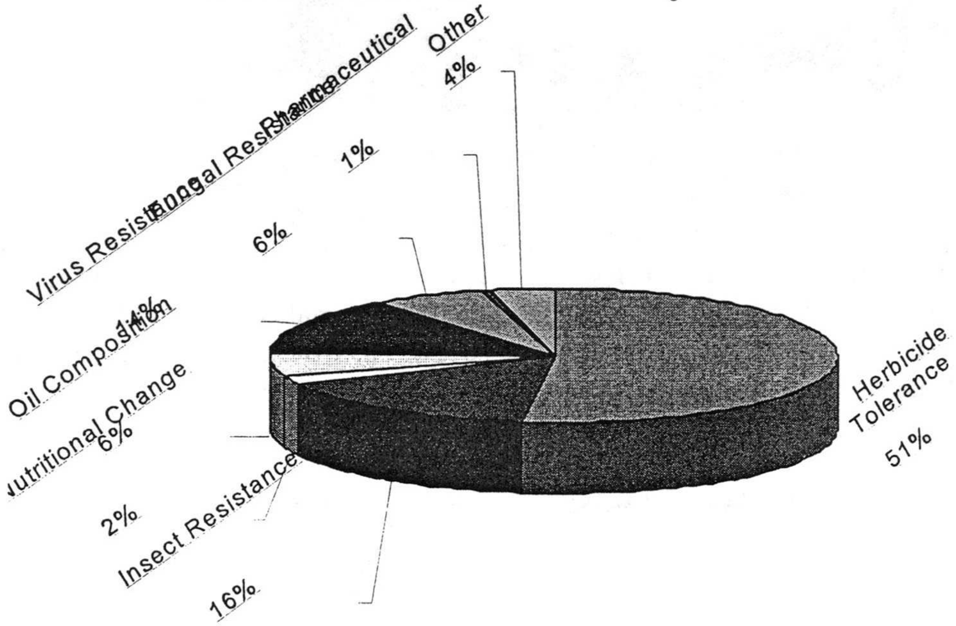
Global Developments in Biotech Research

Most of the research on and production of biotech crops has occurred in North America, with the United States and Canada leading the way, followed by Argentina, China, Australia, Mexico, Japan and South Africa. Commercialization also is beginning in Europe, and, within just a few years, Brazil likely will be a major producer of biotech products as well. The following section examines some of the research and product development that is underway in several of these countries.

Canada

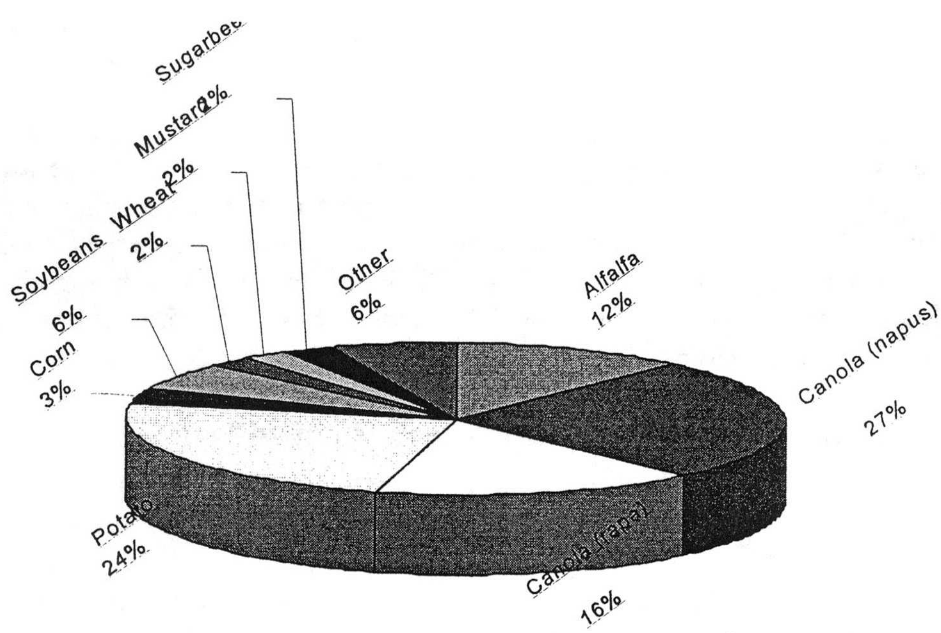
The early focus on crops in Canada has been on input traits, especially herbicide tolerance. Attention now has expanded to output characteristics, with a wide variety of traits being pursued for human, livestock and industrial markets. However, input characteristics such as herbicide tolerance, disease and insect resistance, and stress tolerance still dominate the research agenda. Cost reducing/yield enhancing traits accounted for 87% of the field trials in 1997, with 51% of trials still targeting herbicide tolerance (Chart 6).

Chart 6. Canadian Field Trials by Modified Trait



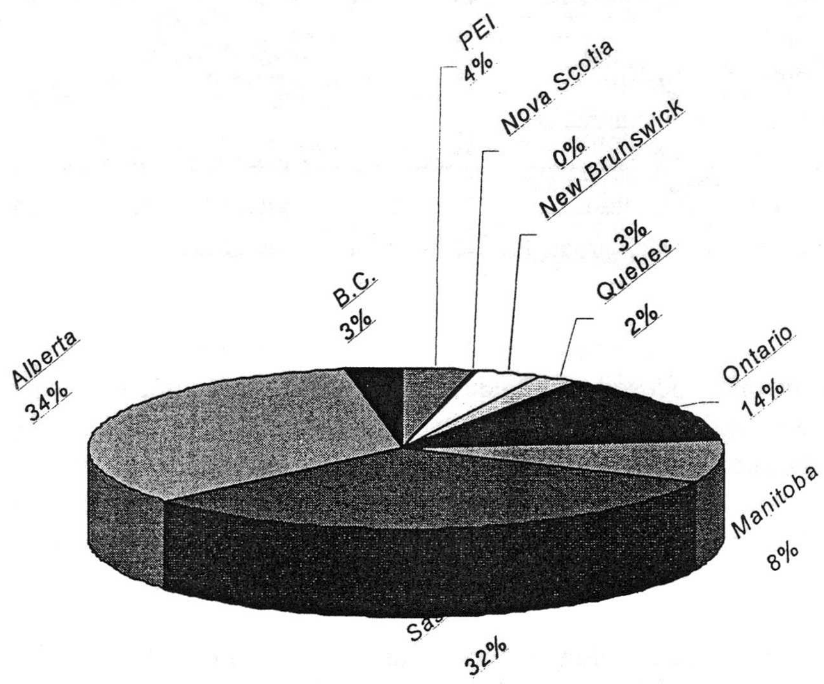
Plant biotechnology research focuses heavily on the Brassica family which includes canola (Argentine and Polish varieties) and mustard. Canola has proven to be one of the most receptive crops to genetic manipulations and has been the primary focus of much research. This year, canola represented 43% of all field trials and transgenic canola varieties accounted for roughly 55% of commercial acreage in 1998 (Chart 7). Potatoes also are receiving considerable attention, with 126 field trials (24%) in 1998. Other crops of interest include alfalfa, corn, soybeans and wheat.

Chart 7. Canadian Field Trials by Crop Type - 1998



Regionally, the Prairie provinces account for the majority of biotech research (Chart 8). Saskatchewan and Alberta each accounted for about one-third of field trials in 1997. Their research focus is canola. Quebec and Ontario accounted for about 16% of 1997 field trials but their focus is corn and soybeans. Research in the Maritime provinces centers on potatoes.

Chart 8. Canadian Field Trials by Province - 1997



Some of the most significant research initiatives underway suggest commercialization of the products described in Table 33:

Table 33. Canadian Product Developments

Crop Type	Product	Description
Oilseeds	SHEAR (Super High Eurucic	Potential for industrial uses such as lubricants,
	Low linolenic acid canola	
	High stearate canola	
	High oleic canola	
	Canola production from Juncea	Canola oil and meal characteristics introduced in
	Hybrid canola	Improved hybridization, creating male sterility and
	Shatter resistant varieties	
	Canola meal enhancements	Reduced levels or blocked production of "anti- Yellow coated seeds to make meal more attractive, Reduced lignin levels.

Table 33. Canadian Product Developments – continued

Crop Type	Product	Description
Wheat	Waxy wheat Herbicide tolerant wheat High amylose wheat High lysine wheat Selection of large starch Modified protein (gluten) Increased starch levels	Modified starch composition (low amylose/high Commercial release expected by 2003 Contains high levels of non-digestible starch for use Replaces synthetic lysine in livestock feeds For food applications and use as a meat Creates plumper kernels desirable in livestock
Barley	Increased disease resistance Reduced protein content	 Intended to boost malt yields as high protein tends
Alfalfa	Reduced lignin Enhanced chlorophyl production	Increases plant's digestibility Results in increased hay yields

The European Union

While discussion in Europe once focused on mandatory segregation of biotech grains, the EU now has settled on labeling grains and food ingredients that contain genetically modified attributes. And, despite some calls for moratoriums and other bans on the planting and even the importation of biotech crops, Europe's options for buying GMO-free grains and oilseeds likely will become increasingly narrow as biotech adoption expands both in the United States, South America and elsewhere.

Even though the acceptance of biotechnology is proceeding at a slower pace than in North America, there also is considerable research underway on development of biotech crops in European nations. Most of the product development appears centered in France, Italy and the United Kingdom, and a considerable number of new products are in the company pipelines (Tables 34, 35, 36, and 37).

Table 34. Summary of Biotech Developments in France

Crop	Modification Category	Trait	Company/Institution
Chicory	Herbicide Tolerance & Male	Male sterility/Herbicide tolerant	Plant Genetic Systems
Lettuce	Altered Nitrogen Metabolism	Reduced nitrates	INRA
Corn	Altered Carbohydrate Metabolism	Modified starches	Biocem
	Altered Pigments	Regulated chain of biosnthesis of	Biocem
	Herbicide Tolerance	Glufosinate tolerant	Van der Have
		Glyphosate tolerant	Société de Production & d'approvisionnement du
	Herbicide Tolerance & Insect	Glufosinate tolerant/Insect	Novartis/INRA
		Glyphosate tolerant/Glufosinate	Association Générale des
		Glyphosate tolerant/Insect	KWS
	Herbicide Tolerance & Male	Male sterility/Glufosinate tolerant	Plant Genetic Systems
	Insect Resistance'	Insect resistance derived from Bt	Mycogen
			Société de Production & d'approvisionnement du
			Asgrow France
			Hilleshög NK
Melon	Virus Resistance	Zucchini Yellow Mosaic Virus	SEG SEMENCES
Oilseed Rape 1/	Altered Oil Composition	High lauric acid content	Centre Technical
	Herbicide Tolerance	Glufosinate tolerant	INRA
		Glyphosate tolerant	INRA
	Herbicide Tolerance & Male	Male sterility/Glufosinate tolerant	Plant Genetic Systems
	Improved Nutritional Quality	Phytic acid conversion	Limagrain Genetics
Potato	Altered Carbohydrate Metabolism	Improved starch quality	Agrevo France
			Germicopa
Soybean	Herbicide Tolerance	Glyphosate tolerant	Monsanto/Asgrow

Table 34. Summary of Biotech Developments in France—continued

Crop	Modification Category	Trait	Company/Institution
Squash	Virus Resistance	Virus resistant	Asgrow/Petosluis
Sugar Beet	Abiotic Stress Tolerance	Drought resistant	Van der Have
	Altered Carbohydrate Metabolism & Herbicide Tolerance & Virus	Glyphosate tolerant/Glufosinate tolerant/Beet Necrotic Yellow Virus	Monsanto
	Herbicide Tolerance	Glyphosate tolerant	Hilleshög NK
			DLF-Trifolium
		Glufosinate tolerant	SES France
			AgrEvo France
	Virus Resistance	Beet Necrotic Yellow Virus	Van der Have
Sunflower	Disease Resistance	Fungus resistant (sclerotinia	Van der Have/SES France
Tobacco	Abiotic Stress Tolerance	Metallothionein production	Seita
	Altered Nitrogen Metabolism	Reduced nitrate production	Seita
	Herbicide Tolerance	Isoxazole tolerant	Rhône-Poulenc
		Bromoxynil tolerant	Seita
	Virus Resistance	LM Virus resistant	Seita

Source: OECD BioTrack Database. The BioTrack database of field trials includes records of field trials of genetically

Table 35. Summary of Biotech Developments in Italy

Crop	Modification Category	Trait	Company/Institution
Chicory	Herbicide Tolerance & Male	Male sterility/Glyphosate tolerant	Bejo Zaden
Corn	Herbicide Tolerance	Glufosinate tolerant	SES Italia
			Hoechst Schering AgrEvo
			Force Limagrain
			Asgrow
	Insect Resistance	Insect resistance derived from Bt	Hilleshög
			Pioneer Hi-Bred Italia SpA.
	Herbicide Tolerance & Insect	Insect resistance derived from	Mycogen
			Monsanto
			DeKalb

Table 35. Summary of Biotech Developments in Italy—continued

Crop	Modification Category	Trait	Company/Institution
Potato	Insect Resistance	Potato tuber worm resistant	Metapontum Agrobios
Soybean	Herbicide Tolerance	Glyphosate tolerant	Monsanto Italiana S.p.a.
Squash	Virus Resistance	Zucchini Yellow Mosaic Virus and	ESAV/Asgrow/Royal Sluis
Sugar Beet	Herbicide Tolerance Virus Resistance	Glyphosate tolerant Rizomania resistant	Monsanto Europe SA KWS Italia
Tomato	Altered Fruit Ripening Virus Resistance	Improved processing characteristics Cucumber Mosaic Virus resistant Tomato Yellow Leaf Curl virus resistant	Stazione Sperimentale per l'Industria delle Conserve Instituto Sperimentale per la S&G Sementi Spa Vilmorin SA

Source: OECD BioTrack Database

Table 36. Summary of Biotech Developments in the United Kingdom

Crop	Modification Category	Trait	Company/Institution
Corn	Herbicide Tolerance	Glufosinate tolerant	
Oilseed Rape	Altered Oil Composition Herbicide Tolerance Herbicide Tolerance & Male Sterility Male Sterility & Male Fertility	High stearate/laurate oil content Altered oil content Glufosinate tolerant Glyphosate tolerant Male sterility/Fertility restorer/ Male Sterility & Male Fertility	
Potato	Altered Carbohydrate Metabolism Virus Resistance	Altered Carbohydrates Potato Leafroll virus resistant Potato Virus X resistant	
Sugar Beet	Herbicide Tolerance	Glyphosate tolerant Glufosinate tolerant	
Tobacco	Altered Pigments	Phytochrome altered	

Source: OECD BioTrack Database

Table 37. Summary of Biotech Developments in Other EU Countries

Country	Crop	Modification Category	Trait	Company/Institution
Austria	Corn Potato	Herbicide Tolerance Altered Carbohydrate	Glyphosate tolerance Inhibition of amylose	T.B. Agrartechnik Zuckerforschung Tulln Ges.
Denmark	Potato Sugar Beet	Virus Resistance Herbicide Tolerance	Potato Virus Y resistant Glyphosate tolerance	Landbrugets Kartoffelfond Danish Danisco
Finland	Barley Pine/Spruce/Birch Potato Spring rapeseed Sugar Beet	Marker Genes Marker Genes Virus Resistance Altered Oil Composition Herbicide Tolerance	Marker gene identification Marker gene identification Potato Leafroll virus resistance Increased stearic acid content Glyphosate tolerance	Boreal Plant Breeding Finnish Forest Research Inst. Kemira Agro Ltd. Hilleshog AB
Germany	Rapeseed Potato Sugar Beet	Herbicide Tolerance Disease Resistance Herbicide Tolerance	Glyphosate tolerance Glufosinate tolerance Fungal pathogen resistance Glyphosate tolerance	Monsanto Biologische Bundesanstalt/ Deutsche Saatveredelung Hoechst Schering/AgrEvo MPI für Züchtungsforschung Monsanto
Holland	Human somatic cells Potato	Animal Altered Carbohydrate Metabolism Improved Storage	Interleukine 2 T cell growth Increased amylopectin content/ Kanamycin resistance Reduced bruising	Academisch Ziekenhuis Groningen Stichting Proefstation voorde Akkerbouw en de Groenteteelt in de AVEBE CEBECO ZADEN B.V.

Key observations of European developments include:

Biotech developments in Europe have been very broad-based, covering a wide variety of crops and products. Most countries have been involved to some degree.

Much of the development thus far has been centered on feed crops and oilseeds, rather than food crops (not too dissimilar from the development in North America), but there is a growing focus on food and value-enhanced crops. From a crop-by-crop standpoint, European biotech development has been focused primarily on corn and rapeseed (rather than soybeans as in the United States), as well as higher-value crops such as potatoes, sugar beets, and tobacco.

While the private sector is playing a major role in agricultural biotech development in Europe, organizations such as trade associations, academic institutes, and co-operatives also are playing significant roles.

The breadth and depth of biotech development in Europe – and the investment and economic benefits that accompany it – should most likely lead to greater regulatory and consumer acceptance in the future.

South America

Considerable biotechnology research also is underway in South America. Since soybeans are an early biotech crop and some countries there are major producers, it seemed logical that they would move to early adoption. Brazil, the second largest exporter, likely will begin planting Roundup Ready soybeans in 1999 and already has approved its crushing industry's importation of US-origin Roundup Ready soybeans. Argentina, typically the third largest exporter, planted 3.5 million acres (28% of total crop) to Roundup Ready soybeans, and likely increased that number substantially this year. Once Brazil joins the United States and Argentina as a Roundup Ready producer, some 90% of world soybean exports will be genetically modified. Significant research also is focused on introduction of other biotech crops in Brazil, particularly corn varieties (Table 38).

Key observations include:

Biotech development in Brazil has been focused thus far on commercial crops of considerable economic importance, such as corn, soybeans, and tobacco.

The regulatory approval process in Brazil is about where it was in North America in the early 1990s. In Brazil, the planting of most GMO crops is limited only to small, experimental plots grown under government monitoring. However, approval for widespread production of Roundup Ready soybeans is expected by the end of the year, in time for the crop that will be planted in 1999, and this will most likely open the doors to broader approval for other crops, whether developed in Brazil or elsewhere.

Table 38. Summary of Biotech Developments in Brazil

Crop	Modification Category	Trait	Company/Institution
Corn	Herbicide Tolerance	Ammonium glyphosate tolerant	Novartis Seeds
	Insect Resistance	Insect resistance	Monsanto do Brasil
			Novartis Seeds Ltda.
			Pioneer Sementes Ltda.
	Insect Resistance and	Insect resistance, ammonium	Novartis Seeds
Cotton	Insect Resistance	Insect resistance	Monsanto do Brasil
Soybean	Herbicide Tolerance	Glyphosate tolerant	Centro Nacional de Pesquisa de Soja
			Monsanto do Brasil
		Ammonium glufosinate resistance	Hoechst Schering AgroEvo do Brasil
Sugar Cane	Herbicide Tolerance	Ammonium glufosinate resistance	Cooperativa dos Productores de
Tobacco	Virus Resistance	Tomato Spotted Wilt Virus	Profigen do Brasil Ltda

Source: OECD BioTrack Database

Japan

In Japan, more than 40 transgenic plants have been developed to date. A tomato variety resistant to tobacco mosaic virus has been commercially available since 1992. Two rice varieties resistant to rice stripe virus and a petunia variety resistant to cucumber mosaic virus also have been planted since 1994. Other virus resistant melon, tobacco and potato varieties as well as a low protein rice variety and a low allergen rice variety, two late ripening tomato varieties, a long-life carnation variety, three herbicide tolerant canola varieties, and other herbicide- tolerant soybean and corn varieties have been tested in confined fields for assessments of their effects on the environment.[14] Several other corn, cotton and canola varieties are being tested in Japan and awaiting commercialization (Table 39).

Noting the importance of biotechnology to Japan's food and agricultural system, the Ministry of Agriculture, Forestry and Fisheries (MAFF) plans to increase its support for biotech research, targeting the development of rice and vegetables (initially cucumbers and eggplants) resistant to pests and other diseases. The enhanced support program, the "Super Resistance Plan", is aimed at preventing foreign domination of seeds used in Japan and increasing the number of patent filings related to Japanese genetic research.

[14] Japan's Ministry of Agriculture, Forestry and Fisheries, "Current Status Of R&D In Biotechnology And Its Practical Application In Agriculture, Forestry, Fisheries And The Food Industry In Japan," December 1997 http://www.s.affrc.go.jp/docs/sentan/eintro/r&d.htm.

Table 39. Summary of Biotech Developments in Japan

Crop	Modification Category	Trait	Company/Institution
Carnation	Altered Flower Color	Violet Colored carnation	Suntory
Corn	Herbicide Tolerance	Glufosinate tolerant	DeKalb
		Glyphosate tolerant	Monsanto
		Bromoxynil tolerant	Rhone-Poulenc
	Insect Resistance	European corn borer resistant	DeKalb
			Monsanto
			Northrup King
			Pioneer Hi-Bred International
	Herbicide Tolerance and	European corn borer resistant/Glyphosate	Monsanto
		Insect resistant, Glufosinate tolerant	Plant Genetic Systems

Source: OECD BioTrack Database

Key observations include:

Thus far, agricultural biotech development in Japan has focused on many of the same crops as elsewhere in the developed world (corn and potatoes). Research also is underway on several traditional Japanese crops, such as rice and vegetables. Japanese-based biotech development in this group of crops is likely to gain prominence in the not-too-distant future.

With the Japanese government having given a high priority to agricultural biotech research, it may take a more active role in biotech research than have governments in other industrialized countries.

Elsewhere

Development of agricultural biotechnology is taking place in several other parts of the world, including Australia and China. In Australia, agricultural biotech companies include Southern Cross Biotech Pty, which has developed Reporcin, a pig growth hormone, and Biotech Australia, who is active in all facets of the industry, including animal vaccines. In China, the government has reportedly conducted some field trials of biotech crops, but details are not widely available. The Consultative Group on International Agricultural Research (CGIAR) has noted the potential of biotechnology to boost agricultural production in developing countries, and may devote a portion of its resources to research in major developing-country crops such as rice and cassava.

As international trade in the ever-growing number of biotech crops expands, the plethora of regulatory approvals (normally required for each new crop in each new country) will create an increasing drag both on world agricultural trade and biotech research, possibly leading to calls for some kind of multilateral approval process. Monsanto, as an example, is seeking the following approvals for the worldwide commercialization of its biotech products (Table 40).

It is clear that the proliferation of biotech crops around the world is and will continue to be rapid.

However, there are many hurdles that companies must cross to get product approvals – and the approval process, its requirements and timeframe are different in every country. This fragmented approach makes it obvious why an international approval process through the World Trade Organization (WTO) or some other international entity is being pushed by some.

Table 40. Monsanto's Worldwide Regulatory Approval for Crops

Argentina	1996	Roundup Ready soybeans	**Japan**	1996	New Leaf insect-protected potatoes
	1999	Yieldgard insect protected corn			Roundup Ready oilseed rape
	2000	Bollgard insect-protected corn			Roundup Ready soybeans
		Roundup Ready corn		1997	Bollgard insect-protected corn
	2001	Roundup Ready cotton			NewLeaf insect-protected potatoes (new varieties)
Australia	1996	Ingard insect-protected cotton			Roundup Ready cotton
		Roundup Ready soybeans			Yieldgard insect protected corn
	1998	Roundup Ready cotton		1998	Roundup Ready corn
Brazil	1999	Roundup Ready soybeans	**Mexico**	1996	New Leaf insect-protected potatoes
	2000	Bollgard insect-protected cotton		1997	Bollgard insect-protected corn
		Roundup Ready corn			Roundup Ready cotton
		Yieldgard insect protected corn		1998	Yieldgard insect protected corn
	2001	Roundup Ready cotton		1999	New Leaf Plus insect- and virus-protected potatoes
Canada	1995	Roundup Ready canola			NewLeaf Y insect- and virus-protected potatoes
	1996	Bollgard insect-protected cotton			Roundup Ready corn
		New Leaf insect-protected potatoes	**S. Africa**	1998	Bollgard insect-protected cotton
		Roundup Ready soybeans		1999+	Roundup Ready cotton
	1997	New Leaf Plus insect- and virus-protected potatoes			YieldGard insect-protected corn
		NewLeaf Y insect- and virus-protected potatoes	**Thailand**	1999+	Bollgard insect-protected cotton
		Roundup Ready cotton			Roundup Ready cotton
		YieldGard insect-protected corn			YieldGard insect-protected corn
China	1998	Bollgard insect-protected cotton	**United States**	1994	NewLeaf insect-protected potatoes
	1999 +	Yieldgard insect-protected corn		1995	Bollgard insect-protected cotton
EU	1996	Roundup Ready soybeans			Improved ripening tomatoes
	1997	NewLeaf insect-protected potatoes			Roundup Ready soybeans
	1998	Maisgard insect-protected corn		1996	Roundup Ready canola
	1999 +	Roundup Ready corn			Roundup Ready cotton
		Roundup Ready oilseed rape		1998	New Leaf Plus insect- and virus-protected potatoes
		Roundup Ready sugar beets			NewLeaf Y insect- and virus-protected potatoes
India	1999 +	Bollgard insect-protected cotton			Roundup Ready corn
		Yieldgard insect-protected corn	**Vietnam**	1999+	Bollgard insect-protected cotton

Indonesia	1999 +	Bollgard insect-protected cotton Yieldgard insect-protected corn Roundup Ready cotton	**Zimbabwe**	 1998 1999+	Roundup Ready cotton Bollgard insect-protected cotton Roundup Ready cotton

Source: Monsanto company reports, Investor reports

V. The Biotech Revolution: What Is At Stake?

The biotech revolution has generated such great interest so early because the implications are so profound and so far-reaching. And, the previous chapters have clearly indicated the wide range of products that realistically can be expected in the not-too-distant future. The remaining chapters of this report now attempt to identify and elaborate some of the more important of those implications in a systematic fashion. Since the most immediate and most direct of the implications center on the food system, this section develops a framework from which to begin an examination of what is at stake. This section is not intended to present exhaustive categories, but rather to provide a framework that may help stimulate and organize identification and evaluation of critical implications.

The Food and Agriculture System

The food and agriculture system of any country typically is divided into several components, with the relative size and importance of each dependent upon the country=s stage of economic development.

A review of the US food system (1997) shows it contributing almost $1.1 trillion to the total GDP. It represents a large portion of the total economy, 13.3% of total GDP and employment for nearly 18% of the entire labor force. It also reveals that the farm inputs component accounts for one-third, farming about 6%, and the processing, distribution and retail components the remaining 61%.

Inputs	**Farm**	**Processing/Distribution/Retail**			
		Processing	*Transport*	*Wholesale/Retail*	*Food Service*
$357.8b 33.2%	$60.6b 5.6%	$181.5 16.8%	$36.2b 3.4%	$302.5b 28.1%	$139.4b 12.9%

Viewed in this manner, it is apparent that 94% of the activity in the food system involves selling products to the farm sector and taking that sector=s raw materials and turning them into consumer food products. The greatest proportion of the value added, by far, is thus seen as being outside the farm sector.

Developing country food systems may be quite different. The relative size of the components changes as the economy becomes progressively more developed. Typically, as development and modernization occur, the industrial inputs component expands (greater use of mechanization, fertilizers, improved seeds, etc.), along with the processing and distribution component. As new farming technology is introduced and each farmer can produce more, employment declines in the farming sector, releasing labor into the economy for employment in other sectors.

Relative Importance Shifts As Economic Development Proceeds

Inputs	Farming	Processing/Distribution/ Retail

The initial impacts of the biotech revolution will vary greatly around the world, depending upon the stage of development of a food system. This in turn means that the stakes will be different and at different points in the system according to the stage of development.

The Potential Stakes

ADirt@ _Y *ADinner@*

Inputs	Farm	Processing/Distribution/Retail

AFarmgate@ _Y *ADinner Plate@*

Farmers have readily adopted the new biotechnology products because of attainable cost economies, i.e., the net returns from their use are positive. How much more potential is there? Anecdotal evidence would indicate that it is enormous. The cost to farmers of challenging the forces of nature are staggering B the costs of insects, diseases, and weather abnormalities, plus revenue loss from lost product when the efforts to control the natural forces are unsuccessful.

Consider for illustration the following costs:

Nematode infestations are estimated to cost agriculture throughout the world over **$100 billion** annually, a potentially huge saving if biotech methods can prevent such damage.

European corn borer damage costs US farmers some **$1-2 billion** annually.

The corn rootworm causes losses to US farmers of some **$1 billion** annually.

All cotton insect pests cost US farmers an estimated **$720 million** annually. The bollworm and budworm, which can be effectively controlled with Bt cotton varieties, are variously estimated to reduce the value of the cotton crop by $280 million annually.

Livestock B annual losses from diseases, parasites, and insects cause literally untold economic losses around the world each year.

Crop damage from early frosts, and vulnerability to other diseases and insects cause enormous losses of plant and animal foods, losses which have the potential to be greatly reduced and eliminated eventually with promising new technology.

While it is not possible to develop precise estimates of all the savings that might be achieved from all the preventable crop and livestock losses worldwide, it is obvious that the order of magnitude is huge B that might be achieved from hundreds of billion dollars annually in reduced losses (with undoubtedly corresponding quality improvements) B thus both reducing farmers= production costs while greatly increasing the amount of food and fiber available for consumption.

The widespread adoption of biotechnology in a country obviously will affect the relative sales volume of some production inputs. One might quickly surmise that farmers' expenditures for the new technology seeds would expand considerably, while those for pesticides likely would fall over time. Fertilizer sales in the aggregate might be more or less, depending upon the particular crop properties developed (e.g., improved nutrient uptake). Water costs also likely would shift in relative importance as plants are made to be more efficient users of moisture, more drought tolerant, etc.

It is difficult to know on balance how the aggregate size of the inputs component of the food system will be changed because of several offsets (e.g., greater seed sales and lower insecticide sales). But, consider the following:

The size of the farm production component would seem to expand B first, more product results from the adoption of new, loss-preventing technologies. And, second, the emergence of value enhanced products could be expected to add significantly to revenues, over and above what they were for commodities. For example, the 10 billion bushel corn commodity crop at $2.50 per bushel produces a total value of $25 billion. If the average value of the crop is boosted only 10% by value enhanced corn products, some $2.5 billion is added to revenues B if the value boost is 25%, then revenues expand by $6.25 billion.

Today, the gross sales value of all US crop and livestock products at the farmgate is $209 billion. Value enhancement B across all crops and livestock B if only 10% adds $21 billion in sales revenues!

Simple arithmetic makes abundantly clear that the stakes in the biotech revolution are high B billions and billions of cost savings and new sales, and just in the **input** and **farm** components of the food chain.

Inputs			Farm Production	
Fertilizer	Seed	Pesticide		

The portion of the food system from the farmgate to the final consumer comprises just over three-fifths of the total. The final food product is constantly changing in attributes and in value. Over time, more and more service attributes have been added to the basic raw material content, to enhance the value. Consider how the *raw material proportion* of the consumers' food dollar has changed over time:

1950	41 cents
1960	33 cents
Today	20 cents

This vividly illustrates how the addition of services to the product changed relative value proportions of the components.

And, today, nearly 44% of all food expenditures (exclusive of alcoholic beverages) are for food consumption outside the home or prepared outside the home B clearly revealing the demand for the added value service component.

	Food Expenditures At Home	Food Expenditures Away From Home
	billion $	
1950	39.0	12.5
1980	185.8	120.3
Today	380.2	297.9

Biotechnology promises to further enhance the consumer value of food products by again changing and expanding the attributes B and beyond just **adding a service** (convenience) component. The value added may be health-related, or medicinal, or include some other Afunction.@ And, this value enhancement may come about because the raw materials B the genetically engineered components B are made more valuable.

It is much too early to reliably estimate addition to the value of consumer foods from nutraceuticals-functional foods. But, it also is obvious that the stakes are enormous here B a mere 10% increase in value to the present consumer food expenditure base of $678 billion expands the system a whopping $68 billion.

More At Stake

Processing/Distribution/Retail	Consumption

Moreover, this may well prove to be the minor part of the value enhancement to the global food system. The cost to global society today of the numerous diseases and insects that plague the population simply cannot be reliably estimated. But, the addition of a malarial or cholera preventative or treatment to a widely consumed food (such as rice or bananas) in those parts of the world where the diseases are most prevalent would yield incalculable benefits. The reductions in human misery and suffering would be tremendous, as would the added productivity from healthy individuals able to function fully in daily productive economic pursuits.

Summary

What=s at stake? A few simple calculations make clear that the potential benefits from the biotech revolution are enormous B the stakes are very great indeed. The stakes involve billions of dollars, all across the food system B national food systems and the global trade in food, as well. And, the stakes for the global population in terms of the potential promise of nutraceuticals are enormous, not even considering biotechnology=s potential to help curb hunger and malnutrition which continue to afflict a significant proportion of the world=s people.

VI. The Biotech Revolution: Implications for the Food System Components

Many of the implications of the biotech revolution will prove to be obvious. Yet, many will not, nor will tracing through the full extent of their impacts. Also, both their number and their potential magnitude makes them difficult to evaluate without some systematic approach. In this section, we begin this explanation and evaluation of the more important implications by using the food system as the framework – identifying and tracing the implications component by component – starting first with the inputs sector, then moving to the farm sector and on across to the final consumer. In the following chapter, we then examine the "overarching" implications, those that span the entire system.

Inputs Sector

The beginning of the biotech revolution thus far has been centered on the inputs sector. It was launched by agriculture genetic and pesticide companies, for the most part, focusing on the economically more important field crops. Crops with built-in insect resistance can reduce or eliminate the need for insecticide applications, while crops with herbicide tolerance shifted herbicide sales toward specific products. And, biotechnology already has been a major force in consolidation of the seed industry. This section further explores the implications of the revolution for this component of the food system.

Agricultural Chemicals

The biotech revolution already has caused significant shifts in herbicides used on particular crops. Over 30 million acres were planted this year to crops with Roundup herbicide tolerance. Most (25 million acres) was accounted for by Roundup Ready soybeans, with Roundup Ready cotton also a sizable portion.

Monsanto acknowledges that Roundup sales volume currently is increasing at a 20% annual rate, and usage on particular crops has been rising even faster. In 1996, when Roundup Ready soybeans first were planted on one million acres, the use of glyphosate (the active ingredient in Roundup herbicide) increased by 13.1% per acre, compared to 9.3% per acre for all herbicides nationally (Tables 41 and 42). As Roundup Ready soybean acreage expanded to nine million acres in 1997, use per treated acre rose 17.4%, while overall herbicide use per treated acre actually declined 0.7%.[15]

[15] Calculations were made based on data in *Agricultural Chemical Usage, Field Crops Summary* from the USDA National Agricultural Statistical Service. Calculating herbicide usage on a per-treated-acre basis was necessary for a valid comparison, since the states and the acreage covered by USDA's agricultural chemicals survey change from year to year.

When Roundup Ready cotton was introduced in 1997, 860,000 acres were planted and glyphosate use per treated acre increased 22.7%, compared to only a 5.8% increase nationally for all herbicides (Table 43 and 44).

It is important to note this discussion refers only to growth rates in usage. The absolute amount of glyphosate applied per treated acre (0.81 lbs) actually was less than the national average (1.218 pounds) which may mean that the adoption of Roundup Ready soybeans contributed to an overall reduction in herbicide volume per acre.

Table 41. Soybeans: Pesticide Usage by Major State, Percent of Acres Treated and Total Amount Applied

Year/State	Area Planted	Herbicide		Insecticide 1/	
	1000 acres	%	1000 lbs	%	1000 lbs
1995					
AR	3,450	91	3,564		
GA	320	87	245	34	69
IL	9,750	98	10,181		
IN 2/	5,000	99	6,019		
IA	9,300	100	8,936		
KY	1,170	98	1,377		
LA 2/	1,070	95	1,394	38	241
MN	5,900	99	5,471		
MS 2/	1,850	99	2,587		
MO 2/	4,600	94	4,918		
NE 2/	3,100	96	3,001		
NC	1,150	91	1,228	10	17
OH 2/	4,050	98	5,923		
TN 2/	1,130	100	1,595		
Total	51,840	97	56,439	2	427
1996					
AR 2/	3,550	92	4,491		
IL	9,900	97	10,670		
IN 2/	5,400	97	5,845		
IA 2/	9,500	99	10,821		
LA 2/	1,100	94	1,645	32	161
MN	5,950	98	7,826		
MS 2/	1,800	99	2,287		
MO 2/	4,100	98	5,373		
NE 2/	3,050	99	3,459		
OH 2/	4,500	98	5,692		
TN 2/	1,200	100	1,770		
WI 2/	920	99	750		
Total 2/	50,970	97	60,629	1	273

Table 41. Soybeans: Pesticide Usage by Major State, Percent of Acres Treated and Total Amount Applied—continued

Year/State	Area Planted	Herbicide		Insecticide 1/	
	1000 acres	%	1000 lbs	%	1000 lbs
1997					
AR 2/	3,600	97	5,019		
DE 2/	225	78	314		
IL 2/	10,000	98	11,136		
IN	5,450	99	7,062		
IA	10,500	99	13,691		
KS 2/	2,450	94	2,947		
KY 2/	1,300	91	1,460		
LA 2/	1,400	90	1,843	29	331
MI	1,900	98	2,452		
MN 2/	6,800	96	6,902		
MS 2/	2,100	98	2,453		
MO	4,900	94	5,521		
NE 2/	3,500	99	4,093		
NC	1,400	98	1,625	35	130
OH 2/	4,500	99	5,307		
PA	370	86	661		
SD 2/	3,500	90	3,059		
TN 2/	1,320	100	1,664		
WI	1,000	100	998		
Total 2/	66,215	97	78,207	2	731

1/ Total applied excludes Bt's (Bacillus thuringiensis). Quantities are not available because amounts of active ingredient are not comparable between products.
2/ Insufficient reports to publish data for one or more of the pesticide classes.
Source: USDA-NASS

Table 42. Herbicide and Insecticide Usage on Soybeans

	Area in USDA Survey States	Herbicides		Glyphosate (Roundup)			Insecticides	
	1,000 acres	1,000 lbs	lbs/ac	applications	1,000 lbs	lbs/ac	1,000 lbs	lbs/ac
1995	51,840	56,439	1.122	1	6,318	0.61	427	0.412
1996	50,970	60,629	1.226	1.1	8,687	0.69	273	0.536
1997	66,215	78,207	1.218	1.3	14,915	0.81	731	0.552
% Change								
1995-96			9.3%	10.0%	37.5%	13.1%		30.1%
1996-97			-0.7%	18.2%	71.7%	17.4%		3.1%

While herbicide tolerant varieties have most affected the soybean sector, insect resistant varieties have had the greatest impact on cotton and corn. Through 1997, insect resistant varieties planted were 18.5% of total US cotton acreage, compared to only 6.0% of corn area. It thus is likely easier to discern an effect on insecticide use in cotton than in corn.

