Agricultural Research: Beyond Food And Fiber

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During the early twentieth century, the business models for most industries were vertically integrated. For example, agriculture was only about food and fiber. As we moved into the twenty-first century the world changed radically, forcing industries to adjust. Vertical integration gave way to horizontal integration models. Agriculture has become integrated

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into a variety of industrial sectors—pharmaceuticals, energy production, chemicals, *etc.*—resulting in new challenges and opportunities. The following is a brief discussion of these challenges and opportunities with an emphasis on agricultural contributions to society beyond food and fiber. The principle influences for this discussion were:

- Thomas Friedman's national best-selling book *The World is Flat* (Friedman, 2005),
- a recent USDA-Research, Education and Economics (REE) Task Force report to Congress (Danforth *et al.*, 2004) supporting the formation of a National Institute for Food and Agriculture, and
- a personal survey of NABC institutions.

One of the strong influences for moving business models toward horizontal integration has been the shrinking world or, as Thomas Friedman would put it, “flattening” of the world. As outlined by Friedman (2005), rapid advances in technology and communications during the past two decades have led to a “smaller,” more integrated world with greatly increased interaction and interdependence among nations. This has resulted in exceptional changes in the global market. For example, world commerce and trade have been significantly changed with the wealth created by three billion people in India, China and the former Soviet Union. In response to these factors, most major industries have made significant changes in their strategic planning, and agriculture is no exception. As the world has become smaller, US agriculture has been pressured to make changes to meet the new challenges of the global market.

Loss of Competitive Edge

Concurrent with these changes in the world scene, the competitive edge of American farmers relative to those of many other nations has begun to be eroded. Historically, US farmers enjoyed a leading role in world agricultural production, using innovative technologies and products to produce crops with higher yields at lower costs. However, many internal factors such as increased land prices, higher labor and fuel costs, and a vast array of other economic pressures are increasing the cost of production and reducing our competitive advantage.

Accordingly, today, US agriculture faces increased levels of international competition in the areas of food and fiber production. For instance, cotton producers in the Mississippi delta have expressed the opinion that Chinese and Indian agriculture are probably second only to the weather in determining US cotton prices. Considering another commodity, the United States is no longer the world’s lowest-cost producer of soybeans (Danforth *et al.*, 2004), with Brazilian farmers selling soybeans at competitive prices; this cost advantage has resulted in midwest farmers cooperatively buying farms in Brazil to produce soybeans for export to the United States.

Ethanol production represents another example. Brazil can export sugarcane ethanol at prices below corn-based production in the United States (Ribeiro, 2005). Clearly, the flattening of the world has resulted in a redefinition of agricultural practices and global competition.

Genetic Engineering

In the past, US agriculture maintained its competitive advantage in the world market through science and technology, most recently through advances in biotechnology and, in particular, genetic engineering. With the commercial introduction of genetically modified (GM) plants more than a decade ago, US farmers were given a significant competitive advantage globally. In 2005, approximately 87% of soybean acreage, 52% of corn acreage, and 79% of cotton acreage in the United States were planted using GM seeds. The advantages of GM soybean, corn and cotton with herbicide resistance and *Bt* insecticides have led to acceptance of the technology in several global markets, resulting in more than $27 billion of global economic benefits (Brookes and Barfoot, 2005). However, as this technology is more widely accepted nationally and internationally, the competitive advantages to US farmers are being lost, resulting in price adjustments and concurrent diminishment of the previously enjoyed advantages of GM soybean, corn and cotton.

Further erosion of the economic advantage of GM plants has occurred as a result of their rejection by Europeans and a few other countries. It should be kept in mind that, while GM plants have been profitable to those in the agricultural industry, consumers have never realized any economic advantage from buying GM foods. Furthermore, because many of the companies selling GM seeds also sell chemical herbicides and insecticides, the ecological and health benefits of GM foods, as compared to those produced through alternative practices, have not been aggressively explained to the public. Hence, the general consumer public has not been moved to embrace GM foods as positive technologies.