Overall insecticide use in cotton varies from year to year depending upon insect infestation levels. This fluctuation was readily apparent in the last two years when insecticide use plunged 31.6% per treated acre of cotton in 1996, but rebounded 12.2% in 1997. However, the effects of insect resistant cotton can be seen by looking beyond the aggregate insecticide level. Malathion is commonly used to control boll weevils, rather than the bollworms and budworms that are targeted by Bt cotton. Excluding malathion, insecticide use fell 46.4% in 1996, significantly exceeding the 31.6% drop across all insecticides, and decreased by another 5.6% in 1997 while overall usage rose.[16]

Biotech crops not only have begun to affect aggregate volume of agricultural chemicals used, but also their prices. To compete with new crop-plus-herbicide or built-in insecticide "systems," makers of agricultural chemicals not included in these systems have had to reduce prices. This has been particularly true in crops where tolerance to nonselective herbicides (e.g., Roundup or Liberty) is available, since the need to use additional herbicides is severely limited or eliminated. For example, Roundup Ready soybeans offered farmers herbicide cost savings of $12 to $19 per acre.[17] (After the $6.50 per acre "technology fee," net savings to farmers are $5.50 to $12.50 per acre.)

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16 Such a comparison for corn is more difficult due to the small acreage of biotech corn planted. Overall insecticide usage per treated acre of corn dropped 13.2% in 1996, but rebounded 7.9% in 1997 (Tables 45 and 46). It is difficult to isolate the effects of Bt corn, since it is targeted mostly at the European corn borer, and insecticides that combat the European corn borer also are used to fight other insect pests.

Monsanto estimates total insecticide usage of 1.5 million pounds annually for European corn borer control in the 16 major corn-producing states in 1997. This compares to 13.6 million pounds of total insecticides used on corn in the 10 states that USDA surveyed. These 10 states represented 86% of the acreage of the top 16 corn-producing states, suggesting that total insecticide usage in the 16 states was 15.7 million pounds. This implies that insecticides used to combat European corn borer represented about 10% of all insecticides used on corn. Since 6% of corn acres were planted to Bt varieties, the apparent reduction in insecticide usage was about 90,000 pounds, assuming no insecticides were used on the acres planted to Bt corn.

The same situation applies regarding effects of herbicide tolerant corn. Imidazolinone tolerant varieties were planted on 4.5 million acres in 1997. However, IMI corn (which is not transgenic) was introduced in the early 1990s and already accounted for 3.4 million acres in 1996. Its subsequent gradual adoption has moderated the impact on herbicide sales in any particular year.

Liberty Link corn was commercialized in 1997 and planted on 700,000 acres. USDA has not included glufosinate-ammonium in its surveyed chemical list, making it impossible to discern the effect of Liberty Link corn on herbicide sales.

17 *The Ag Biotech and Seed Industry,* Furman Selz LLC, March 1998.

Table 43. Upland Cotton: Pesticide Usage by Major State, Percent of Acres Treated and Total Amount Applied

Year/ State	Area Planted	Herbicide		Insecticide 1/		Fungicide		Other Chemical	
	1000 acres	%	1000 lbs	%	1000 lbs	%	1000 lbs	%	1000 lbs
1995									
AZ 2/	365	89	484	97	1,709			92	1,726
AR	1,170	98	4,208	84	1,527	20	201	55	781
CA 2/	1,170	88	1,861	96	2,835			96	6,713
LA	1,085	98	2,400	98	3,176	17	71	70	752
MS	1,460	98	6,234	93	5,691	30	350	91	1,951
TX 2/	6,400	98	7,430	61	5,729			36	1,654
Total	11,650	97	22,618	75	20,668	8	719	56	13,577
1996									
AZ	315	75	357	89	1,029			71	1,703
AR	1,000	99	2,750	93	1,303	28	157	91	1,206
CA 2/	1,000	90	1,856	97	2,031			95	5,180
GA	1,350	100	4,079	73	633			48	1,234
LA	890	81	1,957	97	1,486	17	89	69	546
MS	1,120	99	3,981	95	2,417	7	45	99	2,541
TN	540	100	1,889	89	505	33	97	87	732
TX 2/	5,700	90	5,692	68	5,832			39	2,064
Total	11,915	92	22,561	79	15,236	6	397	60	15,206
1997									
AL	535	100	1,667	85	469	17	22	69	482
AZ 2/	325	87	534	85	705			86	770
AR	950	89	2,882	77	678	10	83	84	1,335
CA 2/	880	93	1,227	92	2,242			98	3,471
GA	1,440	100	4,623	90	895			85	4,397
LA	630	90	2,331	85	1,789	19	85	66	469
MS	985	100	3,124	100	3,972	30	447	97	1,556
MO 2/	380	100	839	71	210			99	573
NC 2/	670	97	1,832	92	339			96	1,093
SC	290	100	875	98	241	18	5	96	467
TN	490	98	1,275	85	417	29	123	79	551
TX	5,500	97	6,401	62	6,327			53	2,398
Total	13,075	97	27,611	77	18,282	7	897	73	17,561

1/ Total applied excludes Bt's (Bacillus thuringiensis). Quantities are not available because amounts of active ingredient are not comparable between products.
2/ Insufficient reports to publish data for one or more of the pesticide classes.
Source: USDA-NASS

Table 44. Herbicide and Insecticide Usage on Cotton

	Area in USDA Survey States	Herbicides		Glyphosate (Roundup)			Insecticides		Insecticides Except Malathion	
	1000 acres	1000 lbs	lbs/ac	Applica-tions	1000 lbs	lbs/ac	1000 lbs	lbs/ac	1000 lbs	lbs/ac
1995	11,650	22,618	2.002	N/A	N/A	N/A	20,668	2.365	18,925	2.166
1996	11,915	22,561	2.058	1.0	991	0.66	15,236	1.619	10,926	1.161
1997	13,075	27,611	2.177	1.3	1,542	0.81	18,282	1.816	11,036	1.096
% Change										
1995-96			2.8%	N/A	N/A	N/A		-31.6%		-46.4%
1996-97			5.8%	30.0%	55.6%	22.7%		12.2%		-5.6%

Table 45. Corn: Pesticide Use by Major State, Percent of Acres Treated and Total Amount Applied

Year/State	Area Planted	Herbicide		Insecticide 1/	
	1000 acres	%	1000 lbs	%	1000 lbs
1995					
DE	145	96	427	43	26
GA	400	89	712	19	88
IL	10,200	98	30,811	28	2,118
IN 2/	5,400	97	16,842	20	759
IA 2/	11,700	99	32,957	28	2,821
KS	2,150	92	4,397	39	645
KY	1,280	94	3,537	15	56
MI	2,450	100	6,791	18	370
MN	6,700	98	15,822	6	400
MO	1,650	94	4,443	30	242
NE 2/	8,000	95	18,804	54	3,104
NC	800	98	1,679	29	286
OH 2/	3,300	98	10,233	17	419
PA	1,380	93	4,169	29	295
SD	2,800	92	4,691	7	153
TX	2,100	91	2,840	58	843
WI	3,650	96	8,487	25	830
Total	64,105	96	167,642	27	13,457

Table 45. Corn: Pesticide Use by Major State, Percent of Acres Treated and Total Amount Applied—continued

Year/State	Area Planted	Herbicide		Insecticide 1/	
	1000 acres	%	1000 lbs	%	1000 lbs
1996					
IL	11,000	99	34,223	27	2,143
IN	5,600	98	18,856	35	1,466
IA	12,700	99	36,109	17	1,779
KS	2,500	94	5,784	40	515
KY	1,300	99	4,159	24	43
MI	2,650	98	7,250	21	318
MN	7,500	97	17,819	13	614
MO	2,750	98	7,547	27	492
NE	8,500	98	19,817	51	3,068
NC	1,000	97	2,565	37	376
OH	2,900	100	10,029	28	591
PA	1,450	98	4,371	54	419
SC	400	98	1,017	26	84
SD	4,000	91	7,091	25	422
TX	2,100	91	2,770	74	712
WI	3,900	93	7,570	37	1,176
Total	70,250	97	186,977	30	14,218
1997					
IL	11,200	98	32,733	44	4,266
IN 2/	6,000	94	18,127	31	1,023
IA	12,200	98	36,144	19	2,323
MI	2,600	98	6,912	11	200
MN	7,000	91	13,956	10	291
MO	2,950	97	8,203	35	475
NE 2/	9,000	98	19,970	62	3,531
OH 2/	3,600	100	12,971	18	711
SD	3,800	93	6,346	10	317
WI	3,800	98	8,689	19	433
Total	62,150	96	164,051	30	13,570

1/ Total applied excludes Bt's (Bacillus thuringiensis). Quantities are not available because amounts of active ingredient are not comparable between products.
2/ Insufficient reports to publish data for one or more of the pesticide classes.

Source: USDA-NASS

Table 46. Herbicide and Insecticide Usage on Corn

	Area in USDA Survey States	Herbicides		Insecticides	
	1000 acres	1000 lbs	lbs/acre	1000 lbs	lbs/acre
1995	64,105	167,642	2.724	13,457	0.777
1996	70,250	186,977	2.744	14,218	0.675
1997	62,150	164,051	2.750	13,570	0.728
% Change					
1995-96			0.7%		-13.2%
1996-97			0.2%		7.9%

Apparently in response to savings that farmers were realizing from soybeans not requiring herbicides other than Roundup, DuPont in September 1997 reduced the price of its Classic herbicide by 40% to 45% and prices of Synchrony and Reliance (used on the competing STS soybean system) by 70% to 75%. Similarly, American Cyanamid this fall dropped prices for Pursuit and Pursuit Plus – among the most widely used soybean herbicides – as well as Squadron and Steel by 33% to 40%. Prices of Raptor and Prowl also were lowered, but less dramatically.

Monsanto also moved to reduce Roundup prices by $10 per gallon this fall, translating to roughly $2.50 to $5.00 per acre of soybeans. However, Monsanto raised the technology fee for Roundup Ready soybean seed by $1.50 per bag, equivalent to about $2 per acre. These moves likely reflect some mix of anticipation of the expiration of the US Roundup patent in 2000 and the price reductions for competing herbicides.

AgrEvo does not charge a seed premium for its Liberty Link corn technology, though farmers typically need to use atrazine and ammonium sulfate in addition to Liberty within that system. In response to pricing pressures in the general herbicide market, AgrEvo earlier reduced the Liberty price $2.50 per acre for the 1998 season, to $4.00 per acre.

While the translation of Bt corn adoption into insecticide cost savings thus far has been difficult to quantify, the link between Bt cotton and insecticide savings is more direct, mainly because of the intensive use of insecticides on cotton. In 1995, the year before commercialization of Bt cotton, farmers lost 2.03 million bales to all insects and spent $880 million on insecticides, according to the National Cotton Council. The bollworms and budworms against which Bt is effective accounted for 785,000 bales of the damage, implying that the $340 million was spent on insecticides to combat the worms.

Monsanto reported that 60% of the growers who planted BollGard cotton in 1996 did not require any insecticide applications, and that most others used only one application, compared to the 4 to 6 applications usually required. This suggests that those farmers saved at least $25 million on insecticide spraying for bollworm and budworm, and potentially as much as $65 million on insecticides to fight all pests.[18] This does not include the 40% of farmers who were able to reduce, but not eliminate, applications of insecticide.

Viewed alternatively, Furman Selz estimates insecticide savings (not including other benefits) from Bt cotton run from $11 to $54 per acre, depending on infestation level. This indicates that for the 1.8 million acres of BollGard planted in 1996, farmers saved between $19.8 million and $97.2 million on insecticides. Thus, considering both ways of estimating impacts, the market for cotton insecticides was reduced by $20 million to $100 million in 1996. BollGard cotton acreage rose 42% in 1997 and may have increased by half again in 1998, implying that the cotton insecticide market has been further reduced, well below what it would have been without the presence of Bt cotton.

Input dealers expect the future trend to be higher seed sales but lower agricultural chemical sales. One-third of the retail agronomic dealerships in a recent survey said they expected seed sales to increase by 30% or more within three years, and another one-third expected increases of 20% to 30%.[19] On the other hand, the dealerships expected "enhanced seed" to continue to have a large negative impact on agricultural chemical sales, with 17% predicting their chemical sales would fall an additional 30% or more in the next three years, while fully one-half of the respondents expect chemical sales to fall at least 20%.

Fertilizer

The biotech revolution thus far has had very little effect on fertilizer usage. Anticipation has been preeminent for years for a potential blockbuster seed product targeted at fertilizer, while promise of nitrogen-fixing corn has become the Holy Grail of plant breeding. While blockbuster products still are not apparent in the near future, some beginning developments likely will affect the fertilizer sector.

Biotech companies may not be able to produce nitrogen-fixing corn quite yet, but they do appear to have focused on crops that require less fertilizer. USDA's APHIS field trials reports indicate that Monsanto is working on corn with "altered nitrogen metabolism." While APHIS permits such ambiguous descriptions to protect confidential business information, interviews with researchers not employed by outside of Monsanto indicate that the company has identified a gene that enhances nitrogen uptake from the soil by as much as 10%. Though the specifics are unknown, this would seem to suggest that less nitrogen would need to be applied to the crop while obtaining higher yields.

Researchers also have been seeking ways to improve phosphate uptake in plants. Purdue University researchers in 1996 were the first to clone phosphate transporter genes, using the

18 Assuming that this 60% of farmers also accounted for 60% of the 1.8 million acres planted to BollGard cotton in 1996 (representing 12.3% of total US cotton acreage).

19 Third Annual Dealership Precision and Enhanced Seed Adoption Survey, conducted in 1998 by Farm Chemicals Magazine and Purdue University's Center for Agricultural Business.

Arabidopsis, a favorite subject for biotech researchers because its small genome permits easier identification and isolation of genes. In the first application to a more complex and economically valuable crop, the researchers in 1998 showed the existence of phosphate transporter genes in the tomato plant. This work is being extended to developing plants that have a heightened expression of the transporter genes, to see if this increases the efficiency of phosphorous uptake.

In research that would lead less directly to lower fertilizer use on crops, USDA's Agricultural Research Service (ARS) has identified a gene that regulates hypernodulation in the soybean root system. Bacteria are involved in the formation of such nodules, and once in place at the nodules, they fix nitrogen from the air, converting it into ammonia. Investigation focuses on whether these hypernodulated plants would leave additional nitrogen in the soil, providing the nitrogen to crops grown in rotation. (Standard soybean plants leave approximately 40 pounds of residual nitrogen per acre.)

Since nitrogen fixation involves interaction between sites on the plant root system and bacteria, researchers also have been looking at modifications to microorganisms to allow crops to be grown with less fertilizer. Research Seeds, Inc., has already commercialized transgenic rhizobia to be used as a seed inoculant for alfalfa, thereby increasing nitrogen fixation and yields. Performance is reported to be best on soils with low nitrogen content and low indigenous rhizobial populations.

Iowa State University researchers are working with another group of bacteria, *Azospirillum*. By "infecting" crops such as corn with *Azospirillum*, the number of root hairs is increased, and the roots themselves are lengthened. In theory, with more root hair surface, less fertilizer would need to be applied to the plant. However, in practice, yields are reported to be inconsistent. Ultimately, researchers hope to be able to use transgenic *Azospirillum* to cause nitrogen fixation in crops other than legumes, but there are technical issues even in the laboratory that would suggest this development to be in the distant future.

Similar to the Research Seeds inoculant, EPA's public reports of field trials of transgenic microorganisms indicate that in 1998 there have been tests of three strains of *Bradyrhizobium japonicum* engineered to enhance "competitiveness" and/or nitrogen fixation in soybean plants. The company name was made kept confidential by the EPA, and no further information was available on the goal of the research (e.g., increasing nitrogen availability for crops grown in rotation).

In addition to modifications to crops and microorganisms for the express purpose of more efficient fertilizer use, a third way in which biotech might affect fertilizer usage is more indirect – the reduction of nutrient content in waste from livestock and poultry. Monogastrics (hogs and poultry) have difficulty absorbing phosphorous from plant-based feeds since it is in the form of phytic acid, which ends up in the animals' excrement. However, ARS has developed corn in which the phytic acid portion of overall phosphorous content is reduced by two-thirds (in plants that still yield well).

Under present practices, manure is applied to fields as fertilizer, with the acreage over which it is spread dependent upon the nutrient concentration in the manure. If the concentration of phosphorous is lowered through the use of low-phytate corn, then fewer acres may be required for a given amount of manure. If low phytic acid corn were to be widely grown, it actually could result in an increased amount of phosphate-based fertilizer being purchased.

ExSeed Genetics, Inc. now is licensing low-phytate corn technology from ARS and it will have two varieties available for 1999 planting. Pioneer Hi-Bred also is attempting to incorporate this technology into its hybrids, but may be another one or two years away from commercialization.

Another way to promote the digestion and absorption of phytic acid by monogastrics is to add an enzyme (phytase) to feed. Phytase recently has been released in the United States by BASF, which also sells it in Europe. Gist-Brocades has a strategic alliance with BASF in animal feed enzymes and also sells phytase. However, a significant drawback to the products now available is that the phytase cannot yet be incorporated into pelleted rations, and is sensitive to temperatures.

Within the five-year time horizon of this study, products with the highest likelihood of being marketed on a significant scale include low-phytate corn and perhaps a more functional form of the phytase enzyme. Both would be mildly positive for fertilizer sales, particularly those containing phosphorous. Over the longer term, however, it is apparent that biotech companies are seeking ways to enable plants to yield well with lower applications of fertilizers. Based on past success in developing crops with desired characteristics, it seems likely that biotech will have some effect on fertilizer needs, though this may stop short of the Holy Grail of nitrogen-fixing corn.

Agricultural Equipment

The biotech revolution also has had little effect to date on the agricultural machinery industry. And, the long-term impact on the machinery market may be modest, as well.

The main issue related to biotechnology thus far affecting equipment use has been the equipment cleaning requirement after planting and harvesting biotech varieties. This is primarily because a few crops have not received approval for importation (for food or feed use, not seed) into particular nations (notably US biotech corn and Canadian canola varieties in the European Union). Farmers planting such varieties must properly clean-out after planting and harvesting to ensure that the crop goes to domestic uses only. Proper clean-out also is necessary to prevent mixing standard and herbicide tolerant seed, which would result in some plants being killed by subsequent herbicide application.

In the future, proper cleaning requirements will increase as a wider range of value enhanced crops are commercialized. Farmers working with more than one product must keep the characteristics of one from "contaminating" another crop. And, proper cleaning also likely will have a food safety element, as well. For example, a crop being grown for industrial oil obviously must not get included in a load of food quality grain.

Agricultural equipment sales also likely will be affected over time by reduced wear from reduced application trips for herbicides and insecticides. As biotech crops are grown on ever larger acreage, this could have a marginal negative impact on machinery sales, particularly tractors. Herbicide tolerant crops also enable no-till and other conservation tillage practices. In 1997, 46% of Roundup Ready soybean acres were planted using no-till, versus 30.5% for all US soybean acres.[20] The reduced cultivation with no-till saves an average of $5 per-acre in machinery wear.

Another result of wider adoption of biotech crops on equipment sales is the ability of farmers to adopt ultra-narrow-row-cotton planting practices. Strippers, available as an alternative to mechanical pickers for several years, cost considerably less than pickers. However, previously gins were inadequately equipped and calibrated to remove foreign matter that the strippers collected, sometimes causing price discounts. Equipment manufacturers and gins have attempted to alleviate the problem, but seed biotechnology is beginning to play a key role. The high level of weed control possible from herbicide tolerant cotton virtually eliminates foreign matter, enabling farmers to use strippers for harvesting.

Overall, while biotechnology will have some effects in specific areas (such as ultra-narrow-row cotton), the total impact on equipment manufacturers is expected to be small.

Biotechnology and the Seed Sector

No sector has been more dramatically affected by the advent of biotechnology than the seed industry. Before commercialization of the first biotech seeds in 1996, the industry was relatively stable and predictable. Pioneer Hi-Bred had just under one-half of the corn seed market and just over one-quarter of the certified soybean seed market in the United States, the only player with double-digit market shares in both crops. DeKalb Genetics and Northrup King each had market shares for corn and soybeans of 5% to 10%. The rest of the industry was severely fragmented among many, often regional, brands.

When biotech crops first entered the market only two years ago, the sector also was split between "gene providers" and seed companies. The gene providers were the large biotech/agrochemical firms such as Monsanto and Ciba-Geigy, which licensed their genetic technologies to seed companies as the means for gaining access to the farmer for their products. Pioneer's large market share made it of great interest to the gene providers, notably Monsanto seeking to get its Roundup Ready gene into a substantial amount of soybean seed and DuPont wanting access to a wide market for its TopCross high-oil corn and STS soybean technologies (both non-transgenic). Delta and Pine Land Company, the largest cotton seed supplier with perhaps three-quarters of the US market, was of interest to Monsanto for licensing its BollGard brand of Bt cotton.

20 Purdue University's Conservation Technology Information Center (CTIC), 1997.

There were some exceptions to the separation between gene providers and seed companies. Ciba-Geigy had Ciba Seeds, and Sandoz owned Northrup King (both now merged as Novartis). And, Monsanto had owned HybriTech Seed since the 1980s, a small wheat research and seed program, and Hartz Seed, which had a significant presence in soybeans.

The commercialization of biotech crops set off a flurry of mergers, acquisitions and alliances with seed companies. The gene providers needed access to seed, not only to incorporate their new developments for sale to farmers, but also to obtain as germplasm for further research and development. Monsanto first entered in early 1996 into a strategic alliance with DeKalb Genetics, including taking an equity investment. Then, in the fall of 1996, Monsanto purchased Asgrow Agronomics from Empresas La Moderna [involving only the row crop seed (mainly soybean) business – ELM retained the fruit and vegetable seed business as part of its Seminis subsidiary]. (Monsanto had entered into a partnership agreement and taken an equity interest in Calgene in 1995, but Calgene had only a limited seed business, which was mostly in cotton via its Stoneville Pedigreed Seed subsidiary).

Dow AgroSciences formed a strategic partnership with Mycogen Corporation and took a controlling interest in 1996. Mycogen had already built itself into the sixth-largest seed company in the United States through acquisitions of Agrigenetics from Lubrizol in 1992 and the Lynks and Keltgen seeds brands from Dow AgroSciences itself earlier in 1996. Mycogen also purchased Morgan Seeds, Argentina's second-largest seed company, in the fall of 1996. Though there were more seed company deals in between, Dow AgroSciences finally acquired the remaining shares of Mycogen in the fall of this year.

In August 1997, DuPont and Pioneer Hi-Bred, two of the largest companies in the agricultural chemical and seed industries, which previously had formed biotech links through licensing agreements, decided to create a formal alliance. DuPont purchased 20% of the equity of Pioneer, and the two formed an equally owned joint venture, Optimum Quality Grains. Optimum began in January 1998 "to develop, produce and market value enhanced ingredients derived from unique grains and oilseeds that meet specific customer needs for food and feed, worldwide." Given Optimum's focus on value enhanced crops, DuPont has kept its STS soybean line separate.

In February 1998, DeKalb Genetics announced that it was considering a sale of the company, setting off a new race to control the "choke point" of seed supplied to the farmer. By May, Monsanto had won the bidding war. DeKalb had already become a key outlet for Monsanto's YieldGard corn and Roundup Ready soybeans, and the only seed company to sell Roundup Ready corn in 1998. The acquisition gives Monsanto access to a substantial share of the corn and soybean seed markets.

At the same time, Monsanto also moved to acquire Delta and Pine Land Company. Delta and Pine Land and its Paymaster Subsidiary, along with the Stoneville subsidiary of Calgene, have been the sole suppliers of BollGard cotton seed, and more recently Roundup Ready cotton seed.

Both the DeKalb and Delta and Pine Land acquisitions are being reviewed by the US Department of Justice.

The scramble for seed companies has continued apace during the remainder of 1998. Cargill sold its seeds division – Cargill Hybrid Seeds operations in North America – to AgrEvo and the operations in the rest of the world to Monsanto. This focus on international acquisitions is fast developing this year, as the seed company-gene provider alliance in the United States has taken shape. The process of gene providers securing access to foreign seed began in 1996, with Mycogen's purchase of the Morgan Seed Company, the second-largest seed supplier in Argentina, and forming a strategic alliance with Verneuil Holding in France. Within the same month, Monsanto formed a technology collaboration with Empresas La Moderna when it purchased Asgrow. In November 1997, Monsanto purchased Agroceres, the leading seed corn company in Brazil with a 30% market share. Then in May 1998, Mycogen acquired Dinamilho, which has a 10% share of Brazil's seed corn market. In June 1998, Monsanto gained seed operations in Central and Latin America, Europe, Asia and Africa when it acquired Cargill's international seed operations.

One area in which little activity has been evident for US biotech companies is the European Union. This is likely due to several reasons. The EU has experienced highly visible consumer resistance to biotech products, prompting considerable hesitancy by EU governments to allow planting of biotech seeds. Also, US biotech companies already have spent tremendous sums purchasing US and South American seed companies, in addition to their considerable outlays for research and development. And, the EU is home of two of the world's main biotech companies: AgrEvo and Novartis. Nevertheless, assuming that there eventually will be broader acceptance of biotechnology, it is likely that access to seed in the EU market will become important as well (especially once biotech wheat varieties are developed).

After securing seed access and distribution systems, the biotech companies began the next steps in acting on a "dirt-to-dinner" vision of their role in agriculture. DuPont agreed in August 1997 to acquire Protein Technologies International (PTI), a value-added processor making soy proteins used in veggie burgers, processed meat products, infant formula, soymilk and other foods. Monsanto and Cargill in May 1998 entered into an agreement to form a worldwide joint venture that would involve Monsanto developing biotech products with output traits and Cargill conducting the grain processing and animal feed manufacturing. This shift from biotech companies integrating into the seed industry – a move that is essentially horizontal – to vertically integrating into bulk commodity processing is further evidence of the restructuring of the food system.

Given the dramatic integration into the seed industry, will the rest of the crop marketing be "taken over" as rapidly and extensively?

There are some specific reasons to believe this will not be the case. Biotech companies have little experience with originating, transporting, hedging, merchandising and processing grain. While some might say that professionals who can figure out how to modify the genetic structure of plants can figure out grain merchandising, it is a high-volume, low-margin business where practices have evolved over time, and the main industry players are very large companies that have succeeded at taking advantage of arbitrage, transportation and futures market opportunities. The managers of biotech companies do not have experience in these markets.

While the managers of the recently acquired seed companies do have some experience farther along the marketing chain, it is mainly in working with farmers to arrange seed production and performing fundamental storage and transportation functions. For the most part, their expertise covers the parts of the marketing chain that are still upstream from the merchandising and bulk commodity processing functions.

If the biotech companies have not yet internalized these capabilities through acquisitions, will they do so in the future?

Archer Daniels Midland, Bunge, Cargill, ConAgra and the other major players in the grain merchandising and processing industries are very large companies in their own right. Acquiring anyone would take tremendous resources, and it would saddle the biotech companies with what is mostly a low-margin business (ignoring ConAgra's consumer food operations). By contrast, the biotech companies have enjoyed high price-to-earnings ratios on their stocks and considerable stock appreciation in recent years.

This would also go against the trend by companies such as Sara Lee toward "de-verticalization," in which they have been shedding basic processing capacity and focusing more on marketing branded products. After all, one way to increase return-on-assets ratio is to reduce low-margin assets.

Given the strong stock performance of biotech companies in recent years in contrast to the lackluster stock performance of several basic agricultural companies (e.g., ADM) in 1998, it would be expected that biotech companies at least are examining acquisitions of grain companies. Persistent rumors to that effect have circulated for months. DuPont hived off a part of its Conoco subsidiary this fall, generating considerable cash and further fueling the speculation. The underlying question is what the biotech firms would gain by acquiring such companies.

In 1998, Optimum Quality Grains' value enhanced crops are estimated to cover 1.42 million acres. Monsanto's Laurate canola accounts for an additional 80,000 acres, bringing the total to 1.50 million acres. Even by including crops such as waxy corn and high-amylose corn which have been on the market for several years, this adds 2.25 million acres, a total of 3.75 million acres. This is a relatively small fraction of the 74 million acres of biotech crops in the United States this year. These present proportions would make acquisitions of large grain merchandising/processing companies appear of dubious value. However, some of the output trait products rapidly being developed and likely to attract significant additional acreage could well change the dynamics very quickly.

What will the coming of additional value enhanced crops mean for vertical integration in the future?

The forward movement across the food chain to processing would appear to be driven by the need for processing facilities for value enhanced products to manufacture components and further process into finished foods. The review of the pipeline suggests that over the next five years several value added products will appear, but that they are unlikely to be of significant enough volume (or value) to warrant biotech companies forward in the food system through major acquisitions. This might suggest that alliances are more likely in the beginning, until the value enhanced product introduction becomes clearer. Biotech companies in the near future likely will obtain benefits of integration through strategic alliances with large grain companies and perhaps acquisitions of smaller operations (including subsidiaries of larger companies).

The Monsanto pipeline from its 1997 annual report suggests that large scale introductions of value enhanced products may be beyond the five-year horizon of this study. In 2000 and 2001, it expects to commercialize oilseeds with modified fatty acid compositions, but since this primarily involves canola, it is questionable how much acreage these crops will claim five years from now. Monsanto has other value enhanced crops in development but does not expect to commercialize until "2002+" including modified basic fatty acid composition and also valuable individual elements, such as high beta-carotene canola oil.

This, plus its recent alliance with Cargill, would suggest that most of Monsanto's needs related to the handling and processing of value enhanced crops can be met through the joint venture over the five-year time horizon. Monsanto also has spent substantial sums acquiring companies over the last couple of years and still must maintain a sizable research budget.

DuPont appears in the opposite position. It has pursued seed access mainly through joint ventures rather than outright acquisition – with Pioneer and Optimum Quality Grains. DuPont is a massive company, and the recent partial spin-off of Conoco and expected sale of the remainder in the future, places it in an enviable cash position.

Nevertheless, the growth of Optimum's value enhanced crops still is limited, and the flagship product (high-oil corn) does not require processing beyond the feed mill. Producers still can feed high-oil corn on the farm, so some portion of production never requires specialized handling. Thus, Optimum's output would seem not to justify the acquisition of a large grain merchandising/processing facilities quite yet, unless DuPont is structuring itself for the handling of much larger volumes of value enhanced crops in the future.

The situation is similar for Dow. Mycogen's (recently purchased by Dow AgroSciences) value enhanced developments have been rather limited, not requiring large processing capacity. AgrEvo and Novartis still are limited to products with input traits, not yet requiring movement into processing.

Nevertheless, there are a limited number of major grain merchandising/processing companies, and it is likely that the biotech companies are closely watching means of securing access to them. Strategic alliances would enable access to grain handling and processing capacity without necessitating large cash outlays (e.g., Monsanto formed an alliance with Cargill shortly after large sums spent to purchase DeKalb Genetics and Delta and Pine Land).

DuPont does have a gap in the marketing chain between the farmer and delivery of slightly processed soybeans to its new PTI subsidiary. However, the soy protein products market still is small in comparison to markets for soyoil and soymeal made by the large crushers. Thus, alliances or purchases of smaller processors seem sufficient at the time for companies like DuPont/Optimum and Dow AgroSciences.

There are only a few companies in the soybean crushing industry other than the large grain companies. There are more participants in corn wet-milling (despite ADM and Cargill's large share of capacity). Some operations are more or less "stand-alone" subsidiaries of larger companies. A sale might make sense to both sides if a biotech company believes it can earn significantly more having the operation process value enhanced crops than the current owner receives processing bulk commodities. Purchase of small or medium-sized operations would enable integrating both the hard assets (i.e., elevators, processing facilities and transportation equipment) and professional capabilities (i.e., grain purchasing, commodity marketing, hedging and transportation logistics) into the biotech company before output of value enhanced crops expands. And, the size of the processing operation would be more proportional to the volume of value enhanced grain that will be produced in the foreseeable future.

By forming alliances, however, biotech companies would have the additional benefit of gaining access to the largest and most competitive grain merchandising/processing companies in the world, such as ADM, Bunge and ConAgra. A biotech company through an alliance can secure one or more of these large companies' capabilities without huge capital outlays.

Alliances also can open access to farmer cooperatives for biotech companies, which might not be possible through acquisitions. Cooperatives have the attractive features of ability to provide access to the farmer in selling seed at retail and potentially in arranging for contract growing of value enhanced crops, as well as having some grain handling and merchandising capabilities. Some co-ops also are significant players in the processing sector. Thus, alliances could be used to span most of the area from "dirt to dinner."

What about the construction of new processing facilities for biotech crops?

A final issue is whether the biotech companies could simply construct their own facilities for the processing value enhanced crops. Alternatively, if a biotech company were to form an alliance with a group of farmers, the producers may be willing to pay for and operate the processing facility if the agreement is binding and the farmers expect to get an adequate premium. Similar farmers groups have banded together to build processing facilities in an attempt to capture more of the value added to the grain, notably in the corn wet-milling industry.

An argument against such arrangements in the near term is that sizable new facilities have come on line in the soybean crushing industry during the last couple of years (and additional new capacity is possible), while the corn wet-milling industry also has been experiencing overcapacity during the last couple of years. Therefore, the prospects for a new facility to be able to "fall back" on processing bulk commodities if processing volume for value enhanced crops is insufficient does not appear enticing at the moment.

Nevertheless, the potential exists for biotech companies and/or associated farmer groups to build facilities for specific value enhanced crops, where there is compelling demand for the processed products, and the economics of growing and processing the crop are right. This may coincide with opportunities for smaller processing facilities that can be built and operated at economies that are competitive with the current world-scale facilities that dominate the processing sector (somewhat analogous to the rise of "mini-mills" in the steel industry). Still, since the world-scale facilities enjoy significant economies of scale, it should be emphasized that the operational economics would have to be relatively close to those of large facilities, and the proper site and value enhanced crop would have to be chosen, in order to make such a venture viable.

The Farm Sector

As the sectors move to accommodate the new processes, new technologies, new products and markets, and, likely new policies – a completely new system develops. The farming sectors around the world already are increasingly interdependent and buffeted about by a wide range of economic, political and natural forces well beyond their borders. The advent of biotechnology promises to bring more major shifts.

While farm sectors will differ in terns of the influence biotech will have, the general nature of the changes and implications likely will be similar the world over. This section explores the likely developments for the US farm sector as illustrative of those that can be expected elsewhere, especially in the developed countries.

Agriculture Today

Very powerful trends have been driving agriculture over the last several decades, forcing evolution of the sector and its place in the rural economy (Table 47). The farm population that was 25% of the total in 1935 is well below 2% today and so small it no longer is counted separately by the Census Bureau. And, farming's place in the rural economy has changed from once being the economic engine to a relatively small force today – perhaps fewer than 10% of the rural counties have as much as 20% of the economic activity dependent on farming.

Table 47. Number of Farms by Size (Sales), 1996

Sales Size	Number	% of Total	Sales	% of Total
	thousands		billions	

Less than $100,000	1725	83.6	44.9	20.4
$100,000 to $249,999	208	10.1	48.4	21.9
$250,000 to $499,999	79	3.8	34.7	15.7
$500,000 and over	52	2.5	92.5	41.9
Total	2064	100.0	220.5	100.0

Source: ERS, USDA.

Today's farms are in two distinct categories:

- **Commercial** farms numbering 339,000 (16.4% of total US farms), with 1996 sales of $175.6 billion (80% of total US farm sales).
- **Non-commercial** farms numbering 1.73 million (83.6% of total farms), with 1996 sales of $45 billion (20% of total farm sales).

For most of this century, farmers' primary focus has been on the technical aspects of farming, on reducing unit costs of output. Perhaps because they are commodity producers and price takers, most farmers have paid relatively less attention to the marketing function, leading many to suggest this – and risk management – as an area of emphasis for improving farm income. It has already become apparent that biotechnology can make contributions to further decreases in unit costs, and is becoming clearer that it has enormous potential to improve farmers' margins through expanding the revenue base, as well. Value enhanced products increasingly will offer farmers new opportunities, but also will create the need for farmers to locate new product markets and information about pricing options, negotiate contract premiums for wider margins, and produce the product to the contractor's precise specifications. Farmers still must focus on lowering their on-farm costs, but increasingly they will be driven to search out wider margins, in nontraditional markets.

These changes and the changing basic market for commodities likely will precipitate an evolution of commercial producers into two broad groups – those continuing to concentrate mostly on cost reducing/yield enhancing *biotech commodities* (traditional producers) and those focusing on differentiated, *value enhanced crops* (industrial producers). The former group can be expected to concentrate on cost efficiencies while the latter seek margin enhancements through development of value enhanced markets.

- **Traditional Producers**. These large producers are likely to embrace biotechnology products, but will focus on the cost reducing/yield enhancing varieties that are similar to traditional bulk commodities, require little change in production or management procedures. They will focus on investment in land and machinery and will increasingly embrace modern technology with expectations to increase the size of their operation. They likely will continue to own a major portion of their operation's land and resources. These operations likely will maintain the characteristics of most commercial farms today.

- **Industrial Producers.** These operations will differ from traditional farms in the type of biotechnology products they adopt and in developing new sophisticated business and management strategies. These growers will use high technology operations to better focus on trait-specific commodities and specific attribute raw materials. They will use extensive, coordinated markets with wider margins through contracts and strategic alliances rather than the general commodity markets.

  There also may emerge a group of producers whose primary focus is on developing and supplying markets competitively, rather than managing their own assets. In contrast to the large-scale growers that typically own most of their assets (land, machinery, equipment), this "negotiator" arranges for most services through sub-contracts, custom operations, hired labor (often through a custom service), and leases (sub-contracts) land. The competitive advantage of the negotiator is knowledge of markets, leveraged resources from basic contractors, and personal deal-making capacity. In many ways, these farmers will be middlemen for many operations, negotiating with end-users (processors/handlers/distributors) to produce trait-specific commodities or specialty crops; and then negotiating further with landowners, and owners of machinery and labor needed to produce the commodity.

Today's commercial farms little resemble a "way of life" as they once did. In recent years, they have become thriving, business operations using high levels of technology and fully focused on market growth. Biotechnology and precision farming are promising cost savings and significant returns to early adopters. They likely will prove as important or more than any previous technological or economic development.

Biotechnology, in particular, likely will greatly affect the structure (and numerous other aspects) of the farm sector as we know it. However, the effects are likely to vary greatly between cost reducing/yield enhancing crops and value enhanced crops.

Cost Reducing/Yield Enhancing Crops

Crops that are substantially equivalent to their traditional counterparts and are developed to reduce production costs or boost yields likely will cause relatively small changes to the farm sector. Key aspects include:

Management and Operations

- Increased management skills may be needed – greater evaluation of the "biotech package" will be required;
- A new cost structure (technology fees) may require different assessments before selecting a new "seed system";
- Information requirements on competing crops and products may become greater;
- Few new investments or capital are likely to be necessary;
- Less labor may be required.

Contracting and Legal Requirements

- Saving seed not allowed under technology agreements – on-site testing by biotech companies to test for compliance is allowed;
- Non-biotech refuges may be required, to prevent pests from developing resistance;
- No added incentive to contract production, unlike with value enhanced crops;
- Growers must ensure that crop is sold domestically if the export market is closed (e.g., the crop is not approved for use elsewhere);
- May be small amount of non-GMO contracting for specific food uses (baby food, tofu, etc.).

Farm Consolidation

- Definite advantages to early adopters, likely to be larger farms;
- Increased yields pushing prices lower may increase returns to scale, possibly accelerating the trend towards larger farms.

Vertical Integration

- Little possibility for integration, except into seed production;
- Opportunity for small scale purposes, e.g., new product testing.

Storage and Identity Preservation (IP)

- IP may be needed for products not approved in export markets;
- Increased demand for storage facilities.

Value Enhanced Crops

The changes effected by value enhanced crops (high oil corn, high methionine soybeans, etc.,) on the farm sector could be more substantial. Among the major factors are:

Management and Operation

- More labor will be necessary;
- Need for closer and more skilled management;
- Information needs grow considerably, including:
  - ◊ Greater reliance on the contractor;
  - ◊ Legal information related to contract;
  - ◊ Farm press and extension services may be less helpful, as they likely will have with no product history information, and the products will have a smaller market;
  - ◊ Internet sources of data (premium listings) may become more important;
  - ◊ More complex choices of crops to produce and companies offering premiums for them;
  - ◊ Overall, greater information requirements but fewer sources, particularly for early adopters;
  - ◊ Greater investment needed for storage facilities and IP equipment.

Contracting and Legal Requirements

Contracts may guarantee outlets and premiums for product, but two major questions remain. All of the following are possibilities:

- Who bears the risk?
  - ◊ For a commodity-like product with access to many of the traditional market outlets, there may be a flat price offered;
  - ◊ For new, highly specialized products, there may be a flat price offered, along with a premium;
  - ◊ Premiums may increase for crops with a higher "yield drag."

- Who negotiates with whom?
  - ◊ Seed/technology companies;
  - ◊ Grain companies;
  - ◊ Coops may play a greater role, credibility with farmers, own storage facilities, etc.

Consolidation

- Advantages to early adopters;
- Small farmers less likely to be first to attempt growing specialized crops;
- Contractors deal more with large farmers – small farmers could gain business through co-ops or open sign-ups;
- After initial adoption, small farmers find a niche with some products.

Vertical Integration

- Co-ops work with biotech companies as "franchisees" to deliver producers and product;
- Grain companies may establish closer ties with larger farmers;
- No indication of biotech companies or others wanting to own farmland; but might buy land for high-risk industrial and/or high-value nutraceutical products.

Storage

- IP required for all outlets and points along the distribution chain;
- Outlets may be more distant and require more investment;
- Greater delivery and timing constraints.

<u>Outstanding Issues</u>

- Concern already exists – before biotech – about concentration and consolidation throughout the food industry, and about the continued role and function of independent family farms.

- Given the long tradition of independent family farms in the United States and elsewhere, there is concern that biotech leads to increased contracting, eventually turning farmers into contract employees of large companies. How legitimate is this concern? Would crop farmers eventually follow the contract broiler grower model? Would farm numbers stabilize or shrink if this course of events took place?

- Even though biotechnology may lead to added vertical integration, the "chain" always skips owning farmland for their own production purposes. Why? What "rate of return" scenario always precludes this?
- How will small farms be affected by biotechnology? Is ability to afford biotech seeds (gene fees) a misplaced concern, given the apparent economic benefits? Will they benefit substantially from lower costs of production? Will more niche low-volume highly specialized production opportunities become available?
- How will farmers' relationships with seed and other input companies be affected by the biotech revolution? How will relationships with lenders be affected?

Agricultural Processing Sector

The term "grain" is used throughout this section to refer to cereal grains, oilseeds and other field crops.

The processing segment of the food marketing chain is not a single industry. Rather, it is composed of at least three distinct divisions: bulk commodity processing; food manufacturing; and feed manufacturing. Bulk commodity processing encompasses activities traditionally thought of as processing, including soybean crushing, wheat flour milling and corn wet-milling. The food manufacturing category mainly consists of makers of packaged food items that are sold through grocery stores, but it also more broadly encompasses a range of food items made in an industrial process and sold through a variety of outlets. Feed manufacturing refers to making compound feed through grinding and mixing of ingredients such as cereal grains and protein meals, whether done by a feed company, feedlot, or hog or broiler production operation.

Bulk Commodity Processors

Yield Enhancing and Cost Reducing Crops. Bulk commodity processors likely will be little affected by yield enhancing or cost reducing biotech crops. Generally, the new crops are "substantially equivalent" to their nonbiotech counterparts – quantity, content, and nutritional value of the meal, oil, and other derived products are little different than the standard commodity.

Any effects on bulk processors likely are in operations and sales. On the operations side, a direct effect is that herbicide tolerant crops contain significantly less foreign matter upon harvest than nonbiotech crops, especially soybeans and cotton. Monsanto reports foreign matter reduced by one-third for Roundup Ready soybeans, a noticeable effect for crushers located in areas with traditionally high weed pressure (Mid-South and Southeast). For cotton, herbicide tolerant varieties permit farmers to adopt the growing practice of ultra-narrow row planting which enables harvest by cheaper, efficient strippers.

Indirectly, biotech crops that enhance yield will increase supplies and lower farmers' cost curves. For example, seed companies report Bt corn can improve yields 16 bushels per acre over nonbiotech varieties. To the extent that supplies are larger and crop prices reduced – not necessarily farmers' margins – the trend is reinforced among grain merchandising and processing firms toward high throughput in large scale facilities.

Biotech crops also may affect bulk commodity processors if sales to customers sensitive to the presence of biotech products are made more different (e.g., EU buyers of corn gluten feed or soymeal). However, since their introduction, large commodity processors have steadfastly maintained there is no reason that biotech crops should not be commingled in their raw material and output streams.

Since biotech crop introductions in 1996, foreign importers of soymeal could purchase from Brazil rather than the United States (at least for the part of the year when Brazil had exportable supplies). However, recent higher US exports to the EU in years immediately prior to widescale planting of Roundup Ready soybeans, suggest little impact on bulk processors. Moreover, Brazil now has approved Roundup Ready soybeans for planting, and significant acreage is expected in 1999.

Although it appears unlikely, there may be some niche market opportunity for identity-preserved grain if the end-consumer were willing to pay for processed products guaranteed to not contain genetically modified material. Since 1996, Greenpeace and other organizations have published lists of potential suppliers of nontransgenic commodities. However, telephone conversations with these firms reveals they often are very small operations, and that while they have storage capacity and have even put together shipments in the past of such items as food-quality soybeans, most were operations with "good intentions" with little real capability to put together nontransgenic commodity shipments of any size.

Moreover, potential buyers, often in the EU, typically requested a guarantee from the suppliers of 100% nontransgenic. This almost always proves to be a "deal-breaker," as suppliers would provide signed statements from farmers who grew the crops, but were unwilling to take legal liability for an entire shipment. As a result, the few shipments reported to have taken place involved very small volumes – insignificant in terms of the scope of overall US commodity exports to the EU.

Value Enhanced Crops. The effects of value enhanced crops on bulk processors may be more far-reaching. Value enhanced crops that require processing and can generate enough additional value to "pay" for processing will be able to carve out niche markets. A segment of US processing capacity likely will be focused on such value enhanced crops, and the remainder of the processing sector may continue to mill standard commodities, which may include yield enhanced/cost reducing biotech crops commingled with nonbiotech crops.

Only biotech crops that intrinsically have additional value to merit identity-preservation, handling and processing will succeed commercially. (This ignores crops that do not require processing such as corn that could be fed to livestock on the farm where produced.)

At a minimum, value enhanced crops will result in heightened management requirements at companies/facilities that process these crops. Managers must decide whether they want to process a value enhanced crop, or to process only standard commodities. This may even involve a decision of whether to enter into the processing business, or whether to build a new facility.

At companies that process value enhanced commodities, heightened operational, marketing and risk management skills will be necessary. At the facility, managers must ensure the IP system remains intact by dedicating bins to storage of the value enhanced grain, and then properly supervising employees to make sure that no commingling of value enhanced and standard grain – or two different varieties of value enhanced grain – takes place during load-in or load-out. If the output from processing a particular variety of value enhanced grain has a specialized use, then company management must enter into agreements with customers that will purchase the product at a profitable price. The company also must be able to sell any by-products, requiring sales skills that might be a deterrent to new entrants, as companies considering such a move often underestimate the difficulty of selling processed products, believing that commodities "sell themselves."

Risk management is another difficult area for companies processing value enhanced grain. The raw materials and/or the item produced may not have a close economic relationship with commodities for which there are futures contracts or major exchanges. For example, if soybeans can be modified to contain oil used only in specific industrial applications, then the value of that oil may not fluctuate in step with soybean oil futures traded on the Chicago Board of Trade. If the secondary products made during the processing of seven commodities – in this example, soybean meal produced when retrieving the value enhanced oil – are not equivalent to the standard products (in nutritional quality or other attributes), another level of complexity is added. Large companies may be able to approach investment banks or other sophisticated financial institutions about having derivatives written for the value enhanced products; but this involves transaction costs and likely would be out of reach for smaller organizations interested in processing value enhanced grains.

Still, while these management needs must be addressed, the most important question about processing these crops is whether it takes place at facilities dedicated solely to processing such crops or at facilities that process value enhanced crops part of the year and standard crops for the remainder.

An associated question is the size of facilities to process value enhanced grains. Technical factors oppose performing "runs" of both standard grains and value enhanced grains at a single processing facility. Specifically, most agricultural processing involves continuous flow of raw materials rather than processing of discrete batches. If not, then some products may have to be sold at a discount.

One possible scenario for the birth of an industry over the next five years is outlined below. The processing of value enhanced crops likely will take place in separate runs at facilities that still spend the majority of the year processing standard commodities. Only after one or more value enhanced crops that have demonstrable economics and that can command an adequately sized market are introduced will investors and credit providers be willing to dedicate a facility to the processing of such crops. Similarly, it probably will be necessary for one organization to be a trailblazer in setting aside a facility for the processing of value enhanced grains, which if successful will entice other organizations to construct facilities or carve them out of their existing "stable" of facilities.

Food Manufacturers

Food manufacturers generally are much more rigid in the suppliers they use and the "sanctity" of maintaining their end-products than are bulk processors. Food manufacturers tend to use a small number of suppliers verified to be capable of delivering product meeting strict specifications. Food manufacturers also are more likely to have long-term contractual agreements with their suppliers, though the price of the ingredients they purchase may be tied in a predetermined way to a market price that fluctuates (e.g., three cents over CBOT futures prices for soybean oil). On the output side, prices for packaged food products tend to change much less frequently and sharply than day-to-day and second-to-second price changes for the grains and oilseeds that bulk processors purchase, as well as the vegetable oil, protein meal and starch-based products that they produce.

Also, food manufacturers are already unwilling to change the labels on their products except for marketing reasons (e.g., a more eye-catching label featured in a new advertising campaign). The consumer acceptance issues associated with biotechnology could add another level of complexity, though a label that could go beyond stating that the item contains genetically modified material and make a positive claim (e.g., margarine that reduces cholesterol) may be attractive to manufacturers.

By the very definition of a value enhanced product, the product must offer a health benefit, a processing advantage (e.g., functionality) or some other valuable trait, or else the manufacturer will not use the product and certainly not pay a premium for it. Food manufacturers typically have to store and use a range of ingredients, which makes them relatively well-positioned to handle value enhanced product alongside standard product. Furthermore, many food manufacturers leave some flexibility on the label for switching oils or other ingredients according to price (e.g., "may contain soybean oil and/or cottonseed oil"). Thus, food manufacturers are likely to make clear-cut decisions about whether to use a value enhanced product – and store it in an IP manner – or else exclude it entirely from the raw materials they use.

Feed Manufacturers

The feed manufacturing industry encompasses both traditional, independent feed mills and feed mills which are a "captive" part of livestock and poultry feeding operations. For example, Tyson Foods' feed milling capacity may be as high as 12 million tons per year, exceeding that of Purina Mills, now a division of Koch Industries. Due to its vertical integration, the poultry sector is a leader in the use of captive feed mills, though large operations across all species, including cattle feedlots, often have such feed milling facilities.

Feed mills focus on having the right mix of nutrients (e.g., energy, amino acids) in the rations that they produce. They use linear programming models to meet predetermined nutrient levels at least cost. Any feed ingredient from a value enhanced crop will have to be able to deliver nutritional characteristics at equal or lower cost than alternative sources. For example, if a high-lysine biotech soybean is developed, the meal will have to be priced competitive with animal-based protein ingredients (e.g., fish meal, poultry, byproduct meal), as well as synthetic lysine. Because these alternative sources of nutrients are well known and their prices often are reported publicly, it is easier to quantify the value of feed-oriented, biotech traits than traits dependent upon people's tastes and preferences (e.g., oil with a more healthful fatty acid profile).

Another aspect of this relatively strict adherence to least-cost formulations is that livestock and poultry operations are likely to be open to biotech developments that save money and/or improve feeding performance. There is no consumer acceptance issue for the initial consumers of the feed (i.e., livestock and poultry); the operations would be affected only if people who purchase meat and poultry demand it not come from animals fed genetically modified product. In the livestock market, acceptance of BST as a growth hormone for dairy cattle has paved the way somewhat.

There will be drawbacks for both captive feed milling operations and independent feed manufacturers. The link between the consumer and the producer is most direct for poultry operations, as the company provides the feed that is used and then slaughters the birds and sells the parts in branded trays at grocery stores, or further processes the poultry meat into packaged food items (e.g., Tyson frozen dinners). If one poultry company is known to use biotech product while another company does not, then consumers may choose to purchase one product over the other. Similarly, if one independent feed milling operation is known to use a particular biotech product while another company does not, then a livestock operation may choose to purchase nonbiotech feed rather than put its own sales of fattened livestock at risk.

Although independent feed manufacturers have to be cognizant of the aversion of some customers to frequent changes in feed rations – and potentially toward the inclusion of biotech products – such manufacturers are selling a near-commodity and must compete on price. Accordingly, they are more likely than captive operations to alter rations according to market conditions. Whereas feed costs represent only a portion of the overall cost structure of a livestock or poultry operation, the cost of ingredients is the main determinant of finished feed sold by an independent feed mill. Because of their flexibility to switch among different ingredients and their need to go with the lowest-cost ingredients, independent feed manufacturers may generally be more receptive to incorporating into their rations biotech products that have a significant advantage.

Grain Handling and Transportation System

The term "grain" is used throughout this section in a generic sense to refer to cereal grains, oilseeds and other field crops such as peas, lentils, canary seed, etc.

This section examines potential implications of biotechnology for grain handling and transportation in North America. There has been a great deal of discussion in recent years regarding the expected increase in identity preserved (IP) handling requirements accompanying the introduction of transgenic crops. In some cases these special handling requirements arise from the need to ensure that transgenics are not co-mingled with other transgenics or non-transgenic grain of the same type, even though their respective end-use performance characteristics may be very similar. In other cases, the need for segregation or IP arises from the fact that the transgenic grain has unique end-use performance characteristics. Clearly, the nature of these new handling requirements will depend heavily on the type of genetic modification involved, the degree of risk associated with co-mingling with other grains, the ability to visually identify the variety and distinguish it from other varieties of the same grain, and the cost of testing for varietal purity or other identifying features.

Besides the issue of special handling requirements and IP, there are a number of other important implications of the commercialization of transgenic varieties for grain handling and transportation. For example, the adoption and commercialization of transgenics is likely to affect grain flows, as proprietary rights to certain varieties and their unique performance attributes dictate that only certain companies are involved in their handling and processing. The costs associated with identity preserved handling may also result in an increase in the proportion of some crops that bypass the bulk handling system and are shipped directly to nearby processors.

The commercial control of novel transgenic varieties by a small number of companies also has the potential to fundamentally impact the role grain companies play in the marketing of certain crops. Currently, grain companies play a key role in the movement of grain from farmers to end users, whether they are domestic processors or offshore buyers. These companies participate in this process by taking ownership of the grain, blending it with other parcels of similar grain, aggregating the grain into economically sized shipments and selling it to various other players – other trading companies or to end users. Throughout this process, these companies also play a role in price discovery and the transference of price and quality risk. The introduction of varieties with highly specialized end-uses very likely will change this role to one of providing a handling service for a fee as opposed to trading the grain in the traditional sense. It is likely that these companies will take ownership of the grain less frequently. However, they still will be required to maintain and warrant that the product being handled will remain pure and will not be co-mingled with other crops. These and other possible implications are examined in greater detail below.

Scientific Versus Economic Viability of Transgenic Crops

Underlying many of the above issues is the question of how many transgenic crops will ultimately prove to be economically viable and enter the bulk grain handling and transportation system. While we now know that it is scientifically possible to produce a multitude of crops with novel traits, this does not suggest how many will prove economically viable. For example, several genetically altered canola varieties are being developed with unique fatty acid profiles and highly specific end-uses. However, in virtually all cases, the genetically modified product has been developed to replace an existing product. Laurate canola, for example, has been developed to compete with imported palm kernel and coconut oil (which have high lauric acid content) in the production of liquid soaps, detergents and other products in North America.[21] Whether the market value of laurate canola will be sufficiently high to offset the additional costs associated its production, handling and processing (versus using palm kernel or coconut oil) remains an open question.

A related question is whether the markets for the transgenic crops are large enough (and lucrative enough) to warrant introduction into the bulk handling and transportation system. It can be expected that a number of transgenic crops will be produced that will never enter the bulk handling system. This is likely to be the case where either the volume produced is too small to warrant the introduction of a new segregation (and possibly other IP measures) into the commercial handling system, or the risk of co-mingling with other varieties is too high (as would be the case with a toxic variety).[22]

While dozens of new transgenic crops with novel output traits are currently being developed, it is expected that only a limited number will have sufficient economic value to warrant the introduction of new segregations and identity preserved handling requirements within the bulk, commercial grain handling and transportation system.

Segregations/Identity Preserved Handling Requirements

It is important to recognize that the notion of identity preserved grain represents a continuum as opposed to a singular concept. At one end of the continuum is a highly generic commodity, such as corn. This type of commodity can be readily co-mingled, has a small number of readily measurable quality parameters (moisture, dockage, broken kernels, etc.), is visually distinguishable from other grains and represents a relatively low risk in terms of inadvertent co-mingling with other low value commodities.

At the other end of the spectrum is a highly specialized, high value, variety that requires a high degree of IP, is not readily distinguishable from other varieties and represents a high risk in terms

21 Calgene (the leading developer of laurate canola) also has touted the benefits of laurate canola oil for use in making candy coatings, coffee whiteners, reduced-fat cream fillings, crackers and whipped toppings.

22 A study prepared for the Canadian Wheat Board in 1997 estimated that the cost of adding a new segregation ranged between C$0.60/tonne and C$1.28/tonne. (Meeting Customers' Quality Requirements with Quality Segregations – by Maurice Demmans and Clarence Roth – December 1997).

of inadvertent co-mingling with other products. An example of this would be a genetically altered soybean variety that has a modified fatty acid profile used for a specific industrial purpose and is toxic to humans. In addition, this particular soybean variety may be visually indistinguishable from other soybean varieties and requires a costly testing procedure for identification (thereby making it unfeasible to verify its identity at regular intervals in the marketing process). In such a case, not only will the handling system may be forced to provide the physical capability to handle this soybean variety separately (i.e., the physical segregation), but additional safeguard measures will be required to ensure that there is no possibility of mixing this variety with other soybean varieties. In fact, the participants in the handling system may not be willing to take on the risk of ensuring the complete segregation of this product. This can be referred to as "zero tolerance" IP.

Within these extremes, a number of alternative IP requirements can be defined. For example, malting barley is currently IP in both Canada and the United States to some degree in the sense that it is often sold and segregated according to variety. Given that it is not possible to visually distinguish between most malting barley varieties, voluntary systems have been put in place to ensure that requirements for varietal purity are met. Similar voluntary systems will undoubtedly emerge in the future for some transgenic crops, particularly in cases where the risk of co-mingling with other varieties is small (in terms of public health risks, trade sanctions, etc.). In such cases, the grain handling company and/or shipper will enter into a voluntary agreement with the buyer, processor or the "owner" of the seed variety to handle the crop in a certain fashion, or simply guarantee a certain level of varietal purity in the sales specifications. This may involve measures such as obtaining documentation from farmers certifying the variety grown, requirements to handle a restricted number of varieties in approved facilities, sanitation procedures, etc. In some cases the transgenic grain may be identified by the inherent quality of the seed. For example, a relatively simple test may be devised to identify soybeans with a particular fatty acid profile, which would greatly facilitate the IP process.

The complexity of the IP issue becomes clear when a scenario where commodities and varieties requiring both low level and high level IP are handled in the same system. Depending on the reason for the IP and segregation, the presence of one variety requiring a high level of IP will require that all similar, inseparable commodities are monitored and tested in the same manner. A toxic commodity (as in the above example) would require "iron-clad" handling procedures to ensure non-contamination of other grains, as well as testing to ensure purity. In addition, and perhaps more importantly, the non-toxic, indistinguishable varieties handled in the same system, would require similar monitoring and testing procedures.

In cases where there is a higher perceived or real risk associated with co-mingling, additional IP measures may be required and are likely to be imposed by a regulatory body such as the US Federal Grain Inspection Service (FGIS) or the Canadian Grain Commission (CGC). For example, transgenic crops with specialized output traits are likely to require a higher level of IP. Again, the type of IP system required will depend heavily on the degree of risk associated with the product and the ease with which the product can be identified. A relatively high risk product that can be easily identified and distinguished from other varieties may not require an elaborate

IP system as it can be easily tested at key points in the marketing chain. On the other hand, a high-risk product that is not readily identifiable may require more rigorous IP requirements.

Future Models for IP Handling Systems

Cost Reducing/Yield Enhancing Transgenics. Genetic modifications to crops that relate only to the input characteristics of the plant, such as herbicide tolerance, insect tolerance, etc., are likely to have more limited IP requirements since the seed will perform the same as non-transgenic varieties of the same crop. The major issue with these transgenics is the mere fact that they have been genetically modified through recombinant DNA technology, which may prohibit their entry into some domestic or export market channels (e.g., herbicide tolerant canola to Europe). By allowing transgenics with trade restrictions into the commercial handling system (and in fact even by allowing their production), the risk is introduced that non-transgenic grain may become contaminated. Rather than requiring elaborate IP measures to deal with transgenic and non-transgenic varieties of the same crop, one option is to allow the co-mingling of transgenic and non-transgenic varieties, with the recognition that one of the costs of introducing the transgenic variety may be the loss of certain domestic or export markets. In such cases a great deal of industry consultation is required, as these decisions will affect a number of parties. Another option is to develop IP protocols within the commercial grain handling system that are acceptable to the various markets (as discussed in the next section).

Value Enhanced Transgenics. For transgenics that alter the functional characteristics of the crop, the IP requirements are likely to be more substantial. In cases where the product poses significant health risks, one option will be to simply not allow the product to enter the commercial handling system. Rather, the crop will be either shipped to local processors or will be handled by other means such as utilizing containers, possibly loaded on the farm.

In cases where the risks are trade-related or purely economic (such as loss in value associated with the blending of two varieties with different end-use characteristics), transgenic varieties will be allowed to enter the commercial handling under various IP protocols. In some cases this will involve transgenic varieties that are not readily distinguishable from non-transgenic varieties and that require costly testing procedures.[23] One method to deal with these types of transgenics will be to utilize a system of audit trails and sampling throughout the marketing chain, accompanied by "official" varietal testing at key transaction points (such as export position). Under this system, if a cargo fails to meet the requirements for varietal content, the shipper would have recourse to the party that last handled the grain. This party would then have the opportunity to test the sample it took when it received the grain, and so on. The basic principle of this system is to work backwards in the marketing chain until the source of the "contamination" is determined and claims assessed. This type of system is currently being examined by the Canadian grain industry under the leadership of the Canadian Grain Commission.

23 Currently, the Canadian Grain Commission charges roughly C$500 per sample for full high protein liquid chromotography (HPLC) and electrophoresis. The cost of an electrophoresis sample on 30 kernels is approximately C$155 per sample.

The advantage of the above system is that the requirements for costly and time-consuming tests are kept to a minimum. However, there appear to be a number of shortcomings of this type of system as well. First, this type of system relies heavily on the integrity of the participants to ensure that representative samples are taken at each point in the marketing chain. Second, in cases where there are tight tolerances, one farmer (or small grain company) may be responsible for the contamination of an entire cargo. In such cases it is difficult to recover the costs of demurrage, discharging, loss of value, etc. Finally, the existence of volunteer grain in most fields will make it extremely difficult to guarantee 100% varietal purity. To limit the likelihood of volunteer grain, growers of transgenic varieties will be required to adopt sanitation procedures and policies similar to those used by organic farmers.

As noted above, some transgenics will have inherent quality characteristics that allow them to be readily identified. In these cases, the ability to monitor the identity of the grain at multiple points in the marketing chain is enhanced considerably. However, they may still require strict IP policies and practices due to inseparability from other varieties.

Clearly there are significant obstacles to accommodating IP shipments within the existing commercial grain handling system. To facilitate this process, research will be needed to hasten the development of more cost-effective testing procedures for transgenic and non-transgenic varieties. Another possibility is the introduction of additional genes that provide visual markers to facilitate identification and the IP process. Companies involved in developing new transgenic crops should recognize that an important part of the economic viability of the variety is the ability to identify it in a cost-effective fashion.

The Role of the Grain Company in Marketing

Traditionally, grain handling companies have played an important role in the marketing and price discovery process for most crops. In most cases, the companies are free to buy and sell a given commodity and in the process they assume risk in return for the chance to earn a positive handling margin or profit. Thus, most crops are traded in a relatively unrestricted marketplace with multiple buyers and sellers (as well as multiple potential destinations) where the activities of grain companies play an important role in the determination of the market price for the commodity.

Two major exceptions to this are wheat and barley produced in Western Canada which are handled on behalf of the Canadian Wheat Board (CWB) by a number of grain companies. However, even in this case, the grain companies compete to some degree for deliveries of CWB grain by varying the cost of their handling services to the farmer. Although they take on virtually no price risk, they do assume all quality and purity risks associated with handling and shipping the grain.

With the introduction of transgenic crops, with highly specialized end uses, crops will become "de-commoditized" in the sense that their value will be driven largely by the unique characteristics of the particular variety (sometimes referred to as hedonic pricing). In addition, many of these transgenics are likely to have very limited marketing channels and will not be traded in an open market to the same degree as in the past. For example, a particular transgenic corn may be controlled by one company that has contracted the production with producers and/or signed exclusive processing agreements with a limited number of companies. While grain companies may still play a role in handling this type of corn, they are much more likely to do it for a fixed handling fee than to trade the product in the traditional sense where they take beneficial ownership and assume all risks – price, purity and quality. Thus, grain companies may find that their role increasingly changes from one of grain trading, to that of providing a grain handling service. This service may include administering a contract system with farmers, as well as ensuring that various IP protocols are met with respect to both the production and handling of the crop. This will require greater management capability on the part of grain companies in the areas of testing and monitoring, as well as a much higher level of communication with farmers. The hallmarks of success for grain companies of the future will be strong relationships with farmers, highly trained field staff and solid information systems for monitoring and tracking the flow of grain.

Handling Margin Formula

With the growth in value enhanced biotech crops, it is necessary to question what effect will toll handling, or fixed fee handling, have on margins? In very simplistic terms, for the operator of grain handling facilities, fixed fee handling will reduce price risk born by the facility operator, increase handling and IP risk, reduce blending opportunities, reduce (eliminate) arbitrage opportunities, and reduce futures market opportunities.

In North America, toll handling fees likely will be higher than current "visible" elevation rates to compensate for lost opportunities elsewhere (e.g., blending, arbitrage) in addition to covering the added cost of IP requirements. Will increased handling costs impede the development of value enhanced biotech crops and their ability to compete?

To clarify the margins that fixed fee arrangements will need to generate in order to compete with the traditional commodity handling and merchandising system, the following formula has been developed.

$$M_{ve} = \frac{[(S_{ve})(M_{com} - R_p + R_{ip} + O_b + O_f + O_{arb} + O_{tl} + C_{ip})] + [(1-S_{ve})(R_{ip} + O_b)]}{S_{ve}}$$

Where $M_{ve} > M_{com}$

In simplistic terms, this formula states that the theoretical fixed fee margin for a value enhanced crop is equal to the traditional margin, reduced due to the lower price risk, increased by factors for lost opportunities, increased to cover the cost of the identity preservation program, increased for negative impacts on handling other grains, and weighted with respect to the portion of the facility utilized by the value enhanced crop program. In addition, it is argued that the fixed fee must be greater than the margin for the standard commodity to attract grain companies to handle the value enhanced crop. The following provides a more detailed description of the formula and its components.

M_{ve} is the theoretical gross handling margin to be earned through handling value enhanced grain for a fixed fee (tariff), or toll. In theory, this margin must be equal to or greater than the gross margin generated by handling standard varieties of the same crop. It should be said that for the grain handling business in North America, handling is often bundled with other services such as input sales and financing, and therefore a specific "grain handling margin" is often difficult to isolate. Nonetheless, handling value enhanced grain must provide the handler the same, or better, returns as handling the commodity, or else the grain company is better off not handling the value enhanced grain.

S_{ve} is the portion of the total space of the facility dedicated to handling value enhanced grain. In determining the appropriate margin for handling/marketing value enhanced grain, consideration must be given to the factors directly related to the value enhanced grain as well as to factors effecting the profitability of other crops (if any) handled by the facility (see $1-S_{ve}$ below).

M_{com} is the typical handling margin earned at the facility for similar commodities and therefore is presented as the "base case."

R_p is a risk factor representing the price risk usually associated with handling the standard commodity. This factor is deducted from the base case margin since handling grain for a fixed fee will reduce any price risk exposure for the facility operator.

R_{ip} is a risk factor representing the risk associated with handling the value enhanced grain under an identity preserved program. The onus on maintaining the sanitation, segregation and identity of the grain handled is on the operator of the facility. Therefore, the margin must be large enough to compensate for this added risk. This is a positive factor in the equation, contributing to the required margin (M_{ve}). This is not insignificant. The greater the risk of commingling the value enhanced grain, the greater the margin required by the facility operator to handle the crop. As indicated elsewhere in this section, handling some combinations of crops may prove to be too risky for any firm to handle. It should be clear that consideration, or calculation, of this factor, must include other crops handled by the facility.

O_b is a factor representing the opportunity (and profit potential) of blending. In most grain handling operations, a significant portion of revenues are earned through blending. This is the process of purchasing various qualities of the same grain, and purposely commingling low quality grain with higher quality grain at selected rates to achieve a higher grade (and higher price) for the whole amount of grain. Facilities handling value enhanced grain under a toll arrangement have no price risk and therefore no opportunity to benefit from this type of blending. This factor is presented to compensate for the loss of blending revenues.

O_f is a factor representing the additional profit opportunities available from futures trading and hedging. Facility operators that buy and sell the grain moving through their facilities most often reduce price risk through the process of hedging in futures contracts. Hedging is not a perfect science and there is more often than not, a time lag between buying (or selling) the physical grain and the first opportunity to hedge the transaction in the futures market.[24] This time lag provides both opportunity and risk – price movement in the futures can either be beneficial or detrimental to the hedger. It can be argued that, on balance, when hedgers enter and exit the futures markets, this hedging activity provides additional margins.

O_{arb} is a factor representing the additional profit opportunities available from arbitraging a cash or inventory position. When operators of grain handling facilities take ownership of the grain handled, they search for the best opportunities to purchase or sell the grain, regardless of the market. This "arbitrage" between markets provides additional positive revenues. In the event that a grain handling facility is handling grain on a toll basis, this revenue must then be compensated for in the toll, or margin for the value enhanced grain.

O_{tl} is a factor representing the profit opportunities available from handling commodities, through properly executed transportation and logistics programs. Transportation programs and pricing policies often provide additional revenues for grain handlers. Through the use of contract rates, multi-car incentives and other such programs, grain handlers can increase their handling margins for grain they own. Again, this revenue must be compensated for in a fixed fee arrangement.

C_{ip} is the cost associated with an IP program. Depending on the extent of the IP program and the risk associated with it, the operator of a grain handling facility will incur additional expenses including, but not limited to, sampling, testing procedures and information and monitoring systems.

$1\text{-}S_{ve}$ is the portion of the total space of the facility not dedicated to handling the value enhanced grain.

The formula describes two basic areas of revenue. First, there is revenue generated from the portion of the facility dedicated to the value enhanced grain being handled, segregated from all other grain in the facility:

$$(S_{ve})(M_{com} - R_p + R_{ip} + O_b + O_f + O_{arb} + O_{tl} + C_{ip})$$

The margin to handle the value enhanced grain (M_{ve}) must be equal to or greater than a typical margin (M_{com}), while also compensating for lost ancillary revenues such as from blending (O_b), transportation and logistics (O_{tl}), futures trading (O_f) and arbitrage (O_{arb}). Moreover, the margin to handle value enhanced grain must compensate for additional risk due to segregation requirements (R_{ip}) as well as the cost to perform the identity preservation requirements. The lack of price risk (R_p) allows the margin requirements to be reduced.

[24] Although cash grain is traded (bought and sold) virtually 24 hours a day, futures markets are open only for short periods (less than four hours) each day.

The second area of consideration is the potential lost revenue opportunities relating to the other grains handled in the facility that must be compensated for:

$$(1-S_{ve})(R_{ip} + O_b)$$

Depending on the characteristics of the value enhanced grain, segregation may be an issue for both the value enhanced grain and the other grain being handled. For example, a facility handling both standard canola and Laurate canola would be running the risk of commingling either. For this reason, the risk – in dollar terms – of commingling the value enhanced biotech canola with the standard canola must be considered and weighed.

Each of these two areas of consideration is weighted by its share of the space of the facility. The sum of these is then divided by the total space allotted to the value enhanced grain (S_{ve}) to obtain a margin on a per unit basis (ton or bushel).

Considering risk as a cost, it is clear that the reduction of price risk to the facility operator is the only area of cost reduction. All other components increase the cost, and the required margin, to the operator. In theory, therefore, the cost to handle value enhanced crops is higher than the cost to handle standard commodities.

How much higher is the question. Grain companies will accept calculated risks and will operate in a fashion to mitigate those risks. Ultimately, they will determine the marketing channels through which new value enhanced biotech crops will flow.

Marketing Flows and Nature of Shipments

Related to the above is the impact of biotechnology on the marketing flows and nature of shipments. Clearly, the most effective method of IP is to ensure that the grain is handled within a closed loop system and never enters the bulk handling and transportation system. Thus, in cases of high risk crops, it is expected that marketing flows will bypass the commercial handling system and grain will be shipped directly to a local processor, likely by truck. This will reduce the amount of grain entering the commercial system, although grain companies may still play a role – through the utilization of facilities that specialize in the handling of the high risk crop, in monitoring the crop and coordinating the shipment of the grain from the farm gate to the processor.

As noted above, the flow of transgenic varieties is likely to be controlled by a relatively small number of companies in the future that will be in a position to determine who has the right to handle and/or process a given product. Thus, grain companies and transportation providers will face an increasing risk of being locked out of the marketing chain for certain crops/varieties unless they are able to negotiate a handling agreement with the company that controls the product. This seldom occurred in the past when most crops were true commodities in terms of their handling and processing.

With the de-commoditization of some crops, it is also reasonable to expect that in some cases, grain will be handled in smaller parcels and by different modes, such as trucks and containers. While ultimately this will impact the design of grain handling facilities, it is likely that this will take place over many years, as companies carefully assess the economic viability of new transgenic crops before investing in specialized handling systems.

Consolidation/Vertical Integration

With transgenic crops expected to account for the majority of crop acreage in North America in the future, and a small number of companies controlling the predominant varieties, the question arises as to how much vertical integration will occur into the grain handling business. While numerous strategic moves have been made by the biotech companies to acquire seed and biotechnology research companies,[25] to date, none have vertically integrated into the primary grain handling business. Perhaps the most notable exception is the joint venture entered into by Monsanto and Cargill. In this arrangement, Cargill will be handling and processing value enhanced crops developed by Monsanto. This includes the marketing of byproducts – such as meal from crushed Laurate canola – to Cargill's Nutrena Feed Division.

The burden will be on the grain companies to demonstrate that they can provide grain handling services and act as an interface to farmers on a more cost effective basis than the biotech companies. The introduction of transgenic varieties may also have the effect of accelerating the consolidation of grain handling companies in North America as they attempt to position themselves to play a role in the handling of these new varieties. One of the most desirable features of a grain handling company in this regard will be the ability to provide a broad, geographically diversified origination network. This type of network offers the potential for biotech companies to gain access to a large number of farmers through a single relationship with the grain company (e.g., Monsanto-Cargill). Geographic diversity further reduces the risk of crop failure due to factors such as a localized drought or early frost.

It is expected that on balance, biotechnology will increase the amount of grain handled by the commercial handling and transportation system. While some transgenic crops will bypass the commercial handling system and be trucked directly to local processors, this is likely to be more than offset by the yield increases achieved through better weed control, disease resistance, insect resistance, and even drought tolerance. The contribution of biotechnology to the development of hybrid crops also will result in significant yield increases in the future.

Configuration of Grain Elevators

The grain handling system in North America has been undergoing a process rationalization, with the building of high throughput (HTP) elevators to replace the existing smaller, less-efficient elevators. This is particularly pronounced in Western Canada, where 60 new HTP elevators are expected to be constructed over the next two to three years. For the most part, these HTP

[25] Including Monsanto, Dow AgroSciences, Novartis, Dupont and AgrEvo.

elevators, with fewer separations than their smaller counterparts they are replacing, are designed to handle large volumes of a few grains. It is expected that over the next three to five years the number of primary elevators in Western Canada will fall from approximately 1,050, to around 400. The question has been raised as to whether this restructuring of the elevator system makes sense in light of expected release of many new transgenic crops in the coming decade.

On balance, it is expected that while some modifications will be required to handle transgenic crops, a large portion of the grain will continue to move in bulk (particularly input trait transgenics). The major modifications to the grain handling system are more likely to be in the areas of information systems as opposed to physical modifications to the elevator. Only a small number of transgenic crops will prove to be economically viable, thus it is not expected that the number of segregations will increase significantly over the next five years. However, as more output trait oriented transgenics reach commercialization, the need for additional segregation (i.e., number of bins) may indeed increase. In this regard, Canada may well have an advantage over other countries given that the system already deals with a large number of segregations. For example, there are approximately 68 segregations for wheat and barley alone in Western Canada.[26]

Another pattern that is likely to emerge is the concentration of production of specific transgenic crops around a selected elevator or local processor. This presents both risks and opportunities to grain handling companies. Elevators in some locations are likely to see their handling volume suffer as local IP processors of certain transgenic crops are constructed. On the other hand, these companies may be able to play an important role in the origination and delivery of these crops to the processor by positioning themselves properly. This might include dedicating smaller facilities to transgenic crops as opposed to closing them down.

Impacts on Transportation

The impacts of biotechnology on grain transportation (primarily rail and truck transportation) are expected to be much less dramatic than on the grain handling companies. There are two reasons for this:

- Railways and trucking companies already operate in an IP environment in the sense that there is seldom ever any co-mingling of shipments while they are in the possession of the carrier. In addition, it is generally the shipper, not the carrier, that bears the responsibility for the quality of the grain loaded.

- Railways and trucking companies seldom take ownership of the cargo or get involved in the marketing of grains. Thus, the introduction of transgenic crops likely will not have a significant impact on their role in the grain marketing system.

26 This, of course, does not mean that every elevator is equipped to handle all of these segregations. Soil types, climatic conditions and other factors result have a limiting effect on the number of segregations required at any given location.

However, the grain transportation sector likely will be impacted by the introduction of transgenic crops in several ways. First, while the total amount of grain produced is likely to increase (with the associated yield advantages of transgenic crops), it is not clear that this will necessarily translate in higher rail car shipments. As discussed earlier, it is likely that some transgenic crops will bypass the commercial grain handling system and get trucked directly to a processor. Another possible impact on rail carriers is that there may be an increase in domestic rail shipments as transgenic crops are railed to domestic processors.

The pricing of grain transportation services will also be affected by transgenic crops with unique output traits. Presently, some rail companies price their rail freight on the basis of the shipper's lowest cost alternative. For example, the rates for shipping corn to the Pacific Northwest ports often is related directly to the cost of barging corn down the Mississippi River and exporting through the Center Gulf. To engage in this type of "market-based pricing" the railways rely on a certain degree of uniformity and price transparency. With the introduction of transgenic crops with unique traits, it will be much more difficult to obtain accurate pricing information on the value of these crops. It also raises the question as to whether the railways will be able to differentiate their pricing for different types of transgenic corn, soybeans or other crops.

Finally, a minor implication for grain carriers may be an increased requirement for cleaning rail cars or trucks in between loads to ensure that there is no contamination of different varieties of a given crop.

Role of the CWB

The Canadian Wheat Board sees its role regarding transgenic wheat and barley involving two main areas. First, it has begun a process of consulting with customers to ensure they are fully aware of the implications of allowing transgenic wheat or barley into the system. The CWB does not want to find that a country is unwilling to accept a transgenic wheat or barley variety after it has already been introduced into commercial production. The CWB plans on conducting a major survey of their customers this winter on this point. Secondly, the CWB plans to work with the research community to ensure that it is aware of the traits in wheat and barley that would be desirable from the end-users standpoint. This will include milling characteristics, baking characteristics, malting and brewing characteristic for barley, etc. The CWB does not now see its role as being directly involved in the development of new transgenic varieties for wheat or barley.

The Consumer Sector

Consumer Acceptance in the United States

Consumer reaction to agricultural biotechnology has been fairly quiet in the United States, with some concerns raised by small groups but little reaction from the mass market or major consumer organizations. Many have interpreted this lack of protest as an indication of strong support among the public for GMO foods, but it is unclear from survey data complied to date just how strong consumer support for GMOs may be.

One researcher, Sociology Professor Thomas Hoban of North Carolina State University, reports that over the past decade, surveys have consistently shown generally positive attitudes about biotechnology from American consumers. He reports that:

> A variety of surveys . . . asking different questions, have virtually all arrived at the same result . . . between two-thirds and three-fourths of US consumers support biotechnology and are willing to accept food enhanced by biotechnology techniques.[27]

A recent survey by FDA reported that 78% of Americans agreed with current labeling policy, which requires labels only when there is a substantial change in a food's composition. Even when presented with the position of critics of the current policy, 57% still favored current regulations.

But other surveys have found that American consumers express some reservations about biotech. A poll by Novartis in February 1997 found that 93% of consumers felt that GMO foods should be labeled, with 73% indicating that they felt strongly about this. Moreover, few American consumers are aware that biotech foods have already entered their food supply. Consumer awareness of biotech has hovered around 60% to 70% for the last ten years, according to surveys, but only 30% to 40% of consumers describe themselves as knowing more than just "a little" about biotech.

In Europe, major retailers and food companies have taken public stands against GMO foods. No such opposition has emerged from major food industry players in the United States. Thus far, the only major objections to GMO foods have come from organic-food circles – a fairly small market which accounts for less than 2% of total food sales in the United States.

Labeling

The question of labeling foods that may or may not contain GMOs has been very contentious in Europe and may yet crop up in other markets. However, it has yet to emerge as a major issue in the United States. While seemingly a simple issue at first glance, the question of labeling is in fact quite complex and defies easy answers.

The biotech industry's experiences with BST, and the consumer reaction it briefly sparked, served as powerful influences as the industry prepared to release the first wave of crop biotechnology onto the market. After a long battle over the labeling issues surrounding BST, it

27 Thomas J. Hoban, *Consumer Acceptance of Biotechnology: An International Perspective,*" Nature Biotechnology, March 15, 1997.

was finally decided that retail product manufacturers could label their dairy products with wording along the lines of "made with milk from cows not treated with BST" as long as this was not done in such a way as to imply that the product was somehow better for this. Consequently, on products that label themselves as BST-free, one typically sees a disclaimer such as "there is no difference between milk from cows treated with BST and those not treated with BST."

The industry has been largely opposed to labeling, and following the BST example, they successfully supported legislation that made it illegal to label non-GMO foods in such a way as to imply that they were better than foods containing GMOs. However, labeling also could be a positive factor for agricultural biotech, since it allows manufacturers to convey the benefits of products to consumers. Monsanto, for instance, has been running an advertisement campaign in Europe promoting the positive uses and potential of GMO foods, and the UK Safeway grocery chain successfully launched a tomato paste labeled as "genetically modified." The paste, made from tomatoes developed by Zeneca, carried a label with wording to the effect of "genetically modified for superior performance" and has been a success in the franchise's stores.

Labeling of foods with GMOs has been a major issue in Europe, but after more than two years of debate, the complexities of the issue have stymied efforts to find a resolution acceptable to all parties. European consumers feel very strongly they have the right to know whether they are consuming GMOs, and governments as well as consumers have called for food labeling. The EU's Novel Food Regulation requires food processors to label final products that "may contain or may consist" of GMOs. However, as Agriculture Commissioner Franz Fischler has pointed out, this would ultimately lead to nearly all food products being labeled that they "may contain GMOs," which then provides little information to the consumer.

Even if the labeling were required, the question of what products would require labeling is equally difficult. For instance, no genetic material remains in some products such as soybean oil, so they would be truly indistinguishable from their traditional counterparts. Consequently, no labeling would be necessary – but some surveys of European consumers have indicated that they would like such products labeled nonetheless. Would one label meat from a traditional variety cow that had been fed GMOs? After much discussion, European regulatory agencies find themselves still grappling with these questions.

The Opposition: Its Concerns

Opposition to GMO foods has not been nearly as strong in the United States as in Europe, where Greenpeace and other environmental organizations have made it a major issue. Center for Science in the Public Interest (CSPI), the "food police" who have launched campaigns against movie popcorn butter and olestra have not voiced significant opposition to GMO foods, although they called for labeling of GMO foods in a recent letter to the International Association of Consumer Food Organizations. However, several groups – The Campaign for Food Safety (formerly the Pure Food Campaign), The Union of Concerned Scientists, The Alliance for Bio-

Integrity, The Council for Responsible Genetics, and others – have voiced their opposition to genetic engineering of agricultural products. Their concerns with agricultural biotech include[28]:

- Control of plant genetics concentrated in the hands of a few companies;
- New toxins and allergens in foods;
- Other damaging effects on health caused by unnatural foods;
- Increased use of chemicals on crops, resulting in increased contamination of water, food, environment, and animal species – increased incidence of reproductive problems and birth defects, cancer, and other diseases;
- Genetic pollution - accidental introduction of defective genes into the gene pool, weakening species;
- The accidental creation of new plant diseases, new pests, and new weed varieties resistant to herbicides;
- The spread of diseases across species barriers; and
- Disruption of the ecosystem, locally and/or globally, loss of biodiversity, disruption of the food chain and global food supply.

The tryptophan scare in the late 1980s was, in some initial accounts, inaccurately linked to biotechnology. Tainted tryptophan, an amino acid sold as a dietary supplement, killed more than 30 Americans and permanently disabled or afflicted more than 5,000 others with a blood disorder, eosinophilia myalgia syndrome (EMS). The manufacturer, Showa Denko K.K., Japan's third largest chemical company, had used a strain of the B. amyloliquefaciens bacteria which was genetically engineered to produce greater amounts of tryptophan.

However, the company reduced the amount of carbon used to filter out impurities from the final product, and this was the likely culprit behind the EMS cases. Studies have shown that the disease-causing molecule only appears during purification, and cases of EMS have been linked to L-tryptophan produced long before the use of the genetically-engineered bacterium. Nevertheless, some papers carried stories equating genetic engineering of foodstuffs with death and disability, and these images have remained with opponents of biotech until this day.

28 *Health and Environmental Risks,* Students for Alternatives to Genetic Engineering (SAGE).

VII. The Biotech Revolution: Overarching Implications

Business Restructuring

The biotech revolution emerges at a time when economic and other forces already are precipitating a tremendous restructuring of the agriculture and food industries all around the world. If the evidence to date is any guide, biotechnology could well accelerate and expand both the pace and breadth of the reorganization of the global food system.

Consolidation to achieve economies of size and operation long has been evident in the food system, and continues, at varying paces depending upon the component or segment of the food system.

The broiler industry long ago industrialized.

The pork industry today approaches 50% of output from integrated, large-scale facilities.

Dairy is moving rapidly to exploit the economies available, resulting both in major geographic shifts in location of production as well as very significant increases in the size of farms.

The beef industry also moves to capture benefits of integration demonstrated by the broiler and other industries.

The cooperative sector too is experiencing a tremendous restructuring, reflecting the structural shifts among its membership.

Recent Cooperative Mergers and Alliances

Just as in the biotechnology field, the number of mergers and alliances among and between cooperatives has been occurring at a rapid pace. Some this year that are noteworthy include:

Dairy Farmers of America formed January 1, 1998 by the consolidation of four regional dairy marketing cooperatives: Associated Milk Producers Inc. (AMPI) Southern Region; Mid-America Dairymen Inc. (Mid-Am); Milk Marketing Inc. (MMI); and Western Dairymen Cooperative Inc. (WDCI). The new cooperative has 22,000 members in 42 states, and markets more than 38 billion pounds of milk.

ConAgra, Inc. and Farmland Industries, Inc. form a grain-based alliance to improve both companies' services to farmers and grain marketing and export activities. The new alliance will consist of two entities, Concourse Grain, LLC and Farmland-Atwood, LLC. Concourse Grain will market wheat originated by Farmland and certain wheat originated by ConAgra. The alliance will enable domestic and global wheat customers to access multiple classes of wheat, and international customers to be served from multiple US export points.

Cenex, Inc. and Harvest States Cooperatives merged to form Cenex Harvest States Cooperatives. Cenex brings 1,400 local petroleum and farm supply cooperatives and Harvest States brings 540 local cooperatives and 44,000 direct farmer-members to the new organization. The unified membership extends virtually across the entire country. The new organization's operations cover the farm-to-market chain, through products and services that include agronomy, petroleum, grain marketing, feeds, wheat milling, oilseed processing and refining, and food manufacturing and distribution.

Countrymark Co-op, Land O'Lakes complete unification of businesses, form alliance with Growmark Land O'Lakes and Countrymark Co-op recently completed an asset transfer that unifies several businesses operated by the two cooperatives. And, Land O'Lakes, Countrymark Co-op and Growmark formed alliances affecting portions of their seed, feed and energy businesses. The ventures in the energy business involve all three cooperatives; the feed and seed ventures involve only Growmark and Land O'Lakes.

Other alliances announced this year include:

Farmland Industries and AGRIS Corporation form joint venture
Southern States Purchases Gold Kist's Farm Supply System
Land O'Lakes and Dairyman's Cooperative Creamery Association Merge
Land O'Lakes, Harvest States form joint venture in feed
Farmland and SF Services announce merger
Farmland and Farmers Petroleum Cooperative Announce Intent to merge
Farmland Industries, Cenex Harvest States launch Country Energy
Agrilink Foods completes acquisition of Dean Foods Vegetable
MFA Incorporated & Farmland Industries, Inc. consider feed manufacturing and livestock
marketing alliance in Missouri

A new breed of cooperatives also began to appear this year – processing and adding value to commodities and providing new sources of income for their farmer and rancher members by providing an ownership stake farther along the food chain.

Often organized as "closed-membership" cooperatives, they are focused on expanding income by adding value to commodities and paying dividends to their owners, rather than providing services and products for members. In addition to cash investment, they often require a commitment by producer-owners to deliver specified amounts of raw commodities – crops or livestock – each year. The businesses also carry risk because they often enter highly competitive markets, sometimes with new products.

Biotechnology-driven restructuring now appears as an *overlay* to this already-dynamic scene – the activity to date has been centered in the farm inputs component of the food system, but there is ample reason to suggest that this is but early activity in what could become a wholesale restructuring of the food system.

Novartis-LOL Alliance

Novartis Seeds, Inc. and Land O'Lakes, Inc., recently announced formation of a joint venture to focus resources on specialty corn hybrids for the food and feed markets, marking Novartis Seeds' first major entry into the specialty grains business for food and feed.

Novartis will purchase a 50% interest in Wilson Seeds, Inc., an independently operated company owned by Land O'Lakes. Wilson Seeds recently purchased Zimmerman Hybrids, of Evansville, Ind., a leading developer of white corn hybrids, which also is now included in the new joint venture.

In addition, the white corn genetics of Sturdy Grow Hybrids, a breeding company in Arcola, Ill., also will be licensed to the joint venture through Novartis Seeds. Novartis Seeds and Sturdy Grow struck an agreement in March 1998 resulting in the introduction of the first white corn hybrid with the Bt trait, NK Brand N71-T7.

The product line will combine genetic traits for specialty crops with unique properties produced through biotechnology. Wilson Seeds, formed in 1926, has focused its breeding efforts on corn hybrids for food and feed since 1984 and currently sells about a dozen white corn hybrids.

The joint venture will utilize Land O'Lakes' marketing expertise, Novartis Seeds' research and technology, and Wilson Seeds access to the specialty grain arena.

The restructuring thus far largely has been among biotechnology companies – those who developed it – seeking both to augment it (fill in gaps, broaden the base, etc.) through acquisitions, and to guarantee a means for delivery (seed companies with farm/rural distribution networks). The box below illustrates many of the key alliances and mergers that have taken place in recent years. (Appendix A provides a detailed chronology of the mergers, acquisitions and strategic alliances that have occurred throughout the industry.)

Key Mergers, Acquisitions and Alliances

1994 American Home Products buys American Cyanamid for about $9.7 billion.

1995 Monsanto purchases share of Calgene.
Pioneer buys stake in Mycogen for $51 million.

1996 DowElanco purchases interest in Mycogen for $126 million and purchases 15%
directly from Mycogen for $26 million plus its United AgriSeeds business unit.
Monsanto purchases Agracetus from WR Grace for $150 million.
Monsanto agrees to acquire Asgrow for $240 million.
Monsanto gains 55% of Calgene, Inc.

**1997 Monsanto agrees to buy Holden's Foundation Seeds, Corn States Hybrid Services,
and Corn States International** for $1.02 billion.
DuPont, Pioneer agree to form a research alliance and separate joint venture company (Optimum Quality Grains). DuPont invests $1.7 billion in Pioneer, owning 20% of its stock.
DuPont Buys Ralston Purina's Protein Technologies International in a $1.5 billion deal – Protein Technologies International supplies about 75% of the worldwide market for soy proteins used in processed foods.
Monsanto spins-off chemical units into Solutia, Inc.
Novartis AG acquires ag chemical business of Merck and Co.
Rhone-Poulenc announces plans to transform itself into a "life sciences" company. It plans to spin off its chemicals, fibers and polymers businesses into a new company.
Monsanto acquires control of Sementes Agroceres SA, the leading seed corn company in Brazil.

**1998 ABS Global forms strategic partnership with Infigen, Inc. and Pharming Holding
NV** to develop cattle breeding technologies and biopharmaceutical production in cows' milk. The partnership will develop herds of transgenic cattle capable of producing various pharmaceutical products.
Dow AgroSciences increases its stake in Mycogen to 63% in exchange for $75 million.
Monsanto enters into broad technology agreement with GeneTrace to investigate the genomes of plants and animals – a $17.2 million deal.

The pioneering companies have revealed glimpses of their strategies – e.g., Monsanto ("farmgate to dinner plate"), DuPont ("dirt to dinner"). Not long ago, Monsanto and DuPont were primarily considered chemical companies. Now they are transforming themselves into "life sciences" companies and spending billions of dollars on research, technology and other biotechnology assets. Through direct investment and alliances, the two companies are gaining control of seed producers for most major US crops. Despite Monsanto's lead in controlling technology for and developing products in the first wave of biotech crops, DuPont has focused its attentions farther down the food chain. Eventually, DuPont hopes to be able to take orders from food companies for new crop or food products, create the product in their laboratories, contract with farmers to grow the product and then process it into a food ingredient. This merger evidence thus far does give some notion of what the **drivers** are. Appendix B provides details on the business strategies of many key players in agricultural biotechnology.

Monsanto

Strategy

Based in St. Louis, Missouri, Monsanto was a large player in the chemicals business. But it has been rapidly reinventing itself in the last few years as a "life sciences" company specializing in the business of biotechnology. For the last decade, the name Monsanto has been mainly synonymous with two blockbuster products: the artificial sweetener Nutrasweet and the Roundup herbicide. Nutrasweet was acquired as part of the takeover of pharmaceutical company GD Searle in 1985. Roundup is the most successful product to come out of Monsanto's agriculture division, started in 1960.

In the mid-1980s, Monsanto's president Richard Mahoney decided to turn it into a life sciences company. That meant focusing on three areas: agricultural products, food ingredients, and medicine. Mahoney started selling off businesses that did not fit into that strategy, culminating in the spin-off of the remaining chemical business into a new company, Solutia, early last year.

Bob Shapiro took over as president in 1993, and started buying again, targeting seed companies. Monsanto has spent over $8 billion acquiring seed and agricultural biotechnology companies since 1996. In 1996, Monsanto entered into an agreement for 49.9% equity interest in Calgene, a biotechnology company that develops genetically engineered plants and plant products for the food, seed and oleochemical industries. In 1997, Monsanto made Calgene a wholly-owned subsidiary by acquiring all of the company's outstanding shares. Over the last 12 months, Monsanto also paid $4 billion for two companies that were involved in creating new seed varieties, DeKalb Genetics and Delta & Pine Land, the world's largest cotton seed company. Monsanto spent another $1.4 billion for the international seed operations of Cargill. And, in July Monsanto bought UK-based Plant Breeding International from Unilever for another $525 million.

Monsanto also made several strategic acquisitions of agricultural seed companies in 1997. The company completed the acquisition of Asgrow in February. In September, Monsanto completed the acquisitions of Holden's and Corn States Hybrid Service Inc. In December, the company acquired a controlling interest in Agroceres. It is anticipated that Monsanto will make additional alliances and collaborations with, and acquisitions of, other seed companies to enhance its ability to bring new products to market and to gain worldwide distribution of its numerous agricultural products currently being marketed or in the product pipeline.

Monsanto's acquisition of seed companies is driven by its quest to sell proprietary, genetically engineered traits in the global market. The seed business is the vehicle to deliver the technology. In the United States, Monsanto now holds 85% of the cotton seed market, 33% market share in soybeans, and 15% of the corn seed business. In its ability to merge the seed and crop protection chemicals industries, Monsanto has leveraged biotechnology to created significant new customer benefits not possible through either the seed or chemical industries individually.

The biotech revolution "stakes" – discussed earlier – are enormous, and distributed throughout the food system – not just confined to one segment. The biotech companies developing the means for expanding value so thoroughly across the system are not content to not participate in "capturing" more of that added value. But, to do that requires more active involvement – from ownership to allegiances and alliances, at least – i.e., the "dirt to dinner" strategy now driven from the "inputs end" ("left end") of the food chain.

One of the basic questions of the business restructuring is whether it will continue to be driven from the "inputs" side or the "consumer" side. From the "left" side would suggest that the companies that have developed the new technology will move to advance their control on through the food system – that they will move from segment to segment across the food chain (literally, "dirt to dinner"). This would entail "life sciences" companies becoming food processors, marketers, financiers, and food retailing companies, if much of the added value is to be captured or controlled. How they would accomplish that – in traditional ways such as "vertical integration" through acquisition or more modern arrangements such as strategic alliances, partnerships, etc. – remains to be seen.

Or, whether the "right" (consumer) side of the food system becomes energized and begins to exert influence "backward" through the food chain now is an open question. To date, little of such movement has been seen, despite its apparent logic. Food companies, close in the marketing chain to the consumer, follow changes in consumer tastes and preferences and shifting habits, and would seem the logical place to discern the products that consumers want, and then to "message" those requirements "back" through the system to the food manufacturers and "component producers." While little such transmission from "dinner to dirt" is yet evident, it likely will come as more of the possibilities of biotechnology become evident.

The "Dirt to Dinner" Strategy – Exemplified by DuPont

DuPont	Seed	Chemicals	Contract	Value Enhanced	Processing	Consumer
	Pioneer	DuPont	Optimum Quality	Optimum Quality	Protein	Nutritious Foods

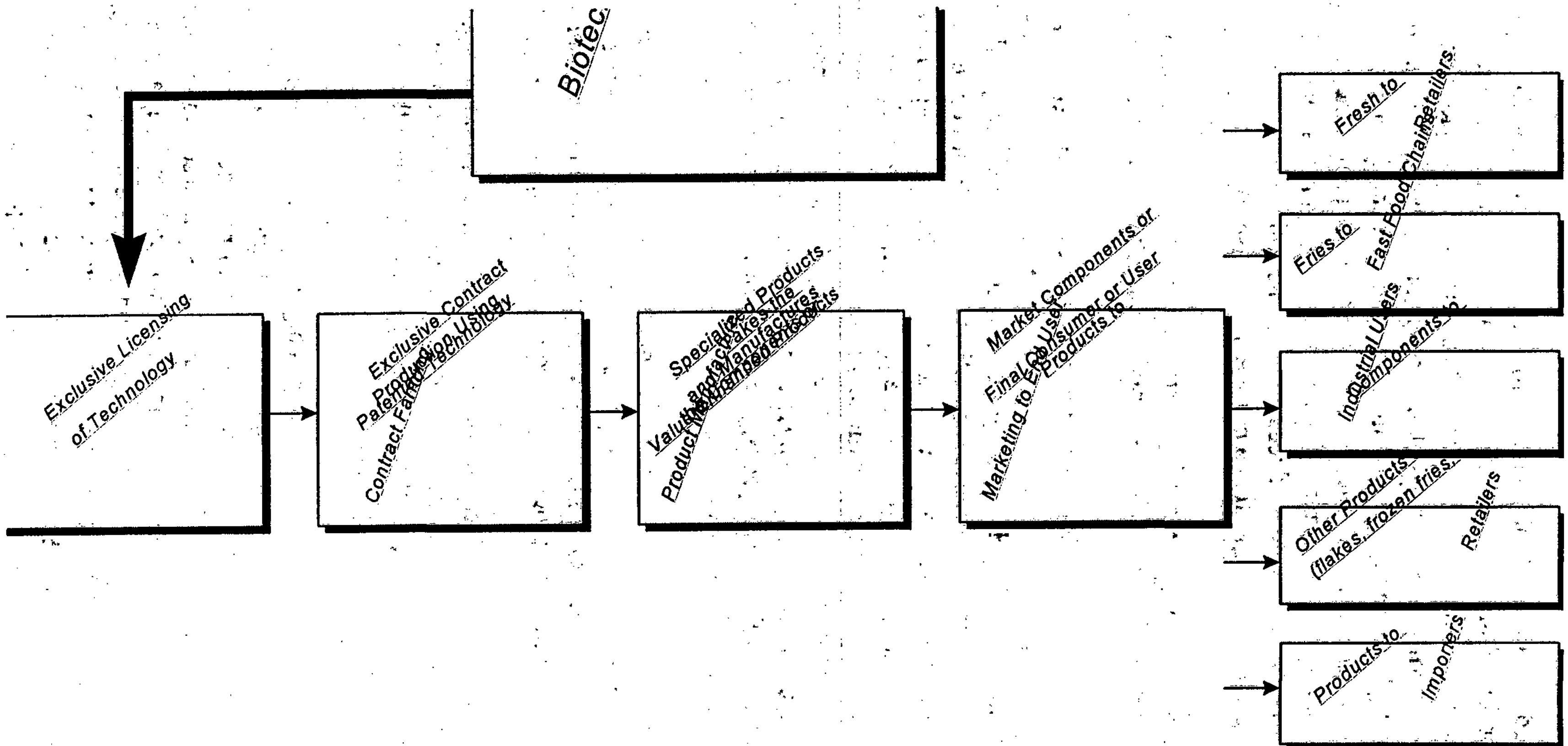
This combination of E. I. DuPont de Nemours, Pioneer Hi-Bred International, Optimum Quality Grains, Protein Technologies International, and Nutritious Foods touches, if not saturates, all points from input supplier to consumer. The commodity/product base may be thin, but it could be expanded.

There is considerable interest in how any eventual restructuring of the food industry may occur, and what the implications could be. Numerous concerns abound, and include:

Concentration of economic/market power in just a few major companies, the originators of the new technology products and the companies with whom they may choose to align themselves. This is perhaps the most widely voiced concern and raises numerous other questions. Will the initiating input companies move to expand their activity to encompass the entire food system? Will this "reach" be broad-based across all food groups and products – or will some companies specialize in one or a very few commodities. (Could a technology company utilize the new technology for one crop – say potatoes – and then through acquisitions, alliances or partnerships control all aspects from raw material through food manufacture for that crop?) By refusing to license the technology to others, it could effectively control the entire food chain for this particular crop product (Chart 9).

Will the food industry be dominated by a few companies controlling the production and manufacture of specific crops and resulting products? For example, might one technology company with partner acquisitions, alliances, etc. control potatoes (say) throughout, another control other vegetables, another oilseeds and products, another grains, etc., so that no more than a half dozen or so companies have effective control? What happens to other companies who are not part of the technology company alliance? Are they left out completely, or if not, might they have to accept unfavorable terms to be included?

Chart 9. An Example New Structure for the Food and Agriculture System (Potatoes)



Such a forward or backward integration across all segments of the food system, whether through acquisitions or formal alliances of various sorts, would produce *a new structure*. The food system long was characterized by a series of discrete "arms-length" transactions with commodity or product ownership transferring several times. Farmers bought inputs from their suppliers, produced their crop and livestock commodities, and then sold them at the farmgate. They thus relinquished ownership at that point and had no further involvement with them as the raw material moved through the system becoming a food product. The commodity typically was assembled by a "first handler" and then sold to processors who produced components which moved to food manufacturers and on to retail (with each change reflecting a change of ownership).

New structures likely will be much different – many of the "arms length" transactions may disappear, shortening the entire chain and perhaps involving far fewer players.

Impacts on Markets and Marketing

The concept of the marketing chain for agriculture and food products is well known and understood – and, the large investments of the past in US marketing infrastructure are very important in the system's overall efficiency. Every year, millions of tons of food commodities are produced, assembled through facilities designed on the basis of efficiency (and, to protect the product, avoid contamination and to meet other specific requirements), stored to permit orderly product flows to processors and then through wholesale and retail facilities and into consumption, both in the United States and abroad. The system has evolved to meet specific characteristics of current products and processes. And, as both are changed by biotechnology, the system and the services it provides at each level will change dramatically.

How much these systems and services will change depends, of course, upon how drastically the commodities are changed and how great additional service requirements become. For commodities that are currently handled, stored and processed in bulk at very low cost, a change in characteristics so that separate handling and processing is required could mean a huge change in the system.

The current system serves bulk commodities very efficiently and other products much less so, but there are many types of products marketed that require more or different levels of services and have quite different costs. Examples of differences can be seen when the system's key functions are examined specifically.

Assembly/Storage. The bulk system is highly efficient, assembling products from millions of farms for storage, shipment, and processing. There are high levels of competition between cooperatives and private firms to provide assembly services, and costs are highly transparent. Virtually each delivery is priced separately with low transaction costs since the products are highly fungible, grade and standards are clear and well known, the markets are large and highly liquid and the price discovery system (based heavily on futures markets) is transparent. Risks associated with inventories or delivery contracts of either commodities or products are minimal and risk management procedures well defined.

How different the assembly/storage function is for biotech products depends on the changes produced. For products with changes in production cost or yield only, changes in marketing will be minimal.[29] However, for products for which the processing (or other) value has been sharply increased although the product appears little changed, the marketing requirements likely will be very different.

For example, corn products that have been transformed into significantly more valuable products will require physical segregation, as well as additional testing to establish their characteristics. Then, that corn will require special protection as it moves through the system to be sure that it is not replaced by "normal" corn, and, in some cases, that the value enhanced corn does not "pollute" the stock of commodity corn. Costs of these extra services are much higher, depending, in part, on the number and difficulty of tests that must be made, the extent to which containers (or other storage units) be sealed and certified, and other special protections to preserve some special attribute of the product.

Grain typically is sold subject to tests for moisture, foreign matter and other "normal" standards. In addition, value enhanced corn will require special tests to determine the extent to which the value added characteristics are present, and be subject to an additional system of discounts or premiums – likely specific in the production contract. Once these markets develop nationally, special definitions, grades and standards likely will develop, as well. However, at present, value enhanced categories likely are highly ambiguous, lack grades and standards and have more volatile premium and discount structures.

Transactions/Costs. While much of the concern about impacts of biotechnology on the marketing system has focused on the high cost of identity-preserved marketing, the additional marketing services required for transactions likely will be costly as well – in part, because of the requirement for additional services, and partly because the current system for fungible commodities has such extremely low costs.

The current system transfers ownership and manages risk in a large number of ways, including spot sales, contracts for future deliveries at specific locations, contracts for the delivery of warehouse receipts, and many others. Price risk is managed through well established and understood procedures. Prices are highly sensitive to actual or anticipated shifts in supply and demand, and markets tend to be highly liquid and

[29] This assumes no segregation requirement on the basis of the biotechnology process used to increase yield or reduce costs. If overseas markets require segregation of products that are produced using certain biotechnology processes, the additional costs will raise questions of whether or not those specific biotechnologies will be used extensively. And, the labeling/handling requirements imposed in thosemarkets will define the additional levels of services required at each point in the marketing chain.

extremely transparent. Market information is widely available from both public and commercial sources.

Marketing transactions for biotech products with little or only modest changes in characteristics likely will be unchanged. However, for value enhanced commodities, marketing transactions likely will require a modified market channel that requires greater amounts of services and is more costly, with the amount of the cost depending both on the amount of services required and the efficiency of the new market channel.

Other Functions – Storage, Transportation, Processing, Wholesaling and Retailing. For each of these services, costs likely will be unchanged for biotech products that are themselves little changed, but significantly higher for those with value enhanced characteristics. And, the increase in marketing costs will depend on the changes made and the amount of additional services required. A key factor in the increase is the extent to which identity preservation is required, and to which increased protection is required. In general, each of these costs likely will be increased significantly throughout the system.

Observations

There are many instances in our markets in which **generic** and **characteristic-specific** commodities are handled side-by-side. In some cases, identical products face separate markets that depend on different uses. For example, milk, fruit and vegetable market orders separate markets for fresh and processed products. Producers focus, at least initially on the "premium" market, usually for fresh (or fluid) products and expect to divert the balance of their output to a "secondary" market, usually the market for processed products. They sometimes limit production to the needs of the premium market (depending on premiums and production costs), but frequently have produced premium-eligible product far beyond market needs, and have profitable sales in both markets. While the marketing requirements for the different markets are unique, the product that is sent to the bottler or the cheese maker in market order areas has come to be identical (although, it once was different and processed products once came from Class B milk). Thus, the market order example is unique, since the market separations are managed in conformity with federal regulations and product use, rather than well-defined demand requirements for commodity characteristics.

Markets defined separately for systems for similar products include food-quality feed grains, especially white corn, high starch and high oil corn, malting barley, food quality oats and others. Food quality soybeans destined for markets in Japan are another example. Organically-grown commodities provide another example (especially vegetables, but other commodities, as well) of side-by-side markets for quite similar products with differences in characteristics. In fact, many fruit and vegetable commodities are produced to rigid specifications (variety, time of planting, cultural practices, harvest processes and timing, etc.) For those commodities, the growth of markets for tailor-made commodities implies relatively small changes.

For other commodities where there are few changes in cultural practices, but major changes in the value of the commodity produced, it still is likely producers will produce first for specific "premium" markets, primarily under contract – but, if premiums are large, likely will produce additional amounts "on speculation" as now is done under the market orders.

Food Quality Soybean Example

In Japan, "food quality" soybeans are used to make a variety of specialty food products, and very white, large soybeans with increased protein levels produce greater amounts of higher quality soy foods. Soybeans for food purposes originally came from China, and Chinese varieties continue to be prized for this purpose. However, Chinese domestic markets have grown to the point where declining amounts are available for export. Japanese importers have increasingly turned to US producers, and prefer US soybeans over Latin American beans for this purpose. And, importers greatly prefer to import soybeans and process them, rather than import processed products.

Three, somewhat separate market channels have developed for food quality soybeans as a result:

Selections in Japan, the result of repeated selection and cleaning processes in Japan from US run-of-the-mill No. 2 yellow soybeans (or higher). The largest, whitest beans are then processed into food products for the domestic markets. This approach also is used (almost exclusively) in Korea, Taiwan and other markets that produce large quantities of oriental, soy-based foods.

Selections in the United States – the IOM market. Soybeans produced in more than 60 counties in Indiana, Ohio and Michigan have higher protein, less oil, somewhat larger beans and whiter color than other US soybeans. A number of firms routinely clean, select and isolate beans from these areas for the Japanese market. The selected beans are then shipped to Japan, where they are again evaluated on the basis of Japanese market criteria. Those selected receive very substantial premiums above run-of-the-mill soybeans, while those rejected are sold locally. While the premiums tend to be significant, they go to the selecting shipper. Producers typically do not receive premiums for IOM soybeans selected for shipment.

Contract production. In the western soybean belt, significant amounts of soybeans are produced under contract for Japanese food markets, (and, for local processing into food products for oriental markets). Contracts vary widely, but tend to specify cultural and handling practices, sometimes specify varieties, and include other constraints.[30] Variety specifications are especially important because yields can be affected, and lower-yielding varieties command higher premiums. In many cases, contracts prohibit pesticides and some require organic production and handling practices. Contracts tend to vary widely, and premiums vary widely, as well. Contract terms frequently are based on local market prices for soybeans, with specific premiums. In recent years, when generic soybean prices were high, the low yields of food quality soybean varieties led to very high premiums. Producers observe that the costs of meeting contract specifications are high and that high premiums are required to stimulate production. The availability of information about this market, practices used and other key trends is low.

The food quality soybean example highlights the difficulty of providing efficient marketing services to a market that is relatively small in size, that demands costly services in both production and marketing (IP, selection, specific variety use, specific cultural practices) and for which market premiums are not easily evaluated. As a result, it is likely that producers will initially require relatively high premiums for the production to specification of characteristic-specific products.

Risk Management

A key uncertainty regarding the likely transition to characteristic-specific commodities is the management of risks of several kinds. The most basic risk is price risk. Today's large, highly liquid markets with their transparent price discovery process permit very low risk premiums and high levels of marketing efficiency. Modified marketing channels for characteristic specific commodities likely will be able to define a stable basis with generic commodities in most cases, and continue to manage inventory and contract delivery risks through the use of new approaches to well established mechanisms – futures contracts, options and others. However, as characteristic-specific products become more important and generic markets become less important, new approaches to manage risk even in these large markets will be needed.

As markets for designer-type crops become better differentiated (either in terms of premiums relative to the basic commodity, or in terms of markets for the starch, protein, or other designer component), producers in several studies indicate that they will increasingly use contracts to insure that their higher costs of production of these products are covered. Costs include the risk of falling short of the specifications for the designer crop, lower yields (from seeds produced for designer qualities, rather than simply for yield), higher agronomic costs (e.g., better weed control), requirements for cleaner, more uniform products of specified color, etc., and required levels of protein, starch, oil, etc.

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[30] In spite of their general apprehension about the need for higher skills to manage contract risks, commercial producers interviewed in a number of studies tend to find the contracting process quite manageable, and to be familiar with it. They believe such commitments reduce risk if they are well designed, and based on a careful risk audit. However, the use of contracts is believed to significantly alter traditional relationships among producers, landlords, lenders, suppliers, custom operators, and other service suppliers in favor of producers, but does so at an additional cost in terms of much greater management cost and complexity.

Both production and marketing of trait-specific crops is seen as more expensive and requiring much greater coordination and planning and much more information than undifferentiated bulk commodities. Major concerns include whether premiums available will cover costs, and the need to "lock-in" sufficient margins before beginning the production process.

For example, four general types of contracts (and a very large number of variations on each) are commonly mentioned for use with grain production:

marketing (or sales);
bailment production agreements;[31]
personal service contracts; and
pool contracts with a closed cooperative.

Marketing contracts involve a firm agreement to accept or deliver a specified quantity of the crop, and are widely used with a large number of variations. Key characteristics are normally described (with tolerances), along with agronomic, storage, and other requirements. Pricing is typically established prior to production, but may be pegged to the commodity market with a premium. Bailment contracts are distinguished by the fact that the contractor provides the seed (and, possibly, other inputs and retains ownership of the output). Pool contracts with a closed cooperative are generally sales contracts involving delivery by the producer to a closed cooperative facility jointly owned and operated by a group of producers for the purpose of adding value to the raw product. These cooperatives typically require the purchase of equity instruments by each producer in direct proportion to that producer's rights and commitment to deliver under the contract.

As producers move to apply new technologies to meet the needs of new markets for designer (or merely modified) products, key considerations include:

Marketing Relationships: Once a producer executes a contract for his product or services, a new relationship is forged. Key dimensions of change involve:

title to the crop;
eligibility for federal crop insurance and farm program provisions;
rights in the event of a contract breach;
assumption of physical and quality risks during production and after harvest;
security interests in the crop produced; and
rights of landlords under crop sharing.

[31] Bailment production contracts are arrangements where the contractor typically provides seeds with a specific genetic trait to the farmer. Title of the growing crop and the finished product belongs to the contractor, while the producer cultivates (according to specifications) the crop on behalf of the contractor. The contractor provides most of the non-land production inputs through personal service contracts. These fee contracts sometimes involve more management decision-making from the contractor. The contractor is providing compensation to the producer for the use of land, labor and machinery.

Yield Implications. Many specialty grains have lower yields than do traditional crops or are susceptible to greater production risks from weather, insects or other sources than standard varieties. Premiums need to be large enough to compensate for any likely differences in yield. Such contracts also tend to delineate the responsibility of both the contractor and producer in the case of yield losses.

Grower Obligations for Quantity. The producer's obligation to deliver a specified quantity also may be a source of risk. Producers should be aware of how shortfalls or excess production frequently are outlined in the contract. Payment penalties for a shortfall could reduce premium payments and even returns well below that which could be achieved in the commodity market. Quantity-oriented contracts that require the producer to locate substitute product involves more risk, especially if the producer assumes "Act of God" production risks, such as natural disasters which are beyond the producer's control.

Grower Obligations for Quality. In most cases, quality standards for moisture, foreign matter, test weight and condition must be met along with the specific trait in the crop (i.e. oil content in high oil corn). Quality is determined by a combination of producers' crop management techniques, genetics, and the normal "Acts of God" that may occur. Penalties may be set for quality problems that are directly related to the producer's practices and are thereby under his direct control. Insurance costs and other maintenance expenses should be specified in the contract and cover the growing, harvest, and post-harvest periods.

Transfer of Ownership. In some cases, title to the grain is held by the contractor and in other cases by the producer. In the latter, ownership risk is present during the production process and potentially during the storage period. Contracts include the definition of the point when ownership is then transferred from the producer to the contractor to understand when the risk is terminated.

Tomorrow's Markets

This advent and growth of markets for specialty, designer-type commodities implies an increasingly market oriented sector, newly released from the constraints of more than 60 years of stringent government programs and regulations. The sector also can expect:

Somewhat greater price volatility as public stockholding is ended, and government intervention is reduced, including annual land idling programs.

Better markets at home and abroad, and better access to foreign markets as current agreements are better enforced and new trade agreements negotiated.

Growing total markets and possibly higher <u>real</u> prices as market needs come to dominate the sector's outlook, replacing the supply surplus orientation that characterized most of the post World War II period.

To an important extent, the technology and market trends are requiring their increasing integration into the production/processing system. Key trends include:

Consumers' rapidly growing demands for product specifications, based on key components (protein, fat, fiber, etc.) and their low tolerance for lack of quality, uniformity or consistency. In the future, far more than in the past, the consumer will be king. This has not affected farmers much in the past when concerns about consumers' preferences were left primarily to processors, and farmers sold commodities. In the future, understanding and satisfying end-user needs will be increasingly important, and will require much greater coordination throughout.

Rapidly growing emphasis on food safety, and legal requirements for accountability and control of processing, storage and treatment applications at each level.

Processor willingness to offer premiums only for commodities that meet increasingly precise specifications.

Information Needs

Farming will be more complex and more technical in the future, and commercial operations will require highly sophisticated knowledge about factors and forces off the farm in much more detail as they plan and manage their operations. One major response to this need is the development and reliance on teams of highly skilled managers, rather than single decision makers, much as is done throughout agribusiness. A second is the increasing reliance on private, commercial information providers.

Knowledge and information will have a more important future role in maintaining effective control of farming operations and in transferring risk, for at least two key reasons. First, producers will need far more information to manage their operations and to deal with their ever-more complex production and marketing systems, and those with the most technical information and knowledge have very large comparative advantages. Second, the dramatic expansion in the use of chemical, biological, and physical processes involved in production has increased both the need and value of information to producers. The ability to understand and utilize new genetically altered or value enhanced crops and technology like precision farming is a strong advantage in agricultural production.

Because of the large and growing value of information and the expanding role of the private sector in providing it, the role of information in the competition for market share also is expanding rapidly, and will continue to do so in the future, especially for new (and even more technical) products. To compete for sales to commercial farmers, the provision of highly specific information (and, increasingly, technical assistance) in the application, use and management of new products will be required. In addition, the suppliers who are able to provide this information convincingly are likely to gain a significant market advantage as a result.

Implications for International Trade Policy

The WTO and Phytosanitary Standards

One of the major breakthroughs in the last round of GATT/WTO negotiations was the agreement on Sanitary and Phytosanitary Measures (SPS). The SPS agreement codified for the first time the principle that such measures should be used only in response to legitimate health or scientific concerns. It states that phytosanitary trade barriers should be "applied only to the extent necessary to protect human, animal or plant life or health . . . based on scientific principles and . . . not maintained without sufficient scientific evidence."[32] It was widely believed that this agreement would at last allow for an objective system of evaluating the scientific basis behind phytosanitary trade barriers. And coupled with the WTO's added power to enforce decisions, it seemed that the days of import bans based on dubious health concerns might be over.

However, the picture was clouded considerably by the WTO dispute settlement panel's recent ruling in the US/EU case over hormone-treated beef. The decision left both sides claiming victory for different reasons. The panel reiterated that bans such as the EU ban on hormones were allowable only if used for health reasons, not if they were implemented for trade reasons. It affirmed that there must be a scientific basis for any food safety standards and found that the EU had not shown sufficient scientific justification for its ban, seemingly siding with the United States and Canada in the dispute. However, it also agreed with the EU that member states could have the right to establish, on a scientific basis, levels of consumer protection that are higher than prevailing international health standards. There has not yet been a test case in the WTO over GMOs or similar agricultural biotech products, and it seems increasingly uncertain how the WTO would rule.

If the WTO fails to live up to its initial promise of allowing for purely scientific decisions in SPS disputes and ending the use of SPS measures as trade barriers, how else could this goal be accomplished? Rules and agreements through Codex Alimentarius could be one answer, although the Codex Commission has not yet considered any measures pertaining to GMO foods. Given that the majority of Codex members are developing countries, where biotech development and adoption have been relatively slow, the problem is not likely to be resolved through Codex any time soon. A new multilateral organization could be formed to take up the issues of GMO approval, regulatory harmonization, and/or risk assessment – but as long as individual members assert the right to reject products based on non-scientific factors, any such organization would have no more power than the

[32] Article 2, Paragraph 2, *Agreement on the Application of Sanitary and Phytosanitary Measures,* World Trade Organization.

current WTO dispute resolution mechanism.

The multiplicity of national approval processes – and the lack of an overarching multilateral approval process – becomes a more acute problem when GMO crops are approved in one country but not in others. This has been the case with several GMO crops this year that are being grown in the United States but have yet to be approved in Europe or other markets. The EU has made it clear that trade could be severely disrupted if unapproved crops are not segregated from traditional and approved GMO varieties.

Unfortunately, neither side in this debate has shown considerable willingness to compromise. Rather than wait for EU approval before planting new GMO crops, the United States has planted the crops and urged the EU to speed up its approval process.[33] The EU considers these actions to be an attempt to force GMOs on an increasingly skeptical European public, and has hinted that it may hold a moratorium on new GMO approvals. Without a multilateral means of solving this type of dispute, many more are likely to appear. The problem could become much more acute if this problem becomes a severe hindrance to trade, or if a crop were judged safe by one country but deemed unsafe in another.

The Regulatory Approval Process

Canada. The Canadian Food Inspection Agency (CFIA) is the lead agency responsible for regulation of agricultural products, but other agencies also are involved in the approval process. Health Canada reviews novel foods for food safety and sets data requirements for safety and risk assessments of all foods. It also identifies hazards and specifies the standards that food inspectors observe. The Pest Management Regulatory Agency (PMRA), a unit of Health Canada, has responsibility for registration and regulation of pest control products, and it evaluates products that have pesticidal properties. Environment Canada works with regulatory agencies to help develop standards for products that may affect the environment, and Agriculture and Agri-Food Canada performs risk assessments for new types of products.

The CFIA governs novel foods based on guidelines consistent with those used by international authorities. Its main principles are:

To build on current legislation where possible, rather than to create new legislation for new products.

To focus on product characteristics rather than the method of production. Currently, all products developed through recombinant DNA technology are evaluated for unintended

[33] The United States has begun to show some flexibility on the situation, as trade associations such as the North American Export Grain Association have begun to call on biotech companies to hold off on the widespread release of new GMOs until they are approved in the EU (see Reuters, *US Grain Exporters Fault Seed Companies on Genetic Mess,* 1998).

effects that may result from the introduction of new genes or DNA sequences.

To conduct evaluations for each product on the basis of its unique characteristics and to establish appropriate safety levels based on the best scientific information. The Agency considers products safe if they fall below an acceptable risk level, a level not defined as the complete absence of risk.

Products that are either new ("not familiar", i.e. bearing little resemblance to existing products) or judged to be not substantially equivalent to existing products are forwarded to Agriculture and Agri-Food Canada for a risk assessment. Once the risk assessment is complete, or if it is not needed, the product would be registered by CFIA and sent to Health Canada for a food safety assessment by Health Canada, if one were deemed necessary. It also would be forwarded to PMRA and/or Environment Canada if necessary. Once this process is complete and the product has been approved, it can be commercialized.

Government policy on the labeling of novel foods is based on the following principles:

- Require mandatory labeling if there is a health or safety concern, i.e. from allergens or a significant nutrient or compositional change (these decisions are made by Health Canada).

- Ensure labeling is understandable, truthful and not misleading.

- Permit voluntary positive labeling on the condition that the claim is not misleading or deceptive and the claim itself is factual.

- Permit voluntary negative labeling on the condition that the claim is not misleading or deceptive and the claim itself is factual.

Japan. In Japan, the approval process for GMO crops differs based on whether the crop is intended for human or animal consumption. In all cases, however, the first step in the process is a review by the Ministry of Agriculture (MoA) to determine whether the product could have an impact on the environment. This review seeks to answer questions such as:

- Could the GMO spread through pollination?

- If the product has a pesticide or other such trait, how will it affect other parts of the food chain?

If the product is intended for animal consumption, the MoA will then evaluate the safety of the product, and its effects on livestock. After this review is complete, the MoA will then approve or disapprove the crop. If the product is intended for human consumption, the Ministry of Health & Welfare (MoHW) and the Council for Food Safety will conduct an evaluation. The MoHW will test the product and obtain data regarding various aspects pertaining to human consumption – digestion, metabolic effects, toxicity, etc. Once the tests are complete, the Council for Food Safety will evaluate the data and make a recommendation to the MoHW, which has the final say in approving the product.

The Japanese government currently is considering the issue of labeling food products containing GMOs. The MoA established an advisory council last year to study the issue, and the Ministry proposed two alternatives earlier this year. One proposal would have made labeling of GMO products mandatory, while the other would have made it voluntary for producers, distributors, and processors. If labels were required for consumer food products, the labels would be one of three types, indicating that the food 1) does contain GMOs, 2) does not contain GMOs, or 3) may contain GMOs. The government is currently receiving public comments on the proposal, and may make a final ruling by the end of the year.

Australia/New Zealand. Regulation of GMOs is handled by the Australia New Zealand Food

Standards Council (ANZFSC). In general, the sale of foods made through gene technology is prohibited unless ANZFSC has assessed them as safe for human consumption. The Australian Quarantine and Inspection Service (AQIS) also may evaluate new crops if there are potential environmental implications. Approved foods will be listed in the Council's standards guidelines.

ANZFSC is still considering the issue of labeling GMO foods. It has recommended mandatory labeling for GMOs that are "substantially different" from existing foods, while a recommendation for foods that are not substantially different from their traditional counterparts is due in December.

European Union. To enter the EU's regulatory approval process, a GMO must have a sponsoring country that proposes the product for review. The product is then open for comments from all member states. After the comment period, the product then goes to three EU scientific committees, then one regulatory committee for review. If the product is approved through all stages, then the sponsor proposes a final legislative procedure at the EU level which would formally release the product for planting, trade, etc., as the case may be.

Once the product is approved at the EU level, member states must change their domestic laws to conform with the EU law governing the product. Austria and Luxembourg have refused to do so, trying to maintain bans on GMO corn. By asserting one of the clauses in the EU charter, member states do have the right to do this, as long as they can establish a scientific basis for doing so. However, Austria and Luxembourg did not do so – the deadline by which they had to submit this scientific justification passed, and they provided no attempt at a justification. Consequently, the EU may take them to the European Court to enforce the EU laws on the issue.

Regulation 90/220, which established the current approval framework, is currently being reviewed by the EU. They expect to have a proposal ready by the end of 1998. However, the review of this proposal could take up to three years.

The Biosafety Protocol

The Biosafety Protocol is currently being negotiated to address the "… safe transfer, handling and use of living modified organisms, … specifically focusing on transboundary movement."[34] It sprang from the United Nations Convention on Biological Diversity (CBD), which called on the parties to the Convention to examine the "need for and modalities of" a biosafety protocol "setting out appropriate procedures … in the field of the safe transfer, handling and use of any living modified organism resulting from biotechnology that may have an adverse effect on the conservation and sustainable use of biological diversity."[35] The United States is not a party to the CBD and so cannot

[34] Decision II/5 of the Conference of the Parties to the Convention on Biological Diversity.

[35] While the WTO's Sanitary and Phytosanitary Agreement provides an *opportunity* for countries to restrict trade in products when it is deemed that it would be necessary to protect "human, animal or plant life and health" (this includes consideration of 'relevant ecological and environmental conditions'), the Biosafety

become a party to the Protocol. President Clinton has signed the CBD, but its prospects for ratification in the Senate seem dim.

As the negotiations over the Biosafety Protocol began, the United States insisted that there was no need for such a protocol, since it felt that GMOs often were essentially equivalent to their traditional counterparts, and thus there was no need for a separate protocol to govern them. However, the parties to the CBD decided that a Biosafety Protocol was necessary. The United States, despite being a non-signatory to the CBD, has been participating in the negotiations, but it has no ability to block agreement on the Protocol. A two-week set of negotiations concluded in August, and will resume in February, at which time negotiations are scheduled for completion. The Protocol may not be formally adopted for some time thereafter to allow for legal editing and processing.

Key issues in the negotiations include the scope (that is, product coverage) of the Protocol as a whole as well as the scope of its various parts. The CBD refers specifically to a protocol limited to "living modified organisms" (LMOs). A significant number of developing countries have argued for a scope which covers all LMOs, including products of LMOs (that is, processed products which contain, or were produced from, LMOs). A number of other countries would like to limit the scope to viable organisms, with the more restrictive parts of the Protocol limited to a subset of these. For example, many developing countries have asked for notification by exporters and consent by importers (Advance Informed Agreement - AIA) for all international shipments of LMOs in order to better track products entering their borders. Prior to consent, a risk assessment would be required which could considerably delay approval for trade to begin.

In contrast, the United States argues that such notice is needed only in a small number of cases, such as when the organism is shipped as seed for the deliberate introduction into the ecosystem. While this also would require a risk assessment, it would be on a more limited subset of trade. And, once approval had been given for an LMO, trade could proceed without the need for continued notification and consent procedures (unless specifically required by the importing country that might deem LMOs a concern). Canada also maintains that there should be some measurement of the degree of risk of each LMO, and that low-risk LMOs should not be subject to AIA. In the context of the AIA procedures, there also is debate as to whether it should be the importer or the exporter who notifies the relevant authority in the importing country of the shipment.

Many developing countries are seeking to impose responsibility of LMOs on exporters. These countries also are seeking that the exporting country be held liable to provide compensation for any adverse environmental impact from the deliberate or accidental release of an LMO. Although the structure of rules for such liability has not been developed, proposals have included the following:

No liability provisions
Requirements for importers or exporters to be bonded

Protocol could place an *obligation* on Parties to assess the environmental impact of a new genetically modified product before trade occurs.

- The creation of an international liability fund
- Placing liability on the country sending the GMOs or deferring this decision until the Conference of the Party has determined how liability provisions within the CBD will be established and implemented.

In the negotiations, the United States is pushing to ensure that trade with non-signatories will not be restricted by the Protocol, and that the Protocol will not supersede or undermine any existing agreements on international trade, particularly those within the WTO. It remains uncertain how these negotiations ultimately will turn out, but it seems quite possible that the United States will be bound by many of its decisions even if it remains a non-signatory. For example, if a Party to the Protocol requires that it be notified of all LMO shipments, that a risk assessment be undertaken on those LMOs by the exporter, and that consent be granted before any shipment can occur, then all countries exporting to that country (including non-signatories) will need to comply with these requirements. With the increasing development and adoption by farmers of LMOs, such approval processes could become very restrictive to future agricultural commodity trade. It is important that a pragmatic approach to trade in biotech products be adopted while ensuring that legitimate environmental concerns be addressed.

Consumer Acceptance

The question of consumer acceptance looms large over the agricultural biotech industry. The pace of acceptance thus far has been quite swift and largely noncontroversial, except for Europe. Continued acceptance of new products likely will portend a bright future for the industry. However, consumer repudiation would put the entire industry in jeopardy, as well as huge investments over many years.

Consumer awareness of agricultural biotechnology varies widely from country to country. Surveys in developed countries found awareness greatest in Germany, Austria, Denmark, and Japan, where over 90% of consumers had heard about biotech. Awareness was lowest in southern Europe (Greece, Italy, Spain), averaging about 40%.[36]

When asked if they would consider purchasing a tomato that had been genetically modified, consumers in Germany and Austria were least likely to do so. Thirty percent of Germans said they might buy such a product, while only 22% of Austrian consumers surveyed would consider doing so. The most receptive consumers were in Canada (74%), the United States (73%), Portugal (72%), and Japan (69%). The results of this survey were largely the same when consumers were asked about a tomato genetically modified to be better tasting or fresher, although overall approval was (somewhat strangely) slightly lower. A different group of surveys found German, Austrian, and Swedish consumers most likely to describe GMO foods as a "serious" health risk (about 60% in each country), while the level of concern was lowest in Italy, Norway, and the United States.

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[36] Thomas J. Hoban, *Consumer Acceptance of Biotechnology: An International Perspective*, Nature Biotechnology, March 15, 1997.

However, other surveys have yielded different results. Some surveys in Japan have revealed that consumers are concerned about GMO foods. One survey by the Society for Techno-Innovation of Agriculture, Forestry, and Fisheries found that 91% of consumers wanted safety information on GMO foods, while 63% were unaware that GMO foods had then already been on sale. Consumer organizations have collected over a million signatures in Japan calling for labeling of GMO foods. In Canada, when consumers were asked if all GMO foods (not just those that are substantially altered from traditional varieties) should be labeled, 98% responded in the affirmative.

Consumer concern about GMO foods has been quite strong in the European Union. While this is attributable to several factors, the news in 1996 that linked Mad Cow disease with the fatal human brain ailment Creutzfeldt-Jakob Disease. Beef consumption all over Europe plummeted as the news spread. While American consumers seem to have considerable confidence in their food safety regulatory agencies, European consumers did not have the same faith even before the mad cow scare. Consequently, their concerns about the safety of their food supply are heightened, and biotechnology had the misfortune of entering the public eye while the memory of this crisis – and of the repeated assurances from public figures that were ultimately proven untrue – was still fresh. Other reasons why Europeans are more concerned about GMO foods may lie in cultural differences in perceptions of food (Europeans see agriculture as less of a business than do Americans, some say) and stronger environmental concerns.

Green parties in Europe soon used the GMO issue to their advantage. The food industry in Europe had always been divided on the issue of agricultural biotech and consumer acceptance. Farmers, research companies, and seed companies comprised one side, while the food processors and manufacturers comprised the other. There has been little, if any, communication between the two groups, and the food companies had taken no responsibility for promoting consumer acceptance of agricultural biotech; viewing this as solely the responsibility of the other camp. As the mad cow crisis unfolded, the greens were successfully able to jump on biotechnology as a new issue and have considerably chilled the debate. However, the fear of falling behind in agricultural competitiveness is becoming a stronger motivating factor to encourage a more positive attitude towards agricultural biotech.

Special Focus: The 1998 Swiss Referendum on GMOs

On June 7, 1998, Switzerland voted by a 2:1 majority against an initiative to ban genetic engineering. The initiative, called the "Gene Protection Initiative (GPI)", had as goals the prohibition of all transgenic animals, the banning of all field releases of transgenic crops, and the prevention of patenting certain inventions of biotechnology. Before the popular vote took place, Parliament committed itself to enact a strict regulatory framework, but no bans.

This was one of the most intense campaigns that Switzerland had ever seen for a referendum. The media's close reporting of biotechnology in the 2½ years leading up to the vote resulted in a marked increase in public understanding. In a thorough survey, general opposition to genetic engineering decreased from 62% to 33% and acceptance increased from 25% to 39%.

The collection of signatures for the GPI began in May 1992 and was completed with about 111,000 names in October 1993. The central features of the proposal were three specific bans, including:

- No transgenic animals should be allowed, not even for biomedical research;
- The release of all transgenic organisms should be banned, including transgenic crops for farms; and
- The patenting of transgenic plants and animals should be forbidden, also products and processes derived from them. This would have included human therapeutic proteins produced in plants or animals.

The main supporters of the GPI were diverse environmental groups ranging from Pro Natura to Greenpeace to the World Wildlife Fund. Further supporters were animal welfare organizations, organic farmers, one consumer group and some NGOs for developing countries. Their arguments for the GPI were based primarily on perceived risks and on ethical grounds. The risks mentioned concerned both human health and the environment. It also was argued that intrusions into an animal's genome violated its intrinsic dignity and that patenting of plants and animals was unethical, because they were products of nature.

Opposition to the initiative was led by an alliance of university researchers with the pharmaceutical industry. Later on, the lobby organization for the promotion of Swiss industry led the campaign. All major political parties of the right joined, and other important partners were the academies, professional associations of scientists and medical doctors, the universities and the National Farmers' Association. Their argument cited most often against the GPI was that its ban on transgenic animals would stop a great deal of medical research. The ban was therefore expected to lead to a loss of jobs and a situation where no new jobs would be created by discouraging start-ups and spin-offs, which had become so important in other industrialized countries. It was argued that pharmaceutical companies would move not only experiments using transgenic animals, but entire research programs out of the country.

Many observers felt during the first few months of the campaign that the GPI was going to be accepted, but the initiative lost ground in the last two months. There were many reasons for this change. Three events initiated by the proponents of modern biotechnology received considerable media coverage. First was a press conference of all Swiss Nobel prize laureates, even those not working in biology. They decried the loss of research potential, pointing to a probable lowering of standards in the universities. Then came a televised interview with three of the seven federal councilors, explaining why the government unanimously opposed the GPI. Finally, scientists organized their own demonstration in the streets of Zurich and Geneva.

With 41% of registered voters taking part in the decision-making process, 67% were opposed to the GPI and 33% for it. Public opinion on gene technology changed very considerably over the last 2½ years. Whereas initially 62% opposed genetic engineering, only 33% opponents remained, while those with a basically positive attitude towards the technology rose from 25% to 39%. Those in favor of general bans decreased from 22% to 12%. The number of those who say they would not eat genetically modified food has gone down from 62% to 48%.

One may wonder whether the experience gained in one country debating the pros and cons of a new technology will help understand or predict the process in another. Although every country has its own social and political traditions, some generalizations, applicable to other countries, would therefore appear justified. Knowledge of modern biology is an important basis for accepting modern biotechnology. Many studies have shown that optimism towards biotechnology increases with factual knowledge. Also, the more different sources spread the same reliable information, the more credible it becomes. Finally, acceptance and understanding need time to develop along with familiarity of products and services.

National and Global Regulatory Framework

Since the mid-1980s, biotech safety issues, along with regulation of testing and approval have been divided among three agencies, including FDA (primarily concerned with food additives), EPA (primarily concerned with impacts on the environment) and USDA (primarily concerned with the testing, control and oversight of genetically engineered plants).

> A continuing question is whether a "super agency" will be created, as some (largely environmental activists) have advocated. However, most observers believe the odds of this are small, especially in the absence of some regulatory problem. While the current system is seen by all concerned to be cumbersome, it has been hammered out over more than 13 years of trial and error and is understood by current participants. Relative to the procedures in Europe and elsewhere, it is both transparent and rapid. There appears to be little effective pressure either from within the government or elsewhere for significant shifts.

Globalization of Regulations

Two decades ago, agricultural and food production was primarily destined for domestic consumption, and food and agriculture issues concerned domestic producers and consumers. Food safety, quality, cost and other issues were based on domestic policies and concerns, and reflected almost totally the US culture and values. In addition, because the US markets were so large, US preferences for products and presentation were generally imposed on imports of products attempting to penetrate US markets.

US policies regulated prices and supported producers' incomes, established food safety levels (often very different from those overseas) and supported infrastructure and other investments across the sector with virtually no concern for foreign markets or competitors, except in the case of complementary products such as tropical products and others.

Today, a very large share of the regulations that affect US producers and consumers have been "globalized," and are the subject of international conventions (such as the Codex Alimentarius, administered by the FAO) or international agreements (domestic support for producers, export subsidies, duties and tariffs and limits to market access and sanitary/phytosanitary regulations). A large number of agreements define these regulations (including, most prominently, the Uruguay Round WTO Agreement and the North American Free Trade Agreement, and many more), and each has an extensive mechanism for both enforcement and extension of the agreement in the future.

The basic concept upon which these agreements were developed is that trade and investment based on competitive production and pricing (rather than government intervention) is the most efficient system available – a conclusion demonstrated by the collapse of central planning in the former Soviet Union, and elsewhere. As a result, the expectation long has been that a series of future negotiations and agreements would lead inevitably to increased market access and larger, more competitive markets.

However, market expansion has been more difficult than expected, with substantial controversies involving approval of a number of "conventional" products. And, the advent of biotechnology is further complicating this process. The concept of equivalency of safety inspection processes is difficult to establish objectively, and continues to limit access for a number of products.

To a large degree, the difficulty of gaining approval for biotechnology products appears both to be political (based on concerns about human or environmental damage that some believe could happen, rather than events or incidents that have been documented – and, based on the argument that extensive labeling should be done so that those with concerns can choose not to consume biotech products). The counter concern is that many such arguments reflect the desire to protect markets, rather than concerns about food safety or quality – that the sanitary/phytosanitary provisions in the Uruguay Round Agreement require both testing and restrictions on trade be based on scientific conclusions.

As the production of biotech products expands and the next round of negotiations under the WTO approaches, the position of the main negotiators regarding these disputes assumes enormous importance. The Uruguay Round began a process of dismantling border measures that restrict trade, and the next Round was widely expected to continue that process with significant, new steps toward more open markets. However, it has become increasingly clear that US producers have made enormous investments in biotechnology as a means of advancing their competitive position across the food and agriculture sectors. The disapproval by major trading partners of products that have been tested and approved for production in the United States will be seen both as a severe violation of previous trade agreements and an indication of future protectionist efforts, and can be expected to trigger severe confrontations – both in the current WTO structure, and in the upcoming negotiating round.

Implications for Agricultural Research & Extension

University Agricultural Research

The shift in agricultural research spending that has taken place in recent years, from the government and academia to the private sector, has changed dramatically the relationships between these players, and biotechnology seems likely to accelerate that change. Private-sector agricultural research has grown substantially since the late 1970s, while public agricultural research has (in dollar terms) remained fairly flat during the same period.

One of the major changes that has taken place in public agricultural research is that public/private collaboration on research has expanded greatly. While this has always been present to some degree, the federal government made efforts to expand private-public cooperation. It allowed for private patenting of products developed through federally-funded research, and it established Cooperative Research and Development Arrangements (CRADAs) as agreements between federal labs and private companies to develop technology.

Biotechnology may increase the trend toward joint private/public research, due in large part to its high costs. Universities have found themselves (and their research budgets) overwhelmed by biotechnology in the past few years, as the costs involved in new equipment, attracting top scientists, etc., have begun to draw funds away from other uses. Some in academia have said that the sudden large flows of funds toward biotech research has made the setting of priorities more difficult. Consequently, universities are likely to become increasingly interested in public/private partnerships, particularly if it leads to innovations that can be commercialized and realize a return on investment. Returns on research investment allow the university to bolster its research budget.

At the same time, biotech companies of all sizes reportedly are showing greater interest in partnering with universities to perform research. The companies benefit not only through the sharing of resources and information on individual projects, but from the links with the university, which may serve as a talent pool for future scientists. Universities often perform basic research that companies may not be willing to fund themselves but can certainly benefit from.

In some cases, the public/private distinction is beginning to blur. One major pharmaceutical company built a building on a major Land Grant University (LGU) campus, and leased the building to the university at a concessional rate. It will be used in conjunction with academic researchers to develop new animal vaccines. This type of relationship can bypass a university's traditional methods for allocating research money. But is this inherently bad? Private/academic partnerships have existed for decades, and both parties usually benefit from the arrangements, so it is difficult to say that increased private-sector involvement in university research will be good or bad.

The University of California-Berkley recently sold Novartis access to its Department of Plant and Microbial Biology for $50 million. Of that, $25 million was initially paid to fund the construction of new campus laboratories. Another $25 million will be paid out over the next five years to fund research. Novartis will have the first opportunity to negotiate the rights to take the department's discoveries to market.

However, several issues remain:

Will increased university investment in biotech-related research (particularly plant and animal sciences) draw funding away from other agricultural disciplines, such as agricultural economics, soil science, etc.?

Will universities be able to maintain their academic independence in an era of increased partnership with (and funding from) the private sector?

Conventional wisdom holds that the private sector will not do basic research that holds little commercial potential but is nonetheless important for future innovations. If the day comes when nearly all research is done by or in collaboration with the private sector, who will do basic research?

How will returns be shared if products are developed jointly by a university and a private company?

Extension Services

Many have questioned how the role of extension services will change in the era of biotechnology. In the past, the traditional flow of agricultural information and research flowed from the LGUs through the extension service to the farmer. With more research taking place outside of the LGUs, the old structure may not continue in its present form. But what will take its place?

Extension agents see their traditional role being filled by several newcomers, including private company personnel (technical and sales), independent consultants, or on-farm technical staff. These trends likely will continue, as more technology is developed in the private sector. The perception of LGU extension agents as independent, unbiased advisors also may change as private/academic partnerships grow stronger. If extension agents find themselves with less information to extend, fewer farmers to extend it to, and greater competition, how can they redefine their role in the coming years? There are several implications for extension services, including:

Can extension services maintain their role as independent evaluators of product claims made by private companies in the biotech era, when research costs have increased? If so, how can they get access to information for new proprietary technology?

Will extension agents find themselves working only with small farmers, with organic farmers, or with those who grow non-biotech crops?

Can extension services carve out a role as market information advisors, e.g., serving as an independent source of information on the various contracts for production of biotech crops offered by technology companies or food processors?

Intellectual Property Rights

Agricultural Biotechnology Patents

The concept of patenting life forms is fairly new. Traditional law held that life forms could not be patented, but a Supreme Court decision in 1980 allowed the first such patent. In a case involving a patent for a crude-oil-eating bacteria, the Court said that as long as the "hand of man" was present in the life form, then it could be patented. A new plant discovery that is not artificially altered, however, still cannot be patented.

In Europe and most other countries, plant and animal varieties cannot themselves be patented. However, what constitutes a "variety" is a matter of debate, and many aspects of a GMO plant can be patented. One can, for instance, get a patent in Europe for a gene, the gene vector, and the transformed plant cell that results from the insertion of the gene, but not the actual plant itself. There is, however, some debate in the EU over whether GMO crops should be allowed to have patents. Some argue that a new variety made by traditional breeding should not be allowed to have a patent, while GMO crops should. The EU recently passed a biotech directive which stated that transgenic crops should get some kind of intellectual property rights (IPR) protection while traditional varieties should not.

Most other countries follow the EU system on these issues, although many recognize "breeders' rights," known in the United States as Plant Variety Protection (PVP). PVP is administered by USDA rather than the Patent Office, and offers protection similar to a patent. They give breeders a "breeders' exception," allowing the breeder to bar anyone else from using or growing their invention.

US patent law now provides 20 years of protection from the date of filing. This was changed in 1995, prior to which one got 17 years from date of patent issue, and as part of an international effort to harmonize patents, as most other countries in the world used (and still use) a 20-year period. In return for changing its patent period, the United States successfully urged other countries to adopt more stringent patent protection.

There remain, however, some differences between US patent law and that prevailing in other countries. Most countries (the EU, Japan, etc.) operate on a "first-to-file" principle, while the United States operates on "first-to-invent." However, many US companies often end up trying to be the first to file, since doing so is a benefit when applying for patents in other countries. Also, many countries publish patent applications during the approval process – the EU, for instance, does so 18 months after date of filing.

The Patent Cooperation Treaty (PCT) is in some ways a multilateral patent approval body. By filing a patent application in a PCT member state, then filing a PCT application within one year, the application is treated as if the applying company had filed the same application on the original filing date in all of the designated countries.[37] There is then two examinations of the application. One exam covers aspects of patent law that are common to all of the designated states, while the second covers aspects of law that are different in each.

Intellectual Property Disputes

Intellectual property disputes are nothing new to the food and agriculture industries. Farm input companies long have been on the lookout for infringement of their patents by competitors. It is likely, however, that such disputes may become more prevalent in the era of biotechnology for two reasons: the amount of money involved in R&D, and the relative ease of copying a new innovation once it has been perfected.

Before biotechnology, seed companies could infringe on another's patents by buying a competitor's seeds and crossing the primary germplasm with their own. These disputes still take place today, including a recent lawsuit in which Pioneer alleges that three of its competitors have done this with its hybrid corn seed. Biotechnology, however, makes this type of action somewhat easier. If a plant's gene map is widely known, and a seed company develops a certain trait, a competitor may be able to reproduce this trait easily. A few examples of disputes that have arisen to date include:

A complicated dispute between Mycogen, Novartis, and Monsanto over the Bt gene. Monsanto alleged a patent violation by the other two parties when they began selling Bt corn after Monsanto already had patented the gene. The jury found that Novartis' product was a unique invention, while ruling for Mycogen in asserting that the patent was so narrow as to be unenforceable.

A patent dispute between Enzo Biochem and Calgene, in which the court ruled against Enzo and invalidated two of three patents. The dispute over genetic antisense technology, used in a variety of medical and agricultural applications, delayed commercialization of the technology for over two years.

An anti-trust suit by Zeneca against Monsanto, in which Zeneca alleges that Monsanto uses its Roundup Ready crop licensing agreements to keep competing equivalent herbicides (such as Zeneca's Touchdown and AgrEvo's Liberty) out of the market.

[37] PCT members include the NAFTA countries, Europe, the FSU, China, India, Japan, Brazil, Australia, New Zealand, and most of the Francophone African countries.

Intellectual Property in Making of Bt Crops

The US Patent Office has granted over 200 patents for the use of the Bt bacterium for insect resistance in crops. Nearly 40 groups have legal rights to one piece of the overall process. The following is a description of the patent process.

Isolate a specific Bt gene from an attractive Bacillus thuringiensis strain:

- **Mycogen** holds a Bt gene library with over 30 issued or pending patents.
- **Monsanto** has bought access to Ecogen's Bt library.
- **AgrEvo** owns a patent to the Cry1Ab Bt gene and believes the entire industry (except DeKalb) is using this gene. AgrEvo also has patented a Cry9C gene.

Find a promoter gene to express the gene:

- **Monsanto** holds a patent for the 35s promoter which is used by many.
- **Mycogen** holds patents on 35 promoters, including the popular UB-1 promoter for monocots.

Modify or synthesize the Bt gene for use in plants. ("plantize" the gene: change some of the DNA makeup to make it more plant-friendly):

- **Mycogen** holds a patent for the process of creating <u>synthesized</u> Bt genes.
- **Mycogen** holds composition of matter patents for the <u>synthesized</u> Bt genes (matter patents cover the genes and the cells, plants and seeds that contain them).
- **Monsanto** also holds a composition of matter patent for Bt genes <u>of a specific DNA sequence.</u>
- **AgrEvo** has a patent for truncating native Bt genes.

Insert the gene via one of these methods:

- Electroporation — electric field drives gene in (**DeKalb** owns a process here).
- Gene Gun — micro particle bombardment.
  - — **DuPont** holds the basic patent for gene gun use (and licenses it to DeKalb and, others).
  - — **DeKalb** holds process patent for gene gun use with bar and pat genes to create glufosinate resistant corn. DeKalb also holds a matter patent for genes using bar/pat genes for glufosinate resistance in corn.
  - — **AgrEvo** also claims ownership to bar/pat technology for glufosinate resistance in corn.
  - — **Pioneer** claims it filed for gene gun biolistics transformation process patents first and hopes to invalidate DeKalb patents.
  - — **DeKalb** holds process patent for Bt corn when using gene gun <u>firing into corn callus.</u>
  - — **DeKalb** holds process patent for Bt corn when using gene gun on <u>regenerable corn cells.</u>
- Agrobacterium — transfer DNA from bacteria.
- Transfection — rub surface of cells with DNA.
- Wiskers — **Zeneca** holds the patent for the use of silicon wiskers to transfer DNA.

Test for transformation of plant (did the DNA get inserted?):

- Selectable marker gene is needed here.
- An herbicide resistant trait is often used. Tissue is sprayed with herbicide. Cells that survive have been transformed. **DeKalb**'s glufosinate resistance patents apply here.
- **AgrEvo** also has patent for glufosinate resistance genes for its Liberty Link system.
- **Ciba** (Novartis) holds a patent for use for hygromycin as a selectable marker.

Tissue regeneration:

- Grow tiny plant tissue out into full-sized plant.

Cross-breed genetically engineered plant with normal plant.

Patent law as pertaining to crop biotechnology is a relatively new field. Not long ago, it was impossible to patent life forms, and in many countries this is still the case. Because the field is so new, it may take many years – and many protracted court cases – before the volume of cases pertaining to agricultural biotech patents and intellectual property rights begins to subside.

The Terminator Gene

The question of how to disseminate a new technology while ensuring the developer a return on his research investment has long been an economic and scientific problem. Companies often have abandoned research in certain areas if they were unable to realize an acceptable return.. For the seed industry, hybrid seeds solved this problem to a degree, but the age-old practice of saving seed remained a disincentive to investment in new seed varieties. The terminator gene (or "technology protection system," TPS) may definitively solve this problem – but not without creating a fair amount of controversy.

The gene, developed by USDA's Agricultural Research Service in conjunction with Delta and Pine Land Co., makes a plant's seeds sterile. Using this technology, seed companies can ensure that farmers do not save seed for future plantings. The licensing agreements that accompany most biotech seeds forbid the saving of seed, but the terminator takes this one step further.

Detractors of the new technology, from environmentalists to rural development advocates, say that the terminator gene will end the traditional practice of saving seed and will keep farmers dependent on the seed company year after year. They also question the effects of such technology on other crops, biodiversity, and are particularly concerned about the effects that could result if the gene were to cross species and be transferred to nearby wild plants. The terminator would hit developing countries particularly hard, since few farmers in these countries can afford to buy new seed each year.

The developers defend the new technology, saying that it is a necessary tool to allow seed companies to protect and realize a fair return from their investments in research and commercialization. A USDA spokesperson said that by protecting these investments and promoting further seed research, the terminator may benefit farmers by giving them greater access to new and improved seed varieties. Delta and Pine Land also has argued that sterile seeds may prevent genetically modified traits such as disease resistance from escaping into wild plants and causing dangerous mutations. Thus far, the terminator has been tested in cotton and tobacco seeds, but it may be years before the technology is transferred to other crops. The company has until October 1999 to license the technology to other companies.

Outstanding Issues

Several issues remain unanswered pertaining to agricultural biotechnology and intellectual property rights, including:

Are existing treaties and agreements sufficient to help companies protect their technology and investments? If not, how can the situation be remedied?

How can biotech companies ensure that their seed agreements will be enforced (particularly prohibitions against saving seed) in other countries?

Different nations have different time periods for granting new patents. Will this discourage trade and/or investment?

There have been many joint ventures (JVs) in the biotech field: AgrEvo, Optimum Quality Grains, and Intermountain, just to name a few. What would happen if there was an unfriendly parting of the ways between parent companies? How would they divide ownership of the JV's intellectual property? How could they ensure that agreements could be honored?

Will the terminator gene be accepted by farmers? By foreign regulators?

Biotechnology in the Developing World

The development of agricultural biotechnology holds the promise of dramatically increasing food production around the world without putting further pressure on already strained land and water resources. It could ease, and hopefully even eventually eliminate, the critical problem of chronic malnutrition that continues to plague almost one billion people. It could transform marginal, poverty-stricken farmers and struggling agricultural systems into productive, self-sufficient and profitable producers and healthy agricultural economies.

Commercial biotechnology developments, however, have so far been concentrated in the developed countries by highly sophisticated companies, and up to now adoption has been by the technically-advanced and already productive farmers. How this technology will be used by the developing world, and whether it will ultimately pull struggling nations and their farmers and populations out of poverty and hunger, or in fact widen the gap between the "have" and "have-not" nations is a subject of much debate.

Developing countries are currently dealing with biotechnology in vastly different ways, due mainly to differences in agricultural policy, political goals and interests and available economic resources. Agricultural biotechnology is by far the least developed in Africa, but even within that region, there are large differences between countries. Kenya, Zimbabwe and Nigeria appear to have the most thought-out programs and priorities in place.

Most Asian countries are involved in biotechnology, but here too are significant differences from country to country. South Korea, Singapore and other newly industrialized nations are applying agricultural biotechnology mainly for high-value products, generally pharmaceuticals, while India and China have focused on agricultural biotechnology to improve crop production. India has devoted much public funding to biotech research, while China – after establishing itself as a leader in traditional forms of biotechnology such as the production of antibiotics – is now relying heavily on foreign technology.

In Latin America, most countries established national biotechnology programs in the 1980s, but because of the lack of a qualified scientific community, the majority of the nations in the region have concentrated more on access to global technology, rather than developing biotechnology through basic research in the country. Argentina, Brazil, Cuba and Mexico are the few countries in Latin American involved in basic biotechnology research.[38]

The United Nations sponsored group, CGIAR, has been closely working with developing countries in the last several years to help develop and expand research in agricultural biotechnology. But funding for biotech research has represented only a very small part of the CGIAR budget, and pales even more in comparison to the funding for biotech research by the public and private sectors in developed countries.

Despite the "Green Revolution" of the 1960s and 1970s, hundreds of millions of people throughout the world continue to be chronically undernourished. Moreover, food production needs are growing persistently, as the world's population continues to increase. The most critical areas, now and in the future, will be developing nations.

Malnutrition is a daily fact of life for some 800 million people. Twenty percent of the population in developing countries suffers from inadequate caloric and nutritional intake. The problem is the most acute in Sub-Saharan Africa, with almost 40% of its population being malnourished. South Asia is still expected to have some 200 million undernourished people by 2010, and the problem will remain widespread in Sub-Saharan Africa with over 300 million people forecast to be "food insecure."

The world's population is expected to grow by 2.5 billion people in the next 25 years, and 94% of that increased population will live in developing countries. The highest growth will come in Sub-Saharan Africa (3.2%), followed by East Asia (1.2%).

Global food production will have to increase significantly in the next 25 years – some experts say by 200% or more. Demand for cereals and livestock products will grow much faster in developing than in developed countries.[39]

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[38] *Agricultural Biotechnology in Developing Nations: Place, Role and Contradictions*, Jose de Souza Silva, the Brazilian Public Enterprise for Agricultural Research.

[39] *World Agriculture: Towards 2010*, the Food and Agriculture Organization of the United Nations, 1995.

Cropland areas are dwindling in developing countries, along with declining access to forests, rangeland and fisheries. In Asia, the current 0.15 hectares of available cropland per person is forecast to fall to only 0.09 hectares by 2025. Around 1.8 billion hectares of land in the developing countries are estimated still to be eligible for crop production, but this is not prime farmland by any definition. At least 45% is under forest or in protected areas and not readily available for production, and another 50% is only marginally fit for production. Almost all of this untapped resource is divided between Latin America/Caribbean areas (48%) and Sub-Saharan Africa (42%). There is little land available in South Asia and in other parts of Africa.

Many people see biotechnology as a way to greatly reduce or alleviate hunger and malnutrition by giving bigger yields on much the same areas, by improving the nutritional content of food, by nutraceuticals that help with disease treatment or prevention, by greatly reducing environmental degradation from area expansion, reducing water pollution, pesticides, commercial fertilizers, etc.

But not everyone is enamored with biotechnology's potential, especially for the developing world. Biotechnology is now sparking the same concerns that were in fact raised against the Green Revolution – that its benefits will go mostly to the world's large, rich farmers, that it could widen the prosperity gap between developed countries and developing nations, and that it could cause potential harm to the environment and regional ecosystems.

Critics also often note that biotech products to date are little suited for developing countries. Rice and wheat are the biggest food sources and production crops in developing countries, and very little, if any, significant biotechnology developments are being made in those crops. Cassava and other tuber crops also are important nutritional crops in those nations, but except for potatoes and squash, very little biotechnology research is occurring in those areas. The potential to produce improved varieties of tuber crops such as cassava is considered high, but so far these crops have been under-developed in genetic terms, and they remain very vulnerable to disease and insects.

The expansion of intellectual property rights to include plants and animals has been an important factor in the growth of biotechnology in recent years, encouraging private sector investment. The recent introduction of proprietary new products and the promise of more to come creates an increasing concern that intellectual property rights could slow down the transfer of improved crop varieties and animal breeds to developing countries unable to afford the technology.

There is likely to be continued controversy about use of the so-called terminator gene. Critics argue this is inappropriate for agriculture in developing countries, since farmers might be unable to afford the new seed every year. The very recent CGIAR decision to exclude it from its research program brought new attention to the issue.

There also is concern in some quarters about the loss of indigenous crops from biotech alternatives. Loss of varieties and individual genes could negatively impact production in developing countries. "Traditional" varieties (indigenous crops) as opposed to "modern" varieties (seeds produced through public and private research) are important because of particular characteristics as well as sources of genetic diversity, and they often have superior performance, especially in marginal environments. Their potential loss is viewed as a threat by some to the long-term sustainability of agriculture in marginal areas. A related concern is that introduction of biotech crops will alter the insect/disease balance that has been reached over time. Widespread use of a crop genetically modified for insect resistance might force the insect to seek other food sources and thus endanger other crops.

The view that biotechnology may not hold much promise for the developing world is confined largely to activist groups such as Greenpeace, the Union for Concerned Scientists and others. These concerns will receive attention from international bodies such as the FAO and the CGIAR. Regardless, more biotechnology research oriented to the developing world is underway. The CGIAR has given biotechnology research high priority, and its various centers are conducting biotech research on rice, potatoes, maize and livestock.

Biotechnology and the Environment

"Supercrops, superweeds, superbugs" – all possible results of agricultural biotechnology according to the experts. Will biotechnology help the world grow more food on less land and stop the steady degradation of the fragile environment, or will the science spin out of control and create environmental problems never before experienced by mankind? Agricultural biotechnology by its very nature will change the environment to some extent, and – also because of its very nature – some of those changes are impossible to predict. Will the beneficial impacts outweigh the possible adverse effects? The controversy over the relationship between biotechnology and the environment likely will intensify as use of the technology spreads, and as with any other developing science, those on the forefront of the biotechnology revolution will have to spend some time anticipating possible problems and identifying solutions.

Environmental Challenges

The global environment faces incredible challenges today from a growing and hungry world. There is a growing concern by experts in the field that the world's natural resources are being severely degraded. Problems include uncontrolled deforestation, massive soil erosion, increasing water scarcity, extensive water quality deterioration, pollution and over-development of vital coastal and aquatic ecosystems, and loss of genetic resources.

The potential damage could include nearly two billion hectares of land (roughly the size of North America) that have suffered some degree of environmental damage over the past 50 years, with significant amounts (perhaps 5 to 10 million hectares worldwide) becoming unproductive annually as degradation proceeds, mostly in developing nations. In those areas of the world, virtually all of the land well-suited to cultivation is already in use.[40] However, current trends imply that per capita

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[40] *Sustainability, Growth, and Poverty Alleviation: A Policy and Agroecological Perspective,* IFPRI and the Johns Hopkins University Press.

availability of arable land in the developing countries could fall by nearly one-half – from 0.65 hectares to about 0.4 hectares by 2010, thus sharply increasing pressure on the land base and making even more difficult the task of protecting these enormously important resources.

The disturbing rate of the destruction of some of the world's most environmentally important forests has received much attention. Although there is disagreement on the size of the area that is being affected, it is safe to say that many millions of hectares of tropical forests are being lost every year to agricultural production and industrialized uses. This rate could slow, as there is more awareness of the problem, but significant areas of important forests are likely to be converted to some form of agricultural use over the next 20 years – some 90 million hectares of additional land may come under crop production by the year 2010 in developing nations, excluding China.

But the increasing pressure on fresh water supplies is seen by many as an even bigger problem than deforestation. Most experts believe that technological advances will continue to make it possible to increase agricultural production with a relatively modest increase of land in use. However, improvements in water use efficiency are unlikely in the medium term. Africa and Asia already show a worsening shortage in per capita freshwater availability. Food supplies in the developing countries are heavily dependent on irrigation, and this dependence is expected to grow. Agriculture now uses more water than any other sector, accounting for nearly 70% of total consumption of managed water resources, but growing industrial and domestic demand will strain the supply even more and will likely cause the price of water in developing areas to increase. In most price wars over water, the agricultural sector is usually the least able to afford the higher costs.

Chemical use in agriculture production is still high, especially in many developing countries. Developing countries account for a large portion of the global consumption of chemical inputs (50% of insecticides for example), and this heavy use has had damaging effects on the environment and human health in many regions.

Finally, concerns about global warming and climate change have caused nations to look closely at environmental policies. Agricultural activities are a major contributor to sources of greenhouse gases, which in turn contribute to climate change.

The Contribution of Biotechnology

Agricultural biotechnology holds great promise for helping to resolve some of the key environmental problems. While biotechnology can enhance the productivity and sustainability of any agricultural system, it is nearly ideally suited to sustainable agricultural approaches because of its capacity to develop crop characteristics specifically suited to a complex, low-chemical environment.

Herbicide resistant gene-modified crops reduce the need for chemical inputs. Farmers using the Roundup Ready soybean, for example, can cut chemical use by 10% to 40%. Bt corn eliminates the need to spray for corn borer.

Higher yielding GMO crops will ease the strain on land resources.

Biotech crops reduce energy usage as farmers have to make fewer passes through fields in applying chemicals. Less fuel use means less carbon entering the atmosphere as CO_2.

Herbicide resistant crops encourage the adoption of conservation tillage, especially no-till, which reduce erosion of topsoil.

The development of nitrogen-fixing plants will reduce the use of chemical fertilizers, which are being used more heavily in developing countries.

The OIL-EATERS

A biotechnology tool called bioremediation puts naturally occurring bacteria to work for the environment. By stimulating the growth and activity of a type of bacteria called *Pseudomonas*, that lives in soil and "eats" hydrocarbons such as oil, this new tool is being used to clean up many of the most seriously contaminated waster sites in the country, at sometimes one-tenth the cost of conventional remedies. After the devastating Exxon Valdez oil spill in Alaska in 1989, biotechnologists at the site used this technique to clean more than 74 miles of shoreline at rates three to five times faster than through conventional reclamation methods.

Agricultural biotechnology also has raised concerns that the scientific community may be dangerously tampering with nature and setting the stage for unknown and unpredictable risks. Critics urge extraordinary caution in the development and use of biotechnology products.

"Superbugs and Superweeds." Many critics are worried that insects or weeds may develop resistance to the technology used to suppress them. Most of the concern has been centered around Bt corn and Bt cotton, in which case it is feared by some that the Bt crops will add so much of the Bt toxin to the environment that insects will develop a resistance to it. In the case of weeds, the so-called phenomena of "weed shifting" could occur, where species most susceptible to the herbicide would decline over time, while less susceptible, superweeds, would build up. Many environmental groups warn that farmers would then be forced to use more pesticides if insects and weeds develop immunity.

Gene Flow and Biological Pollution. New evidence shows that genes can move from transgenic crops to wild relatives more often than once thought. Some scientists worry that as more biotech crops are planted, it is only a matter of time before the transfer of an engineered gene creates a new weed or a super hardy one.

It is clear that agricultural biotechnology could be both good and bad for the environment. Because the technology is so new, accurate predictions of how it will impact the environment are impossible.

Given the large investment in the new science, and the rapid acceptance by farmers, the brisk pace of biotechnology innovations will likely continue, and the environmental impacts will become more evident as it evolves.

Financial Services

Throughout the system, plants and animals bred or engineered for specific end uses require fine-tuned production practices that are virtually unique to each specific end product. Regulations on the use of specific drugs or chemicals require greater coordination of activities at more than one level of the agricultural system. Also, some new technologies, such as prescription application of fertilizer and chemicals for varying soil types in the same field, may not be economical at the single farm level. Much of this change may be dictated to farmers. As a result, input suppliers will need to work more closely with contractors to anticipate producer needs (since some farmers could become more like today's poultry producers, responding to specifications of prime contractors).

Each of these trends suggests that agribusinesses that can effectively develop a greater degree of interdependence among the different levels of production and processing will have the greatest advantage in dealing with the commercial farms of the future. To develop wider margin markets, processors likely will increasingly provide products with higher quality, greater uniformity and lower prices. To compete for these markets, they likely will reduce their reliance on traditional commodities and buy "high specification" grains and livestock. New linkages among food firms, producers, and input suppliers can be expected as this struggle for better markets and better products to supply them proceeds. These linkages could take many forms including acquisitions, joint ventures, contractual and partnership arrangements. In many cases, they could mean a more integrated production and marketing system, motivated by the need of producers and input suppliers to meet both consumer requirements and to deal with larger, more aggressive producers competitively. As a result, the distinction among segments could become even more blurred.

The expected shifts at both the producer and consumer levels could encourage input and food processing firms to seek new alliances and partnerships at many levels. An example of such a partnership could include firms with special technologies (including biological compounds, genetics, special chemical or production and manufacturing processes) to develop a corn borer resistant hybrid or a stress tolerant variety of tomato or a soybean variety with increased protein content. The joint venture may be between the input manufacturer and a distributor/dealer network which has a strong position in local markets and excellent customer contracts and relationships. Many of these potential alliances likely will cross the traditional market boundaries as seed and chemical companies join on a particular product, and equipment firms jointly introduce a chemical product and the appropriate application system. And, the new alliances could extend throughout the entire system from the input supplier to the producer to the processor and distributor, as is currently underway in the hog industry where links exist among feed companies, genetic companies, packing plants and food distributors.

At the same time that new alliances emerge across the sector, producers could actually compete for more than they previously did, in a number of areas. For example, they could compete for contracts to supply large amounts of product to important processors, and they could compete for financing and in many other areas. Unlike now, in the future, they must be increasingly prepared to be as efficient as their neighbor in meeting market demands.

In part because tomorrow's farm sector could have somewhat more volatile markets and prices, farmers are developing a broad range of new approaches to manage their risk. Many of the changes underway in this area still are undefined, in part because the 1996 shift in farm policies was sudden and happened recently. And, while the outlines of change in this area are becoming somewhat clearer, these new relationships are still developing.

To an important degree, the increased blurring of the demarcations between production levels under contract, forward contracting, joint ventures and other arrangements is being done in an effort to control and manage risk, as well as to control and manage operations. In general, these arrangements are re-distributing risk without clear indications of where it will be borne eventually. Some of tomorrow's additional risk will be carried by the market as producers and others become more skilled in the use of market instruments. And, some may be shifted to the government through new risk management programs, or to equity partners.

Key instruments in use or under consideration by large farmers today include:

- Forward contracting for production inputs, other services and crop sales.
- Crop insurance, and other property insurance, from both public and private sources. In particular, disaster-level crop insurance subsidized by the government is being offered for increasing numbers of crops at very low costs nationwide.
- Revenue insurance, based on newly developing government programs.
- Yield insurance.
- Futures and options contracts used to hedge production operations.

The revenue insurance programs, in particular, are being evaluated by the government and will be offered widely in the near future. However, the assessment and management of risk could become an increasingly important competitive issue in the future, especially as fixed investment per farm increases with the use of precision farming, and as greater specialization occurs. In fact, new classes of risk are developing that producers have rarely considered before, including the risk of liability from product contamination and other health risks, or possible contamination through the use of biotech products or other new technologies. At this time, farmers are only beginning to be sensitive to such risks. However, they may become significantly more important as the sector becomes more integrated and consumers more sensitive. Management and control of both conventional price and production risks and other liabilities could become an additional focus of negotiations and competition in the future.

Financing the Farmer – Control of the Crop Value Chain

By many standards, notably economic performance and efficiency, the most envied vertical marketing chain in the US food system is the poultry sector. The integration of this segment of agriculture began three decades ago, incorporating fragmented producers, processors, and marketing-minded integrators. Today, the poultry sector, relative to most other commodity/product value chains is a "model of integrated efficiency."

One question increasingly raised is the future role of biotechnology companies as potential integrators with the ability to finance production agriculture in the future – the combination of technology and financial power working in concert such that value enhanced crops are integrated much like the historical experience of the poultry sector. Current evidence suggests this may well be emerging as a practical possibility. Evidence of the further integration process for crops is linkages between biotech companies and upstream grain and oilseed handlers, for example, the Monsanto-Cargill alliance, enhanced by a Cargill-Toshoku linkage.

The expansion of control by biotech firms across various crop segments must be based on the existence of "practical need." There is little doubt that the new technology, integrated with precision farming procedures and related information systems already reflects an expressed need of producers (the fast pace of biotech product growth). This then raises the issue of how such integration would be financed – "what about ample production agriculture financing?" Twenty year trends clearly show that producers have come to rely much less on public/government financing, and much more on financing from commercial bankers. (The public/government share has fallen from 43% in 1980 to 31% today, while private financing institutions' share rose from 30% to 46% over the same period.) Moreover, individual (i.e., personal) financing has declined (from 27% in 1980 to 23% today) and has been offset in recent years largely by agricultural supplier financing.

The questions that arise at this point include:

> Will industrial financing fill any void emerging from further declines in federal financing and perhaps even commercial financing?
>
> Will commercial banks continue to expand their financing to producers?

Commercial banks, given their tremendous new costs and required return on new integrated equity, likely must look to more lucrative financial markets than production agriculture. They may not entirely abandon agricultural producers, but will look to "bigger" financial deals in order to return their shareholders' value. Government, continuing the trend of reduced public sector role, will not fill any void left by commercial bankers. Would this offer a "window of opportunity" for input suppliers to package input product sales and crop financing along with integrating both production and product marketing practices through the value chain via bulk processing and further sales into domestic and export markets? If this proved an attractive package to producers, especially if financing elsewhere was becoming more difficult, it could start a further integration process for the crop sector driven by an aggressive financial commitment on the part of the new integrators.

The pace and extent of any such integration similar to the poultry model would be heavily influenced by a couple of factors – a high-margin product or a high-risk product. If there are very high margins to be generated, then the biotech company will have the incentive to attempt to control the production, handling and processing functions for that crop, paying a fixed fee (with a premium/discount schedule based on performance) to the farmer and the elevator and processor for their services. The company would thus absorb the risk of a bad crop, but it would be compensated with considerable reward when weather conditions are normal.

The other case in which control of marketing chain segments may be necessary involves a high-risk biotech crop, in terms of potential liability to the company. For example, this might include oilseeds containing a medical substance or oil for an industrial application, both harmful if allowed into regular food products. For such products, the biotech company may want to control the marketing chain to be able to properly monitor the crop, control its processing, and distribution.

VIII. Overview of the Food System of the Future

It is very clear that the advent of new biotech products are producing vast change in the food system as the new technology is being very rapidly adopted by producers and accepted by consumers in large parts of the world. The new products already are yielding considerable raw material cost savings and promise to create vast additional value throughout the system. Those savings and the promise of that additional value already are precipitating major change in the US food system, and likely will cause a fundamental restructuring throughout the global system as business entities attempt to position themselves to capture parts of that added value.

The purpose of this section, drawing upon all the information provided by this study, is to present a synthesis B a suggestion of *one view* of what the food system might be like five years hence (2003). It includes explicit and implicit assumptions about future developments. It is not intended to be a forecast, but rather *one view* whose purpose is to stimulate thinking and help clients develop their own view of just how fundamentally the food system may evolve in the next few years.

Widespread adoption of biotech crops.

United States and Canada. Early products have proved so successful that it is likely that virtually all the major crop acreage eventually will be planted to GMO crops B to reduce production costs but also to obtain wider margins through value enhanced crops. Extensive adoption of GMO vegetable crops also can be expected.

Latin America. Rapid and widespread adoption of crop products in Argentina, Brazil, Mexico and others B becoming a very significant proportion of major field crops in the major producing countries.

Europe. The EU grudgingly moves to embrace biotechnology, recognizing that the fast pace of adoption elsewhere has enormous implications for the global competitiveness (reduced) of its food industry, the cost of its Common Agricultural Policy, and others. Consumer resistance continues but wanes over time.

Japan. Widespread consumer acceptance continues B produces GMO crops extensively, especially vegetables and rice.

Australia. Adoption of several crop varieties has occurred and can be expected to continue at a rapid pace. A significant amount of biotech research also will emerge.

Business restructuring continues. Biotech companies pursue a strategy of attempting to capture a large share of the added value that their new technology now makes possible B this requires a systematic reinvention of the companies themselves in some cases, and restructuring throughout the food system.

Inputs sector. Consolidation continues among agricultural chemical and seed companies B the shake out leaves a few major players able to continue technology development and distribution to the farm sector. The farm machinery and fertilizer industries remain little affected, in terms of restructuring.

Food system. Biotech companies will extend their operations across one or a few food system segments B if not all B to capture the added value. Biotech companies redefine themselves, even more, becoming broad-based food companies, primarily through acquisitions, alliances, mergers and partnerships. Some companies with early leads in certain crops move to dominate the production and processing of those crops.

One company might be structured so as to become predominant in oilseeds (say), providing farm technology to enable low cost production of value enhanced products, intended for component markets or specific end uses. That company would control the raw material from the farm through processing into components; edible oils, industrial oils, animal feed, etc. and on through delivery to the final consumer or end user.

Crop	Farms (Contracting)	Assembly B Identity Preservation	Component Processing	Food Product Manufacture	Consumer/ End-User
A					
B					
C					
D					
E					
C					
F					

Farm sector. The commercial farm sector becomes dominated by two groups. Much of the farm sector continues to produce commodities, but with biotech varieties to further reduce unit costs. A significant portion of the sector moves into production of value enhanced crops and a new system begins to emerge. All biotech companies do not seek to own farmland, but rather contract with farmers (with firm specifications) for value enhanced products. These companies provide farmers with the needed technology and other specialized inputs and instructions (practices), and may even provide financing to farmers (requiring alliance with capital mobilizers). They also take the product from farmers at harvest for identity preservation and to enable movement of the product to specialized processing facilities. Participating farmers are able to shift much of the risk to the technology companies who then use various means (direct contracts with USDA=s Risk Management Agency, for example) to manage it. Required management skills change quickly, information flows shift, markets change character B all fundamentally changing the nature of farms and farmers, especially for those in alliances with biotech companies.

Commodities become components. Commodity production begins to decline and commodities increasingly become higher value components B the Afactory in the field@ notion. Contracting becomes increasingly prevalent and transparency is reduced. Negotiation is much more prevalent and component markets emerge as commodity markets decline.

Business activities extend. Biotech and food companies move crop products to specialized processing facilities and produce components or food ingredients, then move components into next stage processing, and then on into food products and directly to the consumer or to the end-user. Companies may extend their business activities all the way to the consumer with branded products or to just a segment back.

Niche markets thrive. Organic farming continues and natural (non-biotech) niche markets emerge. But, cost and price still dominate the food system, and consumers continue to respond to both.

Food sector grows. The food sector grows in total. Farmers= production costs go down, competitiveness of the system increases in international markets, more higher value products emerge B the value of entire system output increases.

A five year time horizon is a relatively short time in which to see fundamental industry change B it typically is very gradual. Yet, the stage is now set B with enough evidence in hand B to see the broad outlines of food system changes. This view, dim as it may be, likely is enough to propel many firms into significant changes to position themselves for how to expect the system to evolve.

IX. Key Considerations B What to Watch in the Future

The pace of the biotech revolution thus far has been extremely rapid. But, it is only in its beginning stages, and will unfold much more fully in the next five years. As noted earlier, the Astakes@ riding on the continued growth and successful development of the area already are enormous, and will become even more so with each new product and the passage of time. Thus, it is critical from a business perspective to constantly watch the unfolding, monitoring new developments and products, and also factors and forces that could precipitate new directions or change the pace.

The purpose of this section is to suggest some of the many factors that could affect the current development and adoption pace of agricultural biotechnology. Others will emerge over time, but this list suggests those relevant for the near-term.

Key Factors to Monitor

The pace of farmer adoption of existing and new crop and livestock products

Are the economics still there?

The progress in consumer acceptance

Does this continue apace around the world?

Could there be a slowly building backlash?

Actions of regulatory bodies, both domestic and international

Are they changing stances? Becoming more or less stringent?

The development of sanitary and phytosanitary provisions for the next WTO negotiating round

The final negotiation and control of the Biosafety Protocol

Emergence of value enhanced products

For what purpose? How widespread is their use? How big a margin?

Episodes and events

Major risks or scientific blunders

Natures own biological reaction

Activity in the food system

The structure of the food chain B do food companies become more important drivers? Do food companies begin demanding tailor-made components and ingredients B driven from the consumer end Abackward@?

Further marketing chain restructuring B Who is involved? What function will they serve in the food system? Where do they fit in the new system?

Research activity/product approvals/introduction

Which companies introduce products? Is a pattern emerging, suggesting more products to come in a given area?

Foreign companies becoming players? Where?

New Abasic research@ developments reported by public sector agencies

Nutraceuticals and industrial products

A frontier area B any new developments are significant

Size of margins of new products

The role of governments

Encouraging or discouraging B biotech development and expansion

Developing country adoption and reaction

Political stance regarding adoption and use

Pace of adoption of existing products

Development of new products specifically targeted

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APPENDICES

Appendix A. Chronology of Mergers, Acquisitions, Alliances in Ag Biotech, 1993 to Present

1993 **Monsanto purchases 5% of Delta and Pine Land**
For $6 million, Monsanto purchases a share of the leading cottonseed company, and the two collaborate on the introduction of *Bollgard*, Monsanto's Bt cotton.

1994 **American Home buys American Cyanamid** for about $9.7 billion. Analysts and investors have questioned whether American Home might sell the unit as a result of ending a planned $35 billion merger with Monsanto Co. in October 1998. American Home, based in Madison, New Jersey, is the world's seventh-largest drugmaker.

1995 **Monsanto purchases share of Calgene**
For $30 million in cash and an estimated $170 million in assets, including intellectual property, Monsanto purchases 49.9% of Calgene's stock. Monsanto gained access to Calgene's oilseeds technology, and Calgene's seed subsidiary, Stoneville Pedigreed Seed, was licensed to produce Monsanto's *Bollgard* cottonseed.

1995 **Mycogen contracts delivery of Bt corn with Cargill**
Upon commercializing its Bt corn in 1995, Mycogen contracted with Cargill to channel its transgenic seed through Cargill's seed dealer network.

12/95 **Pioneer buys stake in Mycogen**
In a $51 million deal, Pioneer acquires 13.5% of Mycogen and contracts for Mycogen's relevant Bt technology and patents.

1/96 **Monsanto purchases interest in Ecogen**
Monsanto purchases a 14% equity interest in Ecogen for $25 million. Ecogen held an extensive library of Bt genes for its biopesticides business to which Monsanto was able to obtain licensing rights for biotechnology derived commercial applications.

1/96 **DowElanco purchases interest in Mycogen**
DowElanco purchases Lubrizol's 30% interest in Mycogen for $126 million and purchases 15% directly from Mycogen for $26 million plus its United AgriSeeds business unit. In turn, Mycogen purchased Lubrizol's oilseeds technology and patents for $8 million, thus ending Lubrizol's relationship with Mycogen.

3/96 **DeKalb and Monsanto enter into research collaboration**
Signed three cross-licensing agreements covering technology related to insect- and herbicide resistant corn. Monsanto also made an equity investment in DeKalb, acquiring 10% of the Class A voting stock and 45% of the publicly

traded Class B non-voting stock. Monsanto received a non-exclusive license to DeKalb's Bt corn technology, and DeKalb received a non-exclusive, worldwide license for Monsanto's Bt corn.

3/96 **DuPont and Continental Grain in Marketing Alliance**
Formed a marketing alliance to produce and export DuPont's Optimum high oil corn to poultry and livestock industries worldwide.

8/96 **Monsanto purchases Agracetus from WR Grace**
For $150 million, Monsanto purchases Agracetus, a transgenic plant research and development company which had licensed technology to Monsanto previously.

9/96 **BASF buys portion of Sandoz Ltd.'s corn herbicide business**
For $695 million plus $83 million in net working capital, BASF purchases all rights for agricultural uses of Sandoz's corn herbicides in the United States and Canada, including several name brands worldwide and Sandoz Agro, Inc.'s Beaumont, Texas manufacturing facility.

9/96 **Monsanto agrees to acquire Asgrow**
For $240 million, Monsanto acquires Asgrow Agronomics business of Seminis, Inc., a subsidiary of Empresas La Moderna, S.A. Asgrow is a major US soybean seed company with international operations.

9/96 **Monsanto enters into technology collaboration with Empresas La Moderna**
Monsanto becomes "preferred provider" of agronomic and quality traits that will be used by ELM in its fruit and vegetable seed and produce businesses. ELM is the global leader in the vegetable seed market and has 22% market share worldwide.

10/96 **Mycogen acquires Morgan Seeds**
Mycogen paid $27.4 million in cash, including repayment of long-term debt, for Morgan Seeds, Argentina's second largest seed company. Mycogen will merge its Agrigenetics, S.A., subsidiary in Argentina with Morgan to market its seed products in several South American countries.

10/96 **Mycogen forms strategic alliance with Verneuil Holding**
Agreement for Mycogen to exchange its existing European seed business and other assets for an 18.75% interest in Verneuil Holding and to obtain an option to purchase another 16.25% of Verneuil's stock now owned by DowElanco. DowElanco, a partnership of Dow Chemical and Eli Lilly, is Mycogen's largest stockholder, with approximately 48% of the company's common shares. Verneuil Holding markets hybrid seed corn, sunflower, wheat, barley and other seed products.

11/96 **Monsanto and Delta and Pine Land agree to form a cotton seed venture in China**

The venture is between Delta and Pine Land Pte Ltd. and Hebei Provincial Seed Industry Group Corp. Delta and Pine Land China is an 80% owned subsidiary of D&M International, which is jointly owned by Monsanto and Delta and Pine Land. Delta and Pine Land China owns two-thirds of the new venture and one-third is owned by the Hebei Province. The new venture, Hebei Ji Dai Cotton Seed Technology Co. Ltd., will produce and market varieties of cotton seed developed by Delta and Pine Land, which contain the Bt gene technology developed by Monsanto.

11/96 **Monsanto gains 55% of Calgene, Inc.**

Monsanto purchases additional stock of Calgene, giving it a 54.6% of the firm's outstanding shares. The additional purchase amounts to 6.25 million shares, boosting the 49.9% stake it had acquired in June.

12/96 **DowElanco boosts its stake in Mycogen**

DowElanco takes a controlling stake in order to thwart a possible Monsanto acquisition of Mycogen.

1/97 **Monsanto agrees to buy Holden's Foundation Seeds, Corn States Hybrid Services, and Corn States International**

By acquiring Holden's and its two distributors for $1.02 billion, Monsanto becomes the largest US producer of foundation corn (parent seed for hybrids) and will have an important distribution network for its own genetic technology.

1/97 **ArQule Inc. and Monsanto agree to collaboration**

Companies agree to a five-year collaboration to develop new agrochemicals. ArQule will provide some of its molecular compound sets, which Monsanto will use to speed up the development of new crop protection products.

5/97 **Ribozyme and DowElanco sign commercialization agreement**

Ribozyme Pharmaceuticals, Inc. and DowElanco agree to commercialization of RPI's ribozyme technology by DowElanco in several areas of agriculture. Agreement provides DowElanco with a worldwide non-exclusive license to commercialize oil, meal and starch products in corn and other crops. RPI specializes in use of ribozymes (form of RNA) and has demonstrated that ribozymes can be incorporated into corn genomes and modify oil characteristics in corn by changing the ratio of saturated to unsaturated oils.

5/97 **Dow Chemical agrees to buy out minority ownership shares of Eli Lilly and Co. in their agchem venture DowElanco.** Dow paid Lilly $900 million in cash and $300 million of the joint venture's undistributed first-quarter profits. DowElanco has sales of about $2 billion. Dow also is majority owner of Mycogen.

5/97 **Schering-Plough Corp. acquires animal health business of Mallinckrodt Inc.** for $405 million in cash. The unit had 1996 sales of $456 million. With the addition of the Mallinckrodt -veterinary business, Schering-Plough will be the sixth-largest animal health business.

5/97 **Novartis AG agrees to acquire the ag chemical business of Merck and Co.** The business had 1996 sales of $200 million. Novartis has crop protection sales of about $4 billion.

5/97 **Embrex, Inc. acquires technology of Agrimatic Corp.** under development for turkey egg injection processes. Embrex obtained Agrimatic's machinery, technology and patents in this area.

5/97 **Symbiotics Corp. acquires the veterinary diagnostics business of Rhône Merieux.** Symbiotics will pay $12 million in cash, about $3 million in stock, and additional payments conditional on milestones in three years.

6/97 **Zeneca acquires MOGEN International NV** through a proposed public tender offer for its shares. Mogen develops and licenses plant bioengineering technology, including disease resistance genes. This transaction values the company at $50 million.

6/97 **Neogen Corp. acquires Triple Crown division of W.J. Bartus, Inc.** Triple Crown makes and sells equine care products to veterinarians.

6/97 **Pioneer agrees to use the proprietary "GeneScape" genomic bioinformatics and other gene expression technology of CuraGen Corp.** to search for genes for crop performance. Pioneer will make an equity investment of $7.5 million in CuraGen and will fund a five-year research program. Pioneer also will have worldwide seed and ag products rights to any discoveries, while CuraGen will retain rights for human and animal health applications.

7/97 **DeKalb Genetics purchases assets from National Starch and Chemical Company and will conduct joint development of quality grain traits**
DeKalb purchases assets of the Custom Farm Seed (CFS) division. National Starch, a former unit of Unilver and now owned by ICI, is a leading processor of waxy and high-amylose corn and developer of seed products.

7/97 **PE Applied Biosystems division of Perkin-Elmer Corp. acquires Linkage Genetics, Inc.** The combined unit will be called PE AgGen, made up of an animal testing business and a plant testing business. The firm will provide genetic testing services for identification and breeding of plants and animals, for disease screening, and to verify parentage or genetic identity.

7/97 **Delta and Pine Land Co. agrees to have Strategic Diagnostics Inc. develop and supply immunoassay test kits** to assist Delta and Pine in quality assurance and testing of its seed products.

7/97 **Novartis Seeds Inc. is formed by Novartis Seeds AG** to combine its US seed companies into one corporate unit. Formed by the merger of Sandoz and Ciba, Novartis had four companies in the United States: Ciba Seeds, Northrup King, Rogers Brothers and SG.

7/97 **Rhône-Poulenc announces plans to transform itself into a "life sciences" company.** It plans to spin off its chemicals, fibers and polymers businesses into a new company. It also will acquire full control of its Rhône-Poulenc Rorer pharmaceutical subsidiary, and combine it with its vaccine business Pasteur Merieux Connaught. Animal Health and Plant Health will be the other units of the life science group.

7/97 **Royal Gist-Brocades NV acquires the dairy and dietary enzyme business of Genencor International.** The sales of the acquired lines total $3.5 million annually.

7/97 **B.A.T. Industries PLC purchases cigarette business of Empresas La Moderna SA.**

8/97 **DuPont, Pioneer agree to form a research alliance and separate joint venture company (Optimum Quality Grains)**
DuPont invests $1.7 billion in Pioneer, owning 20% of its stock and gaining two board seats. The collaborative venture will study genetic modifications of corn, soybeans, and other oilseeds to improve their oil, protein and carbohydrate composition. The JV will include DuPont's Optimum Quality Grains business and Pioneer's Nutrition Industry Markets business.

8/97 **DuPont to buy Ralston Purina's Protein Technologies International**
$1.5 billion deal – Protein Technologies International supplies about 75% of the worldwide market for soy proteins used in processed foods. This represents a major move of DuPont into the food ingredient business, as PTI is a supplier of specialized soy proteins to the food industry.

9/97 **Monsanto spins-off chemical units into Solutia, Inc.**
The chemical division of Monsanto becomes the independent, public-owned enterprise Solutia, Inc. The life sciences division will retain the name Monsanto and will increasingly focus on technology-driven agricultural products, pharmaceuticals and food ingredients.

9/97 **Novartis Crop Protection signs three-year "chemistry supply" agreement with Chiron Technologies**, a unit of biotech company Chiron Corp. for Chiron to supply combinatorial chemistry libraries generated by Chiron's "multipin" solid-state synthesis technologies.

10/97 **Intellicoat Corp. completes acquisition of Fielder's Choice Hybrids**
Intellicoat, a subsidiary of Landec, paid approximately $3.0 million in cash and $7.8 million in its common stock for Fielder's. Based in Indiana, Fielder's Choice offers a comprehensive line-up of elite corn hybrids and supplies to more than 10,000 producer customers. Intellicoat is developing and testing seed coatings that are designed to reduce seed chilling injury, increase planting flexibility and enable seeds to germinate more rapidly and uniformly. Landec designs and manufactures polymer products for a variety of industrial, medical and agricultural applications.

10/97 **Nestle proposes link with Australian group ForBio Ltd.**
Nestle would market ForBio's genetically modified caffeine-free coffee beans, allowing them to sell caffeine-free beans with improved flavor and aroma more cheaply. ForBio expects that large scale propagation of the new plants with caffeine-free beans would be possible in about two years.

10/97 **Molecular Dynamics and Amersham Pharmacia Biotech sign DNA Microarray Technology Access Agreement with DuPont Agricultural Products**
Molecular Dynamics and Amersham announced their collaboration with DuPont for the continued development of new microarray technologies. DuPont will use these technologies to study gene expression levels in agricultural seed and plant species and to accelerate development of agricultural products leading to greater plant health and disease resistance.

10/97 **Thermo Ecotek signs agreement to acquire Novartis' Bt product line**
Subsidiary Thermo Trilogy Corp. signs agreement to acquire the sprayable Bt-biopesticide product lines from Novartis and Sandoz for approximately $19.1 million in cash. The Bt product line has worldwide annual sales of about $21 million. Thermo Ecotek is an environmental company involved in clean combustion and engineered clean fuels; Thermo Trilogy specializes in naturally derived products for protecting crops and is a world leader in virus, and nematode technology.

10/97 **Monsanto signs plant genetics research collaboration with Millennium Pharmaceuticals**
Monsanto will establish a new subsidiary to collaborate with Millennium in the area of genomics to develop plant and agricultural products. Monsanto will pay Millennium $118 million in upfront licensing and technology transfer fees as part of the collaboration agreement. It also would pay up to an additional $100 million over five years if certain research targets are reached. At the same time, Monsanto hinted that an alliance with a food processor could be in the offing –

enabling biotech crops with enhanced nutritional traits to be processed and kept separate to retain their value.

This deal is said to be the largest ever in the genomics field to date, and is one of the largest cash payments for biotechnology transfer. This also represents a major commitment to genomics research on the part of Monsanto, which also has a nonexclusive deal with Incyte Pharmaceuticals. Monsanto intends to use genomics technology in development areas like pest, chemical and disease resistance for production of improved food additives and for other nutritional products.

10/97 **DeKalb Genetics forms alliance with China National Seed Group Corp.** to produce and market DeKalb corn hybrids in China.

10/97 **AgrEvo forms a new cotton seed business.** The business is a joint venture of Cotton Seed International Proprietary Ltd. of Australia and AgrEvo. AgrEvo, the agricultural joint venture of Hoechst AG and Schering AG, will own 51% of the company, to be called AgrEvo Cotton Seed International. The company will develop cotton varieties incorporating Bt insect resistance and LibertyLink herbicide tolerance.

10/97 **Rhône-Poulenc Agro forms 50/50 joint venture with Biogemma**, pooling their plant biotechnology research resources, targeting plant disease resistance. Biogemma was created earlier this year by French seed companies Limagrain and Pau-Euralis.

11/97 **Mycogen obtains exclusive worldwide rights** for use of the peptidyl membrane interactive molecules technology of Demeter BioTechnologies Ltd. both to develop transgenic disease resistant plants and to fight bacterial and fungal crop diseases by direct spray-on application. Mycogen made an initial \$1.25 million payment, and will make additional milestone payments as products are developed and commercialized.

11/97 **Dow Chemical and Cargill form a joint venture** to be called Cargill Dow Polymers LLC, which will develop and market polylactic acid polymers.

11/97 **Monsanto acquires control of Sementes Agroceres SA**, the leading seed corn company in Brazil. Agroceres gives Monsanto about 30% of the Brazilian seed corn market.

11/97 **Monsanto and Empresas La Moderna, SA form an exclusive relationship with newly-formed ag genomics company Mendel Biotechnology Inc.** Monsanto and ELM each paid \$15 million to fund a five-year research project, and each will get an 20% equity stake in Mendel. Each also will have rights to products of Mendel's research in its area of specialty – Monsanto in agronomics and advances in plant genetics and genomics for several crops, and ELM for research in vegetable seeds and fresh and processed fruits and vegetables.

12/97 **DowElanco forms a partnership with SemBioSys Genetics Inc.** to use recombinant plants to produce proteins for pharmaceutical, vaccine, industrial and feed uses. The first commercial product would be produced in 1999 and the venture is expected to have annual sales of $100 million within the next decade.

12/97 **DowElanco agrees to use Seed Genetics Inc.** to develop, market and license high oil corn inbreds developed using DowElanco technology, as well as future biotech traits. DowElanco will use SGI to commercialize novel biotech-based insect control technology as it becomes available.

12/97 **Hoechst Roussel Vet acquires Tri Bio Laboratories**, a US marketer of poultry vaccines.

12/97 **Agritope Inc. establishes research and development agreement with Vilmorin & Cie**, a subsidiary of Groupe Limagrain Holdings. Vilmorin will purchase $1.5 million in convertible preferred shares in Agritope. Vilmorin also will have an option to purchase additional shares for up to $5.5 million. Vilmorin will provide proprietary vegetable and flower seed varieties and technology for projects at Agritope to be funded by Vilmorin.

12/97 **Garst Seed Company and American Cyanamid agree to collaborate on introducing IMI tolerance** into corn hybrid parents.

12/97 **Zeneca Agrochemicals purchases a 20% equity interest in ExSeed Genetics**, a technology company developing grain products with added value for end users in the milling, feed and food processing industries.

1/98 **Monsanto and IBM form a broad technology alliance** including genomics research. They will work together to develop advanced bioinformatics to identify and map the genomes of major plants and human diseases, using IBM's pattern discovery algorithm "Teiresias."

1/98 **Monsanto and Flamel Technologies SA sign research agreement** for the development of an enhanced formulation of Roundup herbicide. Flamel will apply its Agsome Agrochemical Delivery System to certain proprietary Monsanto products. Flamel will receive R&D payments and potential milestone payments. In addition, Flamel will receive royalties on the sales of all products which utilize the Agsome technology.

1/98 **Mycogen forms joint venture with JG Boswell Company** to develop and market new cotton varieties around the world. Mycogen will hold 51% in the venture, to be called Phytogen Seed Company, LLC and will contribute cash, and cotton breeding material from its earlier cotton breeding activities.

1/98 **ABS Global forms strategic partnership with Infigen, Inc. and Pharming Holding NV** to develop cattle breeding technologies and biopharmaceutical production in cows' milk. The partnership will develop herds of transgenic cattle capable of producing various pharmaceutical products.

1/98 **Monsanto establishes partnership with Ag Canada spring wheat researchers** to develop Roundup herbicide resistant wheat. The multi-year deal will involve Canadian government support through the Federal matching investment Initiative, matching Monsanto funds.

1/98 **Empresas La Moderna increases its share of its seed subsidiary** Seminis Inc. from 62% to 92%, at a cost of $284 million.

1/98 **Dow AgroSciences increases its stake in Mycogen** to 63% in exchange for $75 million and Dow's 16.25% equity interest in French seed company Verneuil Holding. Mycogen will then own 35% of Verneuil.

2/98 **The Scotts Company acquires 80% of privately-held Sanford Scientific Inc.** A plant bioengineering company focused on ornamental plants, Sanford holds exclusive rights to use of "gene gun" technology in turf and ornamentals. Scotts will add Sanford's technologies and expertise to its research to develop turf and flower varieties with improved insect and disease resistance, herbicide tolerance, novel fragrances and other traits.

3/98 **Pioneer sells its 2 million shares of Mycogen Corp. to Dow AgroSciences** at $20.06 per share.

4/98 **Monsanto establishes a plant biotechnology joint venture with Cultor**, a Finnish food and sweetener group, to develop and commercialize micro-ingredients for animal feed production in plants. The new joint venture was based on Cultor subsidiary Finnfeeds International's partnership with Agracetus, which had been formed in 1996 to focus on the development of feed enzyme products in plants.

4/98 **AgriBiotech enters into research agreement with the Noble Foundation** to use plant transformation to develop alfalfa with improved digestibility traits using genes developed by Noble. AgriBiotech will fund the research at Noble and will own the lines developed.

4/98 **Monsanto enters into broad technology agreement with GeneTrace** to investigate the genomes of plants and animals. Monsanto will put $17.2 into privately-held GeneTrace, and obtain options to exclusive licenses to all aspects of GeneTrace's technologies for plant and animal agriculture, funded R&D, equipment purchases, and supply agreements as well as an equity investment.

4/98 **Pioneer expands its gene discovery collaboration with CuraGen Corp.** It will double its funding at CuraGen to at least $5 million annually.

4/98 **Rhône-Poulenc Agro and French research firm Biogemma agree to form a plant biotechnology joint venture** called RHOBIO to pursue agrobiotechnology research in several areas, including disease resistance and enabling technologies.

4/98 **Mycogen acquires Brazilian hybrid seed corn company Dinamilho Carol Productos Agricolas Ltda.** The transaction will be financed through a line of credit from Dow AgroSciences, Mycogen's majority owner. Financial terms were not disclosed. Dinamilho had 1997 sales of about $12 million.

4/98 **DuPont purchases Hybrinova SA**, the hybrid wheat subsidiary of Lafarge SA in France. Hybrinova includes R&D capabilities, a patented chemical hybridizing agent, and a hybrid wheat seeds business. Terms of the purchase were not disclosed.

5/98 **Monsanto agrees to buy Delta and Pine Land** for about $1.9 billion in stock. Monsanto owned 4.7% of Delta Pine and agreed to issue 0.8625 Monsanto share for each Delta Pine share. Delta Pine is a leading breeder, producer and marketer of cotton seed. It currently sells Monsanto's Bollgard and Ingard insect-protected cotton in the United States, Mexico, Australia and China, and Roundup Ready cotton in the United States.

5/98 **DeKalb Genetics agrees to merge with Monsanto** by which Monsanto will acquire all of the shares of DeKalb capital stock that it does not already own. Monsanto, which owns 40% of DeKalb's outstanding shares, has agreed to pay a cash price of $100 for each of the remaining shares or $2.3 billion.

5/98 **Cargill and Monsanto agree to form a worldwide joint venture** to create and market new products enhanced through biotechnology for the grain processing and animal feed markets. The 50/50 joint venture draws on Monsanto's capabilities in genomics, biotechnology and seeds and from Cargill's global agricultural input, processing and marketing infrastructure. Both companies plan to invest $25 million during the first year.

6/98 **American Home Products and Monsanto enter into agreement to combine the two companies** in a merger of equals transaction. The combined company would have a market capitalization in excess of $96 billion. The combined life sciences company will have a new name and strong global businesses in pharmaceuticals, agriculture, animal health, consumer health care and nutrition, with combined expected sales in 1998 of $23 billion. The merger likely will result in a $3 billion R&D budget with $2 billion earmarked for pharmaceuticals and the remaining $1 billion for biotechnology and genomics and related areas.

6/98 **Monsanto Canada acquires a majority equity position in the Guelph-based First Line Seeds Ltd.** The agreement significantly expands both companies' capabilities to serve the Canadian soybean market.

6/98 **Forage Genetics and Monsanto sign letter of intent to collaborate** in the research and development of important agronomic traits that add value to alfalfa. Monsanto will contribute gene technology, and Forage Genetics will contribute alfalfa transformation and germplasm. One of the first commercial targets is likely to be Roundup Ready alfalfa sometime after the year 2000.

6/98 **Pioneer and Monsanto announce agreement** granting Pioneer use of the Roundup Ready gene in hybrid canola. The commercial license, an expansion of an earlier agreement, allows the use of the gene in Pioneer canola varieties.

6/98 **AgriBioTech completes acquisitions of Peterson Seed Co. and W-D Seed Growers** with combined annual revenues of about $25 million. AgriBioTech purchased both companies for about $15 million in cash and 336,365 shares of AgriBioTech common stock with a value of $6 million. Peterson specializes in alfalfa, other forages and turfgrass distribution in the East and Midwest. WD is a leading alfalfa and clover production company managing significant acres of proprietary seed production in the Northwest.

6/98 **Empresas La Moderna agrees to buy two South Korean seed companies** for $117 million. La Moderna will buy the Hungnong Seed Company Ltd. and ChoongAng Seed Company through its subsidiary Seminis. La Moderna also agrees to increase its stake to 90% from 50% in Nath Sluis Ltd., an Indian biotech company, with a $1.5 million investment.

6/98 **Monsanto purchases Cargill's international seed operations** in Central and Latin America, Europe, Asia and Africa for $1.4 billion. The acquisition includes seed research, production and testing facilities in 24 countries and sales and distribution operations in 51 countries. Cargill's international seed businesses specialize in the development and marketing of corn, sunflower and rapeseed seeds and also market soybeans, alfalfa, sorghum, wheat and rice seed. The acquisition does not include Cargill's seed operations in the United States and Canada.

7/98 **Gene Logic and Hoechst Schering AgrEvo GmbH enter into a genomics alliance** targeting the discovery of genes for the development of novel crop protection and crop improvement products. As part of the alliance, Gene Logic will construct a research database using its proprietary gene expression and bioinformatics technologies. The agreement is for an exclusive three-year term with the possibility of a five year extension. Research and database access fees paid by AgrEvo to Gene Logic could reach more than $45 million over the full term of the agreement.

7/98 **Monsanto acquires Plant Breeding International Cambridge Ltd. from Unilever Plc** for about $525 million in cash (20 times revenues!). The deal includes plant breeding operations in Scotland and France, as well as PBI Sattzucht, its German affiliate company. PBI breeds and markets winter wheat, barley, rapeseed, potatoes and other crops, primarily in the UK, France and Germany. PBI's strength in the cereal seeds complements Monsanto's position in corn, soybeans and cotton seeds. Monsanto indicates this acquisition may complete a recent extensive series of seed acquisitions totaling more than $8 billion.

7/98 **Global Agro signs an exclusive agreement with The Salk Institute for Biological Studies** under which Global Agro, an international technology resource organization, will commercialize and license novel plant technologies developed by the Institute.

7/98 **Forage Genetics, Inc. announces a technology commercialization and equity stake agreement with Global Agro.** Forage Genetics will have certain exclusive rights to technology housed within Global Agro, including technology from The Salk Institute.

7/98 **Rohm and Haas forms alliance with Isagro Italia** to distribute crop protection products in Italy. Rohm and Haas agrees to acquire a minority position in Isagro, and Isagro will add a number of Rohm and Haas crop protection products to its existing line.

7/98 **Mycogen Seeds and Novartis Seed amend a cross-license agreement** to allow both companies to market seed corn with their proprietary Bt-based insect resistance broadly through other seed companies. A 1993 cross-license agreement limited each to selling products containing their shared Bt trait only in their respective branded seed products. The amendment permits both companies' distributors to market products containing the trait under the distributors' own brands.

7/98 **Mycogen and Rhône-Poulenc Agro sign a letter of intent to pool plant biotechnology assets** to develop and market biotech plants and seed products containing stacked traits. Initially, cotton and sugarcane containing Mycogen's Bt insect resistant genetics and Rhône-Poulenc's herbicide resistant genetics will be targeted.

7/98 **The Novartis Research Foundation will invest $600 million** over the next ten years to fund the new Novartis Agricultural Discovery Institute (NADI). The creation of NADI is a strategic move to optimize cross-business synergies in genomics research within the agribusiness and pharmaceutical industries.

7/98 **Euribrid and Hendrix Poultry Breeders sign letter of intent** to merge both companies' egg layer breeding businesses, Hisex and Bovans, into a 50/50 joint venture that will be the third-largest layer breeding concern in the world. The merger signals that the avian genetics industry is priming to become part of the consolidation of agriculture that is occurring at the production level. These types of combinations are increasingly necessary for genetics players to access efficiencies, scale and technologies to compete.

7/98 **CuraGen and DuPont agree to collaborate** to explore the power of genomics to enhance crop protection product discovery and development. Under the agreement, CuraGen will use its proprietary processes and technologies to characterize the genetic components and metabolic pathways underlying the action of a highly promising new DuPont crop protection product.

7/98 **AgriBioTech forms a biotechnology commercialization and equity stake agreement with Global Agro Inc. and signs letter of intent with FFR Cooperative** to form a long-term, worldwide research alliance to develop and commercialize improved proprietary seed products. As an equity owner in Global Agro, AgriBioTech will have worldwide exclusive technology rights for all of its turfgrass and forage grass species. AgriBioTech will license its rights from Global Agro to FFR.

7/98 **Forage Genetics, Mycogen and New Mexico State University form a three-way research and development collaboration** designed to improve the forage quality of alfalfa. The initial focus of the program will be the development of transgenic alfalfa with increased bypass protein composition to enhance efficiency of utilization by cattle. Mycogen and New Mexico State will provide alfalfa transformation and gene technology and Forage Genetics will contribute alfalfa germplasm.

7/98 **Mycogen and Croplan Genetics sign a definitive agreement** to co-market TMF brand corn silage hybrids developed by Mycogen. Croplan Genetics, the seed marketing division of Land O'Lakes, will begin taking orders for the silage-specific seed corn later this summer for delivery and planting next spring. The TMF line of seed corn products, sold primarily to dairy and cattle producers, offers improved harvestiblity and better digestibility.

8/98 **Louisiana State University and American Cyanamid sign a global licensing agreement** to bring a new technology to weed control in rice production. The rice lines will be tolerant to a family of herbicides, the imadazolinones, produced and marketed by American Cyanamid.

8/98 **Novartis will invest $20 million to expand its plant biotechnology research facility** in North Carolina. The facility will operate under the name Novartis Agribusiness Biotech Research Inc. and will work closely with Novartis Agribusiness Research centers around the world.

8/98 **A newly established, Belgium-based agricultural biotechnology company, CropDesign NV, will undertake functional genomics research** in plants, focusing on genes that control cell division. CropDesign has completed a $5 million round of financing and expects that the same consortium will invest another $6 million in the 18 months.

8/98 **Forage Genetics and Novartis Seeds agree to work together** to develop, evaluate and release new NK Brand alfalfa varieties with the Roundup Ready trait. Forage Genetics announced earlier this year a global agreement with Monsanto to develop alfalfa germplasm with the Roundup Ready and other gene improvement technologies.

8/98 **Maxwell Technologies and Monsanto sign a technology licensing agreement** covering the use of Maxwell's PureBright technology. The PureBright system utilizes pulsed power to deliver intense light pulses in rapid sequence which kill a wide range of microorganisms in water, pharmaceutical products, on food and packaging surfaces and on medical products.

8/98 **The Missouri Botanical Garden, Washington University, the University of Missouri, the University of Illinois and Monsanto will be partners** in the $146 million Donald Danforth Plant Science Center. The center was created to advance knowledge in basic plant science and generate scientific breakthroughs. Financial commitments included: $60 million from the Danforth Foundation with $50 million pledged over the next ten years, $40 million from Monsanto with an additional $30 million pledged and a 40.3 acre tract of land, and $25 million in tax credits from the state of Missouri.

9/98 **Dow AgroSciences signs definitive agreement with Mycogen** to buy the outstanding shares of Mycogen it already does not own. The Dow division already owns 68% of Mycogen's stock. After the tender, if Dow AgroSciences acquires at least 90% of the Mycogen shares, Mycogen will merge with Dow AgroSciences.

9/98 **Dow AgroSciences announces a $1.2 million research and marketing alliance with Performance Plants Inc.** to introduce a new plant gene technology the could improve the value of canola and other crops. Performance Plant's Growth Enhancement Technology and Augmented Microbial and Plant Expression Technology are expected to produce plants with improved traits resulting in higher crop and oil yields from canola, sunflower, peanuts, cotton and silage corn. GET technology enhances yield and AMPLE technology increases protein or oil content in oilseeds. Performance Plants was founded in 1995 by members of the plant biology group at Queen's University in Ontario.

9/98 **Dow AgroSciences announces plans to invest in a three-year genomics research alliance with BioSource Technologies, Inc.** BioSource has proprietary gene identification technology that will be used to identify and patent novel genes for industrial and agricultural applications. The goal of the alliance is to create specific crop traits desirable for biotech products.

9/98 **Dow AgroSciences forms a new company** to provide the agriculture industry with access to a broad range of biotechnology resources. The new company, Advanced AgriTraits LLC, will serve as a licensing and partnering network. Dow AgroSciences will contribute access to its own proprietary genes and variety of crop traits and hopes to create the most comprehensive portfolio of genetic traits, biotechnology tools and elite germplasm available to companies around the world. Illinois Foundation Seeds plans to sign the first agreement with Advanced AgriTraits.

9/98 **Zeneca announces it will invest $82.5 million in a ten-year research program** in alliance with the John Innes Center and Sainsbury Laboratory. The program will explore advanced genomic techniques for the development of improved wheat varieties. This is the first private investment in cereals at the John Innes Center.

9/98 **Mycogen signs agreements to acquire two seed companies** that develop and market seed products for corn and sorghum in Brazil. The acquisition of Hibridos Colorado Ltda. And FT Biogenetica de Milho Ltda., together with the purchase of Dinamilho Carol Productos Agricolas Ltda in April, position Mycogen to be a significant player in the Brazilian seed corn market.

9/98 **DuPont announces a research alliance with the John Innes Center and Sainsbury Laboratory** to develop new wheat germplasm and grain varieties. Research from the alliance will be commercialized through DuPont Wheat Enterprise, a center that develops cereal-based ingredients for food manufacturing, health care and other industries.

9/98 **Monsanto Australia and Agriculture Victoria Services have agreed to produce canola varieties** which are resistant to Monsanto's Roundup CT Extra Pesticide. Monsanto will pay Agriculture Victoria Services, the commercial arm of the state government's Department of Natural Resources and Environment, to evaluate short and medium term season Roundup Ready canola varieties specifically for Australian conditions. The first commercial variety is expected to be on the market in 2002.

9/98 **Cheminova, the Danish-based producer of generic agrochemicals, reaches a deal with Monsanto** that will allow its Glyfos-glyphosate to be used on Monsanto's GM soybeans in the United States beginning next year's growing season. Cheminova already has a licensing agreement in the United States for glyphosate on ordinary crops.

9/98 **DuPont Crop Protection Products commissions from The Automation Partnership (TAP) its Haystack system** for automated storage, retrieval and sample preparation system to accelerate high-throughput crop protection discovery. Haystack operates as a compound management system, storing neat and dissolved compounds in ideal conditions, scheduling sample preparation and delivering any combination of samples to scientists for screening. This is the first Haystack operation to be implemented in the Agrochemical industry.

9/98 **Bayer AG and AgrEvo GmbH establish an $85 million capital fund** with two US banks to fund new agricultural-related biotechnology companies. The AgBio-Capital Fund will be administered by Burrill & Co. Bank to establish young and innovative companies in the field of plant genetic technology. Bayer and AgrEvo each contributed $25 million to the fund and the remainder will be supplied by Transamerica Business Credit Corp. and Royal Bank Credit Corp.

9/98 **AgriBioTech and Mycogen sign letter of intent** to jointly develop insect resistant alfalfa varieties. Mycogen will screen its Bt gene strain library to identify genes active against the target pests selected by AgriBioTech. AgriBioTech will provide its transformation, regeneration, breeding activities and proprietary germplasm.

9/98 **AgrEvo GmbH agrees to buy Cargill Hybrid Seeds North America** for $650 million by November 2. The acquisition includes research and production facilities in 14 US states and one Canadian province. Cargill will retain ownership of its Inter Mountain Canola (canola seed research and breeding business in Canada and the United States), Goertzen Seed Research (US wheat seed research and breeding business), and Cargill's Canadian seed distribution business.

9/98 **Oxford GlycoSciences Plc signs a five-year, $27.5 million collaboration in plant proteomic research with Pioneer Hi-Bred International.** Pioneer will apply Oxford's proteomics technology platform to its plant gene database to discover genes for improving seed products. The partnership will initially focus on corn and later expand to include research in sunflowers and soybeans. It is estimated that Pioneer has gene sequence information for about 80% of the genes in corn. Pioneer will provide Oxford with a $12.5 million payment up-front, followed by research and development funding and additional payments for certain milestone achievements.

9/98 **Rhône-Poulenc Agro and the National Agricultural Centre for Soya Research in Brazil signed a research agreement** to develop genetically modified soybean varieties suited specifically to tropical markets. The aim of the research is to develop varieties containing genes for insect and disease resistance, as well as tolerance to Rhône-Poulenc's new herbicides.

10/98 **Monsanto agrees to allow herbicide makers to sell products that can be used over its Roundup Ready crops** on the condition that they buy their main ingredient from Monsanto and pay a technology fee. Monsanto entered agreement with Novartis and Cheminova Holding of Denmark, giving them limited rights to make herbicides with glyphosate and to market those products for use with Monsanto's Roundup Ready seeds.

10/98 **Delta and Pine Land is negotiating with the USDA** to exclusively license the US government's interest in the controversial 'terminator' technology patent, a genetic technique that renders crop seed unable to germinate. Under US law, since Delta and Pine worked with USDA to develop the technology, the company has the option to negotiate an exclusive license. Delta and Pine has indicated that it will apply for patents in 87 countries.

10/98 **AgriBioTech seeks to be acquired** as it needs additional resources to fund its growth. The company hired Merrill Lynch & Co. to explore alternatives to boost the value of the company's shares, which have fallen 64% in the last three months. Possible buyers include: Monsanto, DuPont, Novartis, Zeneca, Dow Chemical, or AgrEvo.

10/98 **American Home Products and Monsanto abandon planned combination.** AHP agreed in June to acquire Monsanto in a stock swap valued at $35.08 billion. The collapse leaves AHP once again on its own in the expensive race to develop new drugs, and opens the door to speculation that Monsanto might be a takeover target. Estimated initial sales of the combined company would have totaled $23 billion.

10/98 **Rhône-Poulenc Agro and Dow AgroSciences sign letter of intent to conduct research** in plant biotechnology with the goal of developing genetically modified plants and seed products containing multiple traits. The collaboration will focus on corn, canola, soybeans, sunflower, sugarcane and cotton. Crops will be modified using insect resistance genes from Dow AgroSciences and herbicide tolerance genes from Rhône-Poulenc. This alliance extends the agreement signed by Rhône-Poulenc with Mycogen in July 1998 by adding Dow's insect control genes and opening the effort to additional crops.

10/98 **Eco Soil Systems, Inc. acquired all of Mycogen's license, patent and other proprietary rights to the Xanthomonas campestris microorganism** for use in the control of Poa annua grass.

10/98 **AgrEvo's Dutch subsidiary agrees to acquire Leen de Mos**, a vegetable seed producer in Holland. Leen de Mos operates in Holland and Spain and concentrates on the breeding of various lettuce varieties and glasshouse cucumbers.

10/98 **Novartis Seeds and Land O'Lakes, Inc. form a joint venture** to develop specialty corn hybrids for the food and feed markets. Novartis will purchase a 50% interest in Wilson Seeds, Inc., an independently operated company currently owned by Land O'Lakes. In addition, the white corn genetics of Sturdy Grow Hybrids, a white corn breeding company will also be licensed to the joint venture through Novartis Seeds. Novartis Seeds and Sturdy Grow formed an agreement in March 1998 resulting in the introduction of the first white corn hybrid with the Bt trait.

10/98 **University of California-Berkley sells Novartis access to its Department of Plant and Microbial Biology** for $50 million. $25 million was initially put down to fund the construction of new campus laboratories. Another $25 million will be paid out over the next five years to fund research. Novartis will have the first opportunity to negotiate the rights to take the department's discoveries to market.

10/98 **Forage Genetics establishes a strategic research alliance with FFR** to develop improved alfalfa varieties. The coordinated research program will include technology development, plant breeding and testing. FFR is a plant breeding organization owned by several eastern and southern cooperatives.

10/98 **Bayer AG and Paradigm Genetics Inc. sign contract to collaborate** in the search for novel screening targets which will lead to the development of new herbicides. Paradigm will receive up to $40 million, including milestone payments. Paradigm also will receive success fees for all products that reach the market. This is the third cooperation project in the field of genetic engineering in crop protection that Bayer has signed this year.

10/98 **American Home Products agrees to work with Zeneca Group Plc** to develop new varieties of canola seed by 2001 that are tolerant to the Pursuit and Odyssey brands of imidazolinone herbicides sold by AHP's American Cyanamid unit.

10/98 **American Home Products (American Cyanamid) agrees to work with United Grain Growers Ltd. and AgriPro Seeds Inc.** to develop herbicide tolerant wheat seeds. These could be available in the United States by 2001 and in Canada by 2003.

10/98 **Zeneca Seeds and Cyanamid form global alliance** to combine their technical expertise in canola breeding and crop protection. The agreement links Cyanamid's expertise in herbicide tolerant crops and weed control with Zeneca's expertise in biotechnology and plant breeding. The initial goal is to have improved varieties of SMART canola (tolerant to Pursuit and Odyssey herbicides) on the market by 2001.

10/98 **AgriBioTech in conjunction with Garst Seed Co. agrees to purchase alfalfa business unit of AgriPro Seeds Inc.** (ABI). AgriBioTech is purchasing the alfalfa business unit and the international sorghum business unit, while Garst, a member of Advanta Seeds Group, is purchasing the business units relating to the corn, soybeans, wheat, cotton, sunflowers and domestic sorghum. The program is the world's elite breeder of grazing alfalfa and breeder of the non-dormant variety Salado, the only salt tolerant variety marketed in the world. Garst will retain retail distribution rights for the ABI brand in the United States.

ABT also agreed to acquire Moore Seed Processors and Production Plus+. Moore is the leading handler of creeping red fescue located in Alberta, Canada. The Moore's acquisition will enhance ABT's production access to a number of turfgrass species. Production Plus+ is located in Texas and is a producer and distributor of forage and grain sorghum in the United States and Mexico. The acquisition is expected to bolster ABT's sorghum operation unit, Seed Resource.

11/98 **DuPont and Lynx Therapeutics collaborate on genomics research.** DuPont will have exclusive access to Lynx's DNA sequence analysis technologies for the study of corn, soybeans, wheat and rice. As part of the five-year collaboration, Lynx is assured $22 million and could collect up to $60 million if it delivers on technical milestones and maps the genome of an unspecified crop.

11/98 **DuPont and 3-Dimensional Pharmaceuticals, Inc. announce strategic collaboration.** DuPont has licensed 3-Dimensional Pharmaceutical's proprietary DirectedDiversity technology for generating chemical compounds with a prescribed set of properties. DuPont will have exclusive license to all active compounds identified, and 3DP will receive licensing fees and milestone payments on resulting products.

11/98 **AgriBioTech Inc. sells assets related to the chemical and fertilizer division of Willamette Seed Co. to Wilbur-Ellis Co.** The division has approximately $20 million in sales and the purchase price will be approximately $10 million in cash for fixed assets, inventory and accounts receivable. The chemical and fertilizer division of Willamette Seed specializes in the distribution of chemicals and the manufacturing and distribution of fertilizer to farmers in the Willamette Valley of Oregon, many of whom are contract growers for turfgrass seed production. Sale of the business will allow AgriBioTech to focus on its core forage and turfgrass seed business.

11/98 **Novartis signs 10-year agreement with the Minas Gerais-based cooperative Coopadap (Cooperativa Agricola do Alto Paranaiba)** in order to research and develop hybrid soybean seeds. Novartis plans to launch a new type of soybean seed in Brazil next year. The company reported a US$777 million turnover in Brazil last year, of which US$24 million came from seeds. Novartis plans to invest US$100 million in the country through the year 2000, including the construction this month of a new biotechnology laboratory in Uberlandia.

Appendix B. Strategies of Major Players in Agricultural Biotechnology

AgrEvo

Strategy

AgrEvo's business has two facets; the customer and the technology to address his needs. AgrEvo has technology teams which are based centrally and regional business teams are charged with getting the technology or product to the customer. The technology teams have full responsibility for shepherding a portfolio of molecules or biotech traits from the lab to the market. A corresponding regional business team works with the technology team from the very beginning of the development of any molecule or trait to match the final end-product to the customer's needs. The business teams are in fact organized on a crop basis because it is the crop that determines how much value technology adds.

With virtually no real growth foreseen in traditional crop protection, AgrEvo seeks innovative ways to develop its business; hence the focus on new technologies, new products and new organizational structures. AgrEvo is investing significantly in research and development to ensure the vitality of its product pipeline.

AgrEvo believes the distinction between biotech and non-biotech research will fade in the future. Already, biotechnology is creating value and strategic advantage for them in the seeds business, as well as providing growth opportunities in agrochemicals. AgrEvo expects more of these synergies from its genomics program. With genomics, AgrEvo is targeting new crop protection leads applying the same technologies it uses to focus on crop improvement.

Currently R&D efforts are nearly 80% focused on chemicals and 20% on biotech. However, AgrEvo's balance of R&D spending will increasingly tilt towards biotech in the future.

AgriBioTech

Business

ABT is the largest agricultural seed company in the United States that specializes in developing, processing, packaging and distributing varieties of forage and cool season turfgrass seeds.

Strategy

ABT sees opportunities to enhance profitability in the forage seed sector through increased sales of higher-margin proprietary seeds. ABT also expects forage seed customers will place a premium on new valued added varieties that increase their profitability through increased sales, greater milk or meat production or higher margins. ABT plans to increase its profitability by implementing the following key strategies:

Vertical Integration. ABT seeks to continue to vertically integrate its forage and turfgrass seed operations and thus increase the percentage of the wholesale seed dollar it retains. This is being achieved by owning companies which meet its needs with respect to proprietary research and development, seed processing and the continued development of a national and international sales network.

Development of Proprietary Seed Varieties. ABT believes that its research capability will allow it to develop proprietary seed varieties with value-added characteristics that improve yield, nutritional quality, persistence, and insect and disease tolerance for forages and quality, color, persistence and insect and disease tolerance for turfgrasses. ABT believes that development of propriety seed varieties through traditional genetic research programs has become an essential foundation for transforming the forage and turfgrass seed sectors into high margin businesses similar to the other proprietary seed sectors.

Biotechnology Access. ABT expects that the introduction of proprietary seed varieties with value-added characteristics will provide the genetic platform from which specific value-added genes may be introduced through biotechnology. ABT is seeking to become the licensee or partner of choice for owners of biotechnology genes in order to accelerate introduction of these value-added genes to its customers through biotechnology.

ABT plans to continue to build its company in the United States by acquiring and integrating companies which specialize in research and development, processing and distribution. Its acquisition strategy consists of acquiring geographically dispersed companies with strong management and operations.

Research

ABT estimates that each of the industry's top five alfalfa research companies, including its wholly-owned subsidiaries, spend more on proprietary alfalfa variety development than is spent by all industry members on variety development for all other forage species combined. This minimal level of research expenditure on variety development for secondary forage species reflects the current fragmented nature of the forage sector, and the lack of critical mass within any one company to justify research and development spending.

ABT's goal is to alter this scenario by consolidating the industry and achieving the economies of scale necessary to conduct research on both alfalfa and non-alfalfa forages. This research is aimed at developing value-added forage seed products with improved characteristics in yield, nutritional quality, persistence, and disease and insect tolerance. ABT believes biotechnology breakthroughs similar to those experienced with other crops will follow in the forage and turfgrass sectors, although possibly not for some time.

BASF

Business

BASF Agricultural Products group a large agricultural chemical company with annual turnover of US$ 2.0 billion. This position was achieved after the 1997 integration of the Sandoz Ltd. corn herbicide business. To accommodate its expanded operation, BASF began construction of an 80,000 square-foot expansion of our laboratories and administrative offices in Research Triangle Park, NC.

Strategy

With an expanding line of products, BASF is seeking innovative solutions to crop protection needs in corn, soybeans, wheat, cotton, rice and specialty crops, such as fresh fruits and vegetables. In 1997, BASF introduced Pyramit miticide/insecticide for fruits and almonds, and Nexter miticide/insecticide for citrus.

BASF intends to make an investment in plant biotechnology of US$60 million per year. BASF hopes to develop its first gene-modified varieties within the next five years. In contrast to early genetic varieties providing only agronomic advantages, BASF intends to target varieties with advantageous consumer or processor related characteristics. BASF intends to cooperate with and invest in existing plant breeding companies.

Calgene

Business

Calgene is a biotechnology company that is developing a portfolio of genetically engineered plants and plant products for the food, seed and oleochemical industries. Calgene's research and business efforts are focused in three core crop areas – fresh produce, edible and industrial plant oils and cotton – where Calgene believes biotechnology can provide substantial added commercial value in consumer, industrial and seed markets.

In March 1996, Calgene and Monsanto entered into an agreement under which Monsanto contributed Gargiulo, Inc., $30 million and certain oils and produce related technology to Calgene in exchange for a 49.9% equity interest in Calgene. In November 1996, Calgene and Monsanto closed a transaction whereby Monsanto purchased 6,250,000 shares of Calgene common stock, bringing Monsanto's equity investment in Calgene to approximately 54.6%. In 1997, Monsanto acquired all of the outstanding shares of Calgene.

Strategy

Calgene's business strategy is to build and grow operating businesses in its three core crop areas to facilitate the market introduction of genetically engineered proprietary products. Implementation of this strategy will provide Calgene with direct access to markets where it will sell fresh and processed plant products having improved quality traits and/or cost of production advantages, and to markets where it will sell seed that has been engineered with value-added agronomic traits. Calgene has selected fresh produce (tomatoes and strawberries), edible and industrial plant oils (canola) and cotton as its core crops on the basis of the following criteria:

- Calgene has efficiently transformed and regenerated these crops with proven plant transformation methods, thereby making the crops suitable candidates for genetic engineering.
- These crops offer significant long-term profit opportunities for genetically engineered products in seed (input) or crop and product (output) markets, or both.
- Market characteristics offer a realistic opportunity to attain a leading market share in the input or output markets, or both.

Calgene addresses its core crop opportunities through a combination of operating subsidiaries and commercial partnerships. It is developing genetically engineered, premium quality, fresh market tomatoes and strawberries through its Gargiulo subsidiary. In plant oils, Calgene has developed and is growing genetically engineered laurate canola and is developing a portfolio of genetically engineered canola oils, some of which it intends to distribute and process through its Calgene Chemical subsidiary. Calgene Chemical currently distributes industrial and edible vegetable oils, and manufactures vegetable oil-based specialty chemicals. In cotton, Calgene is currently developing and marketing conventional seed varieties and genetically engineered herbicide resistant seed varieties through its Stoneville subsidiary and is developing and intends to market genetically engineered insect resistant cotton varieties.

In certain market segments where the capital investment and other commitments required to serve the markets exceed Calgene's resources, it has established relationships with major corporations which have leading positions in the targeted segments. These arrangements provide for the other company to pay Calgene royalties based on genetically engineered product sales or usage, to purchase genetically engineered and nongenetically engineered plant-based raw materials from Calgene or to assist in product and market development.

DeKalb Genetics Corp.

Business

DeKalb Genetics Corporation, the No. 2 US seed company, is engaged in the development of seed (corn, soybeans, sorghum, alfalfa and sunflower) and hybrid swine breeding stock. DeKalb uses the application of genetic research to agriculture and is one of the leaders in ag biotech with over 10 biotech corn patents issued over the past two years.

In May 1998, DeKalb agreed to merge with Monsanto, by which Monsanto acquired all of the shares of DeKalb capital stock it did not already own.

Strategy

DeKalb has continued to expand its biotechnology programs. In 1997, a new research station dedicated to developing grain quality traits began operating in Ames, Iowa. An additional breeding program directed to transgenes that influence agronomic traits is slated to open in 1998.

DeKalb also is expanding research into corn with specialty processing traits. The company entered into a research collaboration with National Starch and Chemical Company, a leading processor of waxy and high-amylose corn.

Influx of New Products. Conventionally bred hybrids remain the mainstay of DeKalb's product line, but hybrids with specific traits are accounting for a growing portion of sales volume. In 1997, the company released a record 25 corn hybrids to the marketplace, including 15 products with specific traits.

DeKalb plans to play a leadership role as specific trait products capture a growing share of the market. In 1998, the company made available greater supplies of Bt corn hybrids, while launching the industry's first Roundup Ready corn hybrids. No other competitor will have significant quantities of Roundup Ready corn until the year 2000. DeKalb, which developed the Roundup Ready trait, should also benefit from licensing royalties when competitors enter this market segment.

Speed to Market. DeKalb has made significant investments to accelerate the commercial release of its specific trait products. In 1997, a new foundation seed facility opened in Hawaii, and operations in Puerto Rico were greatly expanded, allowing the company to increase its ramp-up capabilities. Winter resources for research are also critically important to reduce product development cycle time. In 1997, DeKalb nearly tripled its winter research acreage, expanding in Hawaii and opening a new station in Mexico.

Argentina is another key player in DeKalb's speed-to-market objective. For years, the company has grown seed in South America to compensate for US production shortfalls. Now, however, off-season production has become an important means of getting more of the newest products into the hands of customers.

Increasing Capital Expenditures. Overall, seed capital expenditures are increasing dramatically, driven by the company's sales growth and quality upgrade objectives. DeKalb spent more than $48 million in 1997 on North American seed activities, compared with $22 million in 1996. By far the largest project was a new drying, shelling, and bulk storage facility in Constantine, Michigan. The company is also in the process of modifying a newly acquired plant in Dwight, Illinois to condition foundation seed. Another key project in 1997 was a $3 million seed research complex which houses DeKalb's plant pathology, corn germplasm resources, and a corn breeding program.

Looking further ahead, the research pipeline is full of promising products, both conventional and specific trait. DeKalb also stands to benefit from a strong technology position and its cross-licensing agreements with other industry participants. DeKalb expects a growing stream of licensing revenues as biotechnology continues to transform agriculture.

Research

DeKalb commits significant resources (approximately 13 percent of DeKalb Seed's consolidated worldwide revenues in fiscal year 1997) to the research and development of improved products. Total worldwide research and development expenditures by DeKalb Seed were $50.2 million, $40.9 million and $36.7 million for fiscal years 1997, 1996 and 1995, respectively. About 80 percent of research expenditures are for corn, the DeKalb product line with the most attractive margins, while biotechnology research expenditures represented approximately 12% of total seed research and development spending for fiscal year 1997.

DNAP Holding Corporation

Strategy

DNAP Holding positioned itself to bring genetically improved varieties of fruits and vegetables to consumers worldwide. Its strategic assets include premier biotechnology capability, recently augmented by a technology collaboration agreement with Monsanto, more than 15,000 acres of field-grown crops under cultivation in Mexico and the US, and a distribution network covering the United States, Canada, and Mexico.

DNAP Holding will continue developing corporate alliances in agricultural biotechnology, which could include contract research for the production of proprietary varieties using plant genetic engineering, joint ventures for commercialization of its technology and licensing arrangements for its technology. Research includes proof of concept research with new genes or production of genetically modified plants.

DNAP Holding also will bring new products to the marketplace, supplementing the widely distributed Master's Touch brand fruits and vegetables, which offer a consistently high quality choice to consumers in grocery stores, restaurants and foodservice operators. Second-generation products incorporating genetic engineering breakthroughs are nearing the production stage.

Research

Continuing projects at DNA Plant Technology fall into two categories: developing new techniques for altering the genetic makeup of plants, and the application of those techniques for the development of improved varieties. DNAP scientists pioneered and patented Transwitch technology which allows scientists to selectively regulate (switch off) genes that control undesirable traits in plants, e.g., ethylene production in tomatoes and softening in peppers. DNAP scientists also have pioneered and patented many of the enabling technologies necessary for genetic engineering in plants, such as promoters, gene introduction technology, selectable markers, and plant regeneration technology. DNAP scientists have used these technologies to develop new varieties of tomatoes with a shelf life of more than double the typical tomato shelf life of 7-10 days.

DNAP continues to conduct contract research and joint venture development programs with government agencies and a large number of major companies throughout the world, as well as with the ELM subsidiary Seminis Vegetable Seeds, the global leader in commercial vegetable seed sales.

Dow AgroSciences LLC

Strategy

Dow AgroSciences is increasing its focus on biotechnology as the Dow Chemical Company's strategy is to use biotechnology as a key platform to accelerate Dow's growth. The company plans to implement this strategy by leveraging existing capabilities and creating new strengths for Dow.

Dow is making significant investments in biotechnology to provide the company with core enabling technology, fund projects in functional genomics, extend an external network for acquiring technology and capture value. To enhance core enabling technology, Dow AgroSciences continues its internal buildup of research and development capabilities related to biotechnology. Dow Chemical supports Dow AgroSciences' research with its core capabilities in analytical and materials sciences, biocatalysis, process research and information technology. Through Dow's involvement with Mycogen Corporation, the company has access to a significant library of gene technology coupled with the ability to put genes in plants.

Dow also is building a unique data base to assemble the massive amount of data generated in genomics research. With this data base, Dow will be able to leverage its high-speed data analysis as well as applications development expertise and apply it to creating new products.

Dow also is acquiring technology through an external network that includes research and marketing alliances with Performance Plants and SemBioSys. Other alliances include the Plant Biotech Institute at the University of Saskatchewan and, through Mycogen, collaborations with Rhône-Poulenc and Pioneer.

Dow's investment in leading seed companies around the world includes Mycogen Seeds (North America), Morgan Seeds (Argentina), Dinamilho (Brazil), Verneuil Semences (Europe) and Phytogen (US). Dow AgroSciences has formed a new company, Advanced AgriTraits LLC, to serve as a clearinghouse for companies seeking to bolster their biotechnology offerings via strategic alliances and/or licensing arrangements for genetic traits, germplasm and other biotech capabilities. Illinois Foundation Seeds, Inc. has indicated in a letter of intent that it plans to license to Advanced AgriTraits rights to a substantial portion of its portfolio of proprietary germplasm.

Dow also has created value-added grain alliances with food processors and marketers. To capture greater value from our development of seeds with improved quality traits, Dow's approach is to form alliances with companies rather than acquire assets. Two current projects involve growing canola and sunflowers for retail vegetable oil producers in cooperation with grain handlers and oil seed crushers.

In biotechnology, Dow AgroSciences has more than 20 projects expected to contribute significant sales between now and 2005. Dow Chemical also plans to develop industrial applications for biotechnology that include making chemicals and plastics highly cost effective with unique functionality.

Research

Dow AgroSciences LLC and Rhône-Poulenc Agro have signed a letter of intent to conduct research in the field of plant biotechnology to develop genetically modified plants and seed products containing multiple traits (see Rhône-Poulenc box).

Dow also plans to invest in a three-year genomics research alliance with Biosource Technologies, Inc., of Vacaville, Calif. The ultimate goal of the alliance is to create specific crop traits desirable for biotechnology products. This will be achieved by combining proprietary functional genomics discovery technology from Biosource with Dow's sophisticated assay technology. The result will be processes that are faster and more efficient than historical methods of functional genomics.

Dow AgroSciences and Oxford Asymmetry International (OAI) have signed an 18-month research agreement involving the discovery, synthesis, and screening of new chemical compounds for agricultural applications. Under this agreement, OAI will provide Dow AgroSciences with novel compounds that show potential for biological activity and for use as agricultural chemicals.

Delta and Pine Land Company

Business

Delta and Pine Land Company, the No. 1 cotton seed marketer/producer in the United States, is primarily engaged in the breeding, production, conditioning and marketing of proprietary varieties of cotton seed in the United States and other cotton producing nations. D&PL also breeds, produces, conditions and distributes soybean seed in the United States. Monsanto acquired the company in May 1998.

Since 1915, D&PL has bred, produced and/or marketed upland picker varieties of cotton seed for varieties that are grown primarily east of Texas and in Arizona. It has used its extensive classical plant breeding programs to develop a gene pool necessary for producing cotton varieties with improved agronomic traits important to farmers, such as crop yield, and to textile manufacturers, such as enhanced fiber characteristics.

Strategy

Collaborative biotechnology licensing agreements which were executed with Monsanto in 1992 and subsequently revised in 1993 and 1996, provide for the commercialization of Monsanto's Bollgard ("Bt") gene technology in D&PL's varieties. The selected Bt produces proteins toxic to certain lepidopteran larvae, the principal cotton pests in many cotton growing areas. Monsanto created a transgenic cotton plant by inserting Bt genes into cotton plant tissue. The gene and related technology were patented or licensed from others by Monsanto and were licensed to D&PL for use under the trade name Bollgard.

In D&PL's primary markets, the cost of insecticides is the largest single expenditure for many cotton growers, exceeding the cost of seed. The insect resistant capabilities of transgenic cotton containing the Bollgard gene is intended to reduce the amount of insecticide required to be applied by cotton growers using seed containing the gene. In October 1995, Monsanto was notified that the EPA had completed its initial registration of the Bollgard gene technology, thus clearing the way for commercial seed sales. In 1996, D&PL sold commercially for the first time two NuCOTN varieties in accordance with the terms of the Bollgard Gene License and Seed Services Agreement between D&PL and Monsanto.

D&PL also has developed transgenic cotton and transgenic soybean varieties that are tolerant to Monsanto's Roundup herbicide. In 1996, such Roundup Ready plants were approved, and in February 1996, D&PL and Monsanto executed the Roundup Ready Gene License and Seed Services Agreement which provides for the commercialization of Roundup Ready cotton seed. In February 1997, D&PL and Monsanto executed the Roundup Ready Soybean License Agreement which provides for the commercialization of Roundup Ready soybean seed.

D&PL has agreements with other providers of technology that it is evaluating for potential commercial applications and/or introduction. D&PL also contracts with third parties to perform research on the company's behalf for germplasm protection techniques and enabling technologies that have potential commercial applications in varietal crops around the world.

DuPont

Strategy

Maintaining world class efforts in biotechnology and applying it to both the life sciences and traditional chemical businesses, DuPont is positioned to capture the full potential of biotechnology. One-third of DuPont's annual research and development expenditure is focused on these businesses. In 1997, DuPont strengthened its position in the feed, food and industrial materials markets through an alliance with seed company Pioneer Hi-Bred International and through the purchase of Protein Technologies International from Ralston Purina. These actions were to strengthen its position as one of the top suppliers of crop protection and enhanced food and feed products worldwide.

DuPont believes that the application of biotechnology will redefine the company in the coming decades. While currently applied largely in the pharmaceuticals, food and feed businesses, biotechnology also has enormous potential in its traditional materials businesses. DuPont expects that it will eventually produce chemicals and specialty products from plants and microorganisms instead of petrochemicals.

Life Sciences consists of Agricultural Products, with a focus on crop protection chemicals and an increasing role in biotechnology and food. Principal agricultural products include Optimum modified corn and soybeans, the herbicides Basis Gold and Accent for corn, Classic , Canopy and Synchrony for soybeans, Glean and Ally for cereals, Londax for rice, Staple for cotton, and a range of fungicides and insecticides.

DuPont's new relationships with recognized life sciences entities will hasten its becoming a major player in the world of biotechnology. The alliance with Pioneer Hi-Bred International and the purchase of Protein Technologies International from Ralston Purina positions DuPont for major long-term growth in what it views as a business with virtually unlimited potential. ***Unlike other biotech companies that are focused on the current wave of input traits for insect and herbicide resistance, DuPont chose to forgo these opportunities and focus on grain qualities, or "output traits."***

DuPont is convinced there will be strong linkages between biotechnology and the specialty materials that are its stock in trade. Biotech methodology will be effectively employed in the design of sophisticated materials formerly dependent on traditional chemical processes. One outcome is more environment-friendly products in terms of manufacturing processes, applications and ultimate disposition.

DuPont is looking outside for resources that, in years past, it would have developed internally. During 1997, it announced $7 billion in acquisitions, with approximately half of that investment to strengthen its competitive position in biotechnology which, in effect, will redefine its life sciences businesses.

Mycogen

Business

Mycogen Corporation is a diversified agribusiness and biotechnology company that develops and markets seed for improved crop varieties and provides crop protection products and services. The company is organized into two business segments, Seed and Crop Protection. In 1998, Mycogen became a wholly-owned subsidiary of Dow AgroSciences.

The Seed segment produces and markets seed for major agricultural crops and uses biotechnology and traditional and marker-assisted breeding to develop crop varieties with genetically enhanced pest and disease resistance, improved vegetable oil profiles and other value-added characteristics. The Crop Protection segment manufactures and markets environmentally compatible spray-on biopesticide products and operates Soilserv, Inc., which provides crop protection services to growers of high-value crops.

Strategy

Mycogen's primary focus is on expanding and strengthening its global seeds business through internal growth, acquisitions and alliances. It also is exploring opportunities to leverage its technology and intellectual property assets to generate additional revenue by developing and marketing value-added input and output traits in markets not served by the Seed segment. The Crop Protection segment continues to focus on providing specialized products and services to high-value niche markets such as vegetables, tree fruit and nuts, vines and ornamentals.

Mycogen has made significant progress toward its goal of building a global seeds business. Agrigenetics, Inc., d/b/a Mycogen Seeds, a wholly-owned subsidiary of Mycogen, ranks fourth in the United States in sales of seed corn, accounting for the majority of its seed revenues, second in hybrid sunflower seed sales, and among the top five in soybean, sorghum and alfalfa. In September 1996, Mycogen purchased all of the common stock of Santa Ursula S.A.A.I.C. e I., which did business as Morgan Seeds, the third largest seed company in Argentina. Mycogen merged Morgan Seeds into one of Mycogen Seeds' existing wholly-owned subsidiaries, Mycoyen, S.A., which continues to do business under the name Morgan Seeds. Morgan Seeds ranks second in Argentina in seed corn sales and third in hybrid sunflower seed sales and is a major exporter of seed products throughout South America.

Through an alliance with Verneuil, the company also has established a foothold in the important European seeds market. Mycogen also maintains cotton breeding and transformation programs and is evaluating opportunities to enter the cotton seed business to leverage its strong intellectual property position for insect resistant cotton.

Mycogen maintains extensive corn and sunflower breeding programs in both North and South America. Mycogen also maintains breeding programs in cotton, soybean, and sorghum. The objectives of these programs is to develop diverse pools of germplasm that allow it to produce seed products with outstanding agronomic characteristics and wide adaptability that makes such seed products suitable for planting in various climates and maturity zones. Mycogen has entered into licensing agreements to expand access to materials for breeding and developing new products.

In the area of value-added genes for input traits, Mycogen has discovered and patented more than 50 unique Bt protein toxin genes, some of which are being used to develop crop varieties with resistance to insects and other pests. The company maintains a program to discover novel genes with insecticidal activity. It also has licensed genetic material to confer disease resistance and tolerance to herbicides used for weed control.

Mycogen's collaboration with Pioneer to develop Bt-based pest resistance traits in corn, soybean, canola, sunflower, sorghum and wheat has allowed Mycogen to accelerate product development programs in those crops. The Bt gene sequences that produce these pest resistance traits are covered by issued or pending patents.

Specialty Oils - Mycogen Seeds has developed sunflower, rape (canola), corn and peanut seeds with genetically enhanced oil properties. In 1996, it acquired rights to oilseed technology for those crops which it had developed jointly with SVO Specialty Products, a subsidiary of Lubrizol. In addition to producing and marketing seeds for these crops, Mycogen has forward-integrated into production of crude high oleic sunflower oil for AC Humko, the largest marketer of edible oils in the United States. Also in 1996, Mycogen entered into a collaborative program with DowElanco Canada, Inc., a wholly owned subsidiary of DowElanco, to conduct a joint breeding program and investigate and develop value-added traits in canola. The company has targeted other specialty oil opportunities that would be of interest to food ingredient suppliers and purchasers. These projects, currently in a research phase, address opportunities for reduced or no saturate vegetable oils, new feedstocks for all natural hard butters where chemical modification (such as hydrogenation) of the fats can be reduced or eliminated, and fats tailored for use by the confection industry as substitutes for cocoa butter.

High Oil Corn – Through third party license agreements, Mycogen will introduce, for the 1998 planting season, a limited quantity of seed for corn that produces up to twice as much oil as traditional grain corn.

Novartis AG

Strategy

Novartis's overall strategy is to focus on life sciences by disposing of noncore units and using acquisitions to fill out its agriculture and drug lines. In agriculture, Novartis Seeds continues to develop and expand a unique, comprehensive germplasm base using modern breeding technologies, while continuing to conduct extensive research on genetically modified seeds in order to confer traits such as insect resistance, disease resistance and tolerance to environmentally-friendly herbicides.

Research

Research goals include the transfer of genes resistant to herbicides, insects and various diseases; improved yield in adverse climatic conditions or difficult terrain; creation of hybrid species; and improved overall quality of the plant.

In July 1998, The Novartis Research Foundation announced the planned investment of $600 million over the next ten years to fund one of the largest initiatives in plant genomics. The first step will be the creation of the Novartis Agricultural Discovery Institute (NADI), which will be one of the largest single research endeavors dedicated to agricultural genomics research and development.

NADI will be a key to Novartis' strategic focus on biotechnology research, maximizing cross-sector cooperation between Crop Protection and Seeds, and working in tandem with the Novartis Agribusiness Biotech Research facility at Research Triangle Park, North Carolina, and with numerous Novartis research stations worldwide. The new Institute will add to Novartis' substantial number of alliances with leading institutions and major universities in the United States and overseas.

Optimum Quality Grains (DuPont/Pioneer)

Business

Founded in January 1998, Optimum Quality Grains, L.L.C. (OQG) develops, produces and markets value enhanced ingredients derived from unique grains and oilseeds that meet specific customer needs for food and feed, worldwide. OQG was formed to develop markets and to market products developed through the research alliance between DuPont and Pioneer Hi-Bred International, Inc.

This research alliance is one of the world's largest private agricultural R&D collaborations. OQG applies research in genetic modification of soybeans, corn and other oilseeds to improve their oil, protein and carbohydrate composition.

Strategy

Leveraging Demand. To create demand for Optimum High Oil Corn, OQG worked with both overseas livestock producers and domestic grower/feeders. This was because both groups have limited access to other economical animal feed energy sources. The experience allowed OQG to better quantify additional values associated with the product, such as improved milling characteristics, reduced dust and enhanced overall consistency resulting from the identity preservation process. As a result, US acreage of Optimum High Oil Corn has grown from virtually nothing to more than one million acres in just a few years.

Familiarizing Consumers. To create a market for Optimum Low Saturate Soybeans, which produce oil that has only half the saturated fat of commodity soybean oil, OQG partnered with Iowa State University and Hy-Vee Food Stores, Inc., a major Midwest grocery store chain. LoSatSoy oil is on Hy-Vee shelves, fueling demand for a value enhanced soybean that farmers can grow profitably on thousands of acres to support new markets.

Stacking Amino Acid Traits For Better Nutrition. OQG will soon be launching technology that stacks multiple, selected amino acid traits on the Optimum High Oil Corn platform. By listening to the needs of livestock and poultry producers, OQG learned that increased amounts of important amino acids such as lysine and methionine would offer additional, important advantages to these customers and focused our efforts on fulfilling these needs.

Taking The "Beany" Taste Out Of Soybeans. A significant barrier to the increased use of soy protein in the human diet has been the characteristic "beany" taste and the presence of indigestible sugars which cause abdominal discomfort. Research efforts directed at these problems have now produced Optimum High Sucrose Soybeans, which contain higher sucrose for better flavor and have greatly reduced levels of indigestible carbohydrates.

OQG licenses technology to independent seed companies which market seed capable of producing Optimum grains. Optimum Quality Grains partners with more than 80 such seed companies, supplying research, testing and promotional support.

Pioneer Hi-Bred International

Business

Pioneer Hi-Bred International, Inc., develops, produces, supports and sells a lineup of seed genetics including corn, soybean, alfalfa, canola and wheat varieties, as well as sorghum, canola and sunflower hybrids. In addition, Pioneer offers a line of plant microbial products to enhance the value of silages and high moisture grains.

Strategy

Pioneer is an industry leader in research and product development, owns what it believes to be the industry's finest collection of crop genetics (germplasm) the key to its success of in the past and its future. Researchers are focused on improving this germplasm base using the latest in technology.

Seed corn and soybean seed are expected to maintain a dominant role in Pioneer operations for the foreseeable future. Pioneer is focused on developing superior corn hybrids for grain and silage as part of the animal feed market.

Improving traditional agronomic traits continues to be important as researchers are working to develop hybrids with superior harvestable yield, and create products that reduce crop losses, grower input costs, and risk through agronomic improvements such as insect, disease, and herbicide resistance.

End Use Focus. Within Pioneer Hi-Bred's overall research emphasis, focusing on the end use is an area of increasing importance. In the coming years, end users such as livestock feeders, grain processors, food processors, and others are expected to demand specific qualities in the crops they use as an input in developing other products. In the future, the commodity grain market is expected to segment based on these changing demands, which will increasingly influence seed purchase decisions. Developing products for the specialty and identity-preserved markets is also important to the soybean research focus. Pioneer researchers are leading the way in developing soybean seed with improved meal and oil qualities suitable for these markets.

The emphasis on end-use markets was dramatically strengthened by an alliance with DuPont, which was completed in early fiscal 1998. In the alliance, Pioneer and DuPont formed a broad research alliance and a separate joint venture company (Optimum Quality Grains) designed to speed the discovery and delivery of new crop traits that benefit end users. A key focus of the research alliance is to develop corn, soybeans, and other oilseeds with traits that deliver added value for end users of these products.

Research

Currently, Pioneer has more than 1,000 research agreements with third parties specializing in technology that can help improve the core germplasm base. Recent alliances will allow Pioneer to map the genes that make up its seed products. Pioneer was the first commercial seed company to undertake such a project. The goal is to determine which genes, or groups of genes, control valuable traits and eventually have the ability to arrange these genes to work more efficiently in its commercial products.

Protein Technologies International (DuPont)

Business

Protein Technologies International is a leading producer of dietary soy protein, fiber food ingredients, and leading marketer of polymer products worldwide. Principal markets served include food, meat, paper/paperboard and animal feed industries. DuPont purchased Protein Technologies International from Ralston Purina in 1997 to strengthen its position as a producer of enhanced food and feed products.

Products

PTI's food ingredient products include:

- SUPRO and SUPRO-PLUS brand isolated soy protein (high-quality proteins used in processed meats, beverages and nutritional products);
- FIBRIM brand soy fiber (an excellent source of dietary fiber for baked goods, cereals, snacks and beverages); and
- KEYCEL and SOLKA FLOC powdered cellulose (used in many foods as functional ingredients or non-caloric bulking additives).

PTI's soy polymer group manufactures and markets a line of functional soy polymers designed for high-quality paper and paper-board coating products under the PRO-COTE brand name.

Manufacturing: PTI has two domestic food soy protein plants in Memphis, TN, and Pryor, OK, and two international soy protein plants located in Hannan, Japan, and Ieper, Belgium. In addition, there is an industrial protein plant in Louisville, KY, a powdered alpha cellulose plant in Urbana, OH, and a dairy food systems plant in Hager City, WI.

Key Alliances

Nutritious Foods, Inc., an affiliated company of Protein Technologies International, was created in 1995 to develop and market food products using soy protein.

Rhône-Poulenc

Business

Rhône-Poulenc, S.A. is a leading life sciences company, growing through inovations in human, plant and animal health. Rhône-Poulenc Ag Company is the North American arm of one of the world's leading makers of crop and plant protection products. Rhône-Poulenc's crop protection and plant improvement product line includes insecticides, herbicides, fungicides, nematicides and plant growth regulators.

The Specialty Products Group provides products to such markets as golf courses, lawn-care companies and for nursery, sod farm and ornamental plant production.

Strategy

Rhône-Poulenc expects the crop protection market to be dominated by the introduction of new crop protection products supplemented with biotechnology. Therefore, the company is focusing on innovation in both chemistry and biotechnology as the best way to serve its customers and lay a foundation for future growth.

Rhône-Poulenc has invested significantly in ag biotechnology, devoting about 15% of its innovation effort in that area, and expects to introduce three new genes for herbicide tolerance by the year 2003. However, unlike many other companies in the crop protection business, Rhône-Poulenc believes that it is not essential to own a seed company. Instead, Rhône-Poulenc's strategy is to focus on innovation and invest in the development of genes that offer a distinct competitive advantage over other companies. This allows the company to spend resources on research and product development instead of incurring the expense of acquiring a seed company. Additionally, the company has expanded partnerships and alliances to a number of key players in the seed and biotech research industries.

Rhône-Poulenc also is counting on its new lines of "environmental friendly" and "low-dose" crop protection products to contribute substantially to the company's future growth.

Research

Recently, Dow AgroSciences LLC and Rhône-Poulenc Agro, signed a letter of intent to conduct research in the field of plant biotechnology to develop genetically modified plants and seed products containing multiple traits. The proposed research alliance would supplement the collaboration proposed in the July 1998 letter of intent between Rhône-Poulenc Agro and Mycogen Corporation, a majority-owned subsidiary of Dow AgroSciences, by adding Dow AgroSciences' significant portfolio of non-Bt insect control proteins and by opening the cooperative efforts to additional crops.

The collaboration will initially focus on modifying six crops; corn, canola, soybeans, sunflower, sugarcane and cotton. The crops would be modified using proteins developed by Dow AgroSciences, which provide insect resistance, and Rhône-Poulenc Agro's gene sequences, which provide tolerance to herbicides, including glyphosate, bromoxynil and isoxazoles. The letter of intent also provides for future expansion of the research collaboration to allow for the incorporation of additional traits.

Zeneca

Strategy

Zeneca Plant Science (ZPS) focuses on applying bioscience skills to enhance the quality and efficiency of downstream food production while conferring environmental benefits.

Zeneca is one of the leading food biotechnology companies in Europe and is the first company in the world to have a genetically modified whole food cleared for sale on both sides of the Atlantic. Its first commercial tomato puree product, made from genetically modified tomatoes, is now sold in 'Sainsbury' and 'Safeway' stores across the UK. ZPS has embarked on several research projects to improve food quality and crop yields through biotechnology including the development of anti-fungal proteins for the banana industry.

Recently, Zeneca Seeds and Cyanamid formed a global alliance to combine their technical expertise in canola breeding and crop protection. The agreement links Cyanamid's expertise in herbicide tolerant crops and weed control with Zeneca's expertise in biotechnology and advanced plant breeding. The initial goal is to have improved varieties of SMART canola (tolerant to the herbicides Pursuit and Odyssey which kill conventional canola) on the market by the year 2001. The companies will use transgenic and mutagenic procedures to speed transfer of the SMART trait into superior Zeneca hybrids and open-pollinated canola varieties. This technology, applicable to Argentine and Polish canolas, and mustards, will be licensed to other seed companies worldwide.

Appendix C. Glossary of Terms

Agriculture and Agri-Food Canada: Performs risk assessments for new types of products which are forwarded to it by the Canadian Food Inspection Agency (CFIA).

Amino acids: Naturally occurring biological molecules with a variety of functions. Among the amino acids, there are 20 that are used as building blocks for making proteins.

Animal and Plant Health Inspection Services (APHIS): Agency of the U.S. Department of Agriculture that regulates genetically modified plants through a permit system.

Arabidopsis thalia: A member of the mustard plant family that could become the first plant to have its entire genome sequenced (through the Arabidopsis Sequencing Program).

Biosafety Protocol: A treaty currently being negotiated aimed at governing international movements of genetically modified organisms would require Advanced Informed Agreement (AIA), under certain conditions, for international shipments of GMOs.

Biotechnology: The science of shifting DNA and creating specific traits by modifying the genetic makeup for plants and animals.

BollGard (Bt): Monsanto-developed biotech insect resistant cotton variety with Bt bacteria engineered into genes.

***Bacillus thuringiensis* (Bt):** A naturally occurring bacterium that produces a protein toxic to certain insects that cause significant crop damage. The bacteria are often used for biological pest control. Recently, the gene that codes for the toxic protein has been engineered into other soil bacteria and also directly into some crop plants.

Bacteria: One of the five kingdoms of living things. Bacteria are structurally simple single cells with no nucleus.

Bacteriophage (or phage): A virus that infects bacteria. They are used by genetic engineers to introduce genes into bacterial cells.

Base: One of the building blocks of DNA or RNA. A nitrogen containing base combines with sugar and phosphate molecules to make nucleotide. The four bases in DNA are adenine (A), guanine (G), cytosine (C), and thymine (T).

Base pair: Two nucleotides held together by a weak bond between complementary bases. In DNA molecules, adenine is paired with thymine and guanine is paired with cytosine.

Bovine Somatotropin (BST): Also known as Bovine Growth Hormone (BGH). One of the first genetically engineered products to be commercialized, this synthetic hormone is manufactured by bacteria using copies of a dairy cow's genes and is intended to boost milk yields.

Canadian Food Inspection Agency (CFIA): Lead agency in Canada responsible for regulation of agricultural products.

Chromosomes: Threadlike bodies that carry the genes. They can be seen in the nucleus of a cell just before it divides in two.

Clone: A collection of genetically identical copies of gene, cell, or organism.

Codex Alimentarius: International body formed to establish international food standards.

Consultative Group on International Agricultural Research (CGIAR): Cosponsored by the United Nations and the World Bank; probably the world's preeminent public agricultural research body.

De-commoditization: Refers to instances in which the value of crops is driven largely by the unique characteristics of the particular variety, and not by the commodity itself.

Dolly: The first mammal (a sheep) cloned from a cell of an adult. Introduced in February 1997.

DNA: Deoxyribonucleic acid. The genetic material of organisms (except retroviruses), made of two complementary chains of nucleotides wound in a helix.

Environment Canada: Works with regulatory agencies to help develop standards for products that may affect the environment.

Environmental Protection Agency (EPA): The US federal agency charged with safeguarding the environment, which includes regulating the use of pesticides, and approving the use of pesticide resistant genetically modified plants.

Enzyme: Any of various proteins, formed in plant and animal cells or made synthetically, that act as organic catalysts in initiating or speeding up specific chemical reactions.

European corn borer: Insect pest of the lepidoptera class that causes severe damage and production losses to corn.

Federal Food, Drug and Cosmetic Act (FFDCA): Legislation that authorizes EPA to set tolerances or establish exemptions from the requirement of a tolerance for pesticide residues in or on food crops.

Federal Insecticide, Fungicide, Rodenticide Act (FIFRA): Legislation that gives EPA the responsibility for regulating the distribution, sale, use and testing of pesticides in order to protect humans and the environment.

FlavrSavr tomato: Developed by Calgene. First high-profile genetically modified food to reach the consumer marketplace.

Food and Drug Administration (FDA): The US federal agency responsible for regulating food additives and new foods (except meat and poultry products), cosmetics, medicines, and animal feed and drugs. FDA normally gives final clearance for GMO plants.

Functional Foods: Food products that provide a health benefit beyond basic nutrition, either because they have been fortified with added nutrients or genetically modified to contain higher levels of nutrients. Products currently on the market are all nontransgenic.

Gene: The physical unit of inheritance, made up of a particular sequence of nucleotides on a particular site on a particular chromosome.

Gene expression: The conversion of the gene's nucleotide sequence into an actual process or structure in the cell. Some genes are expressed only at certain times during an organism's life and not at others.

Gene flow: The passage of particular genes through a population of animals or plants as a result of cross-fertilizations within the population. Also referred to as "gene jumping."

Gene markers: Genes used to identify certain regions of a chromosome and then to trace the inheritance of that region related to a particular trait.

Gene providers: Biotech/agrochemical firms which license their genetic technologies to seed companies in order to gain access to the farmer for their products.

Genetically Modified Organism (GMO): Transgenic organisms. Any organism that contains a gene from a different organism. GMO's result from the use of biotechnology.

Genome: All the genes in a complete set of chromosomes.

Glufosinate: Chemical name for the active ingredient in AgrEvo's Liberty herbicide. DeKalb has developed GR corn tolerant of herbicides containing glufosinate.

Glyphosate: Chemical name for the active ingredient in the Roundup herbicide.

Health Canada: Reviews novel foods for food safety and sets data requirements for safety and risk assessments of all foods.

High throughput (HTP) elevators: Large elevators with fewer separations than their smaller counterparts, designed to handle large volumes of a few grains.

Human Genome Project: An international research effort begun in the 1980s to map and sequence all 100,000 or so genes found in human DNA.

Identity Preservation (IP): Separating crops with specific attributes from other crops without those same attributes, or biotech crops from non-biotech crops, in the handling process. Crops that have been separated are referred to as Identity Preserved.

IMI: Imidazolinone herbicide tolerant.

Input Traits: Modifications to the seed that reduce farmers' input costs by changing requirements for cultivation, herbicides and insecticides.

Intellectual Property Rights (IPR): The rights given to persons for unique creations of their minds. They usually give the creator an exclusive right over the use of his/her creation for a certain period of time. Protection is normally in the form of patents or copyrights.

In-vitro Fertilization: Fertilization method in which eggs are obtained from the female animal's ovaries, matured and fertilized in a culture environment, and either implanted into recipients or frozen at an early stage.

Lepidoptera: A large order of insects, consisting of butterflies and moths, characterized by two pairs of broad wings covered with very fine scales. The larvae are caterpillars. The European corn borer belongs to this order.

Liberty Link seeds: Products with built-in tolerance to AgrEvo's Liberty herbicide.

Life Science: As in life science companies. companies involved in development of products to enhance the function of plant, animal and human life.

Living Modified Organism (LMO): A term frequently used in Canada to mean transgenic organisms. Any organism that contains a gene from a different organism. LMO's result from the use of biotechnology.

Malathion: Insecticide commonly used to control boll weevils.

Molecule: The smallest particle of an element or compound that can exist in the free state and still retain the characteristics of the element or compound.

Monogastrics: Hogs and poultry.

Nontransgenic: Products containing built-in traits (e.g., insect resistance, herbicide tolerance or modified oil, starch or protein compositions) but are developed using traditional breeding methods, rather than biotechnology.

Novel Food Regulation: EU requirement that food processors label final products that "may contain or may consist" of GMOs.

Nutraceuticals: Modified products with a specific health function. These products have yet to be introduced commercially. Often interchanged with the term "functional foods".

Patent Cooperation Treaty (PCT): A multilateral patent approval body, whose members include the NAFTA countries, Europe, the former Soviet Union, China, India, Japan, Brazil, Australia, New Zealand and some African nations.

Pest Management Regulatory Agency (PMRA): A unit of Health Canada. Has responsibility for registration and regulation of pest control products, and it evaluates products that have pesticidal properties.

***Photorhabdus luminescens*:** A new insecticidal toxin discovered at University of Wisconsin. May challenge the current monopoly of Bt for insect resistant crops.

Phytic Acid: Referred to as phytate. A naturally occurring plant compound used to store phosphorus, and can inhibit an animal's phosphorus absorption.

Plant Variety Protection Act: Passed in 1970 to permit genetic traits and transformation methods to be patented.

Porcine somatotropin: Form of somatotropin (synthetic growth hormone) for use in hogs. The product has not been adopted to the extent of BST.

Porcine Stress Syndrome (PSS): A genetic condition that contributes to the incidence of pale, soft and exudative pork, and that has been found to be associated with other problems such as lower conception rate, smaller litter size and higher mortality rate.

Posilac: Monsanto's branded version of bovine somatotropin.

Recombinant DNA: Novel DNA made joining DNA fragments from different sources.

Roundup Ready: Developed by Monsanto, products tolerant to Roundup herbicide.

Sanitary and Phytosanitary (SPS) Agreement: Concluded in the Uruguay Round. Established for the first time that SPS regulations should be used only in response to legitimate health or scientific concerns.

STS soybeans: Developed by DuPont, soybeanss are tolerant to sulfonylurea herbicide, commonly referred to by the brand name Synchrony

Stacked Trait Product: A product that contains multiple traits or modifications. The first of these, Monsanto's Roundup Ready/BollGard cotton, appeared on the market in 1997.

Terminator Gene: Developed by USDA, and Delta and Pine Land Company (variously called a "terminator gene" or a "killer gene"), Disables a seed's ability to germinate when planted.

Transgenic: Any organism – plant, bacteria or animal – that contains a gene from a different organism. Transgenic products result from the use of biotechnology.

Value enhanced products: Altered composition and/or characteristics to make the product more valuable than a corresponding commodity.

World Trade Organization (WTO): International body established on January 1, 1995, by the Uruguay Round negotiations. Acts as a forum for international trade negotiations, handles trade disputes, monitors national trade policies, administers WTO trade agreements.

YieldGard: Insect-protected corn developed by Monsanto. Provides resistance to the European and Southwestern corn borers.