Despite dwindling economic incentives, there remain several non-pecuniary advantages to the use of herbicide tolerance and insecticide biotechnologies. Farmers use these products because of their convenience, value, simplicity and relative heath/environmental safety compared with the alternatives (Marra and Piggott, 2006).

Confronted with the economic pressures of increasing international competition, diminishing economic value in some of the current agricultural technologies, increasing costs of labor, land and fuel, and poor consumer acceptance of GM products, the US farming industry is facing significant changes. In the past, US agriculture has used advances in science and technology to maintain healthy and competitive business environments. However, since the 1970s, public funding for agricultural research has been stagnant in real terms. Why has this occurred? Well, our grocery stores are well stocked with inexpensive food, and Americans pay a lower percentage of their gross domestic product for food than does any other developed nation. Fewer than 2% of Americans are involved in agriculture, compared with approximately 40% of the world population. And last but not least, the representatives of farming states are a minority in the US Congress.

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NIFA Proposed

Despite these negative factors, several members of Congress have been very concerned about the future of US agriculture and the trends in international competition. They called for a USDA REE Task Force to consider the possible formation of new National Institutes for Agricultural Research. After several months of interviews, meetings and deliberations, the committee recommended that Congress create a new granting agency, the National Institute for Food and Agriculture (NIFA), which would fuel the technological advances required to keep US agriculture strong and competitive. As of the time of this writing, NIFA has not been created.

Table 1. Recent advances in agriculture research by NABC-member institutions.

ENERGY
Corn-based ethanol production systems
Switchgrass biomass energy conversion

FOOD SAFETY/DIET
Lactose-free milk products
Vaccine development against *Campylobacter*
Lactococcus lactis resistance to bacteriophage
Human skeletal research
Enhanced sorghum germplasm
Vitamin-D fortification of cheese
Rapid detection of food-borne pathogens
Replacing antibiotic treatments of poultry
Eggs enriched with omega-3 fatty acids
Plant-derived edible vaccines
Comparative cattle-human genome mapping
Porcine xenotransplantation and drug production
Medical properties of arid-plant compounds

NEW PRODUCTS
Soy oil-based inks
SuperSlurper; high absorbant starch formulations
Bovine growth hormone
Canine parvovirus vaccine
Hybrid striped bass
Feline leukemia vaccine
Megalac fat utilization by lactating cows
Control of fescue toxicosis in beef
Diagnosis of feline immonodeficiency virus
Research on articular cartilage
Vaccines for equine influenza and strangles
Mastitis prevention and management

HEALTH
Tests for avian influenza
High production of proteins in insect cells
Elastomeric absorbable polymers
Biolistic gene gun
Mouse model for asthma
Human fertility assessment
Improved amino acid composition of crop plants
Poultry model for human autoimmune diseases
Isoflavonoid content in corn
Taxol biosynthesis pathway and genes

ENVIRONMENT
Controlled eutrophication remediation
Transgenic fish industry risk
Impact of global warming on agriculture
Remediation of radionuclides
No-till crop production
Enviropig™ utilization of phosphorus

PLANT BIOLOGY
Automated plant tissue-culture system
Peach-tree pest resistance
Sequence of the peach genome
Long-term storage technology
Cold response pathways in plants
Papaya ringspot virus resistance
Soybean resistance to *Phytophthora sojae*
Resistance to barley yellow dwarf virus
Floral scent research
Sequencing the rice genome
Insect resistance to *Bt* proteins
Engineering wheat flowering time
Strawberry breeding
Winemaking technology
Porcine cloning
Improved grain handling
New selectable markers in plant breeding
Maize genome sequencing
Plant resistance to the herbicide dicamba

NABC member institutions were solicited to submit information regarding recent agricultural research beyond food and fiber with significant societal impacts.

Societal Contributions

During the course of the USDA study, it became clear that a new institute would garner little public support based solely on food and fiber issues, partly because the benefits of agricultural research beyond food and fiber are not generally recognized by either the public or legislators. Therefore, NABC member institutions were solicited to submit information regarding recent agricultural research beyond food and fiber with significant societal impacts. A general description of the submissions received is listed in Table 1, revealing some outstanding contributions to society.

Biofuels

One such area of impact is biofuels, which, because of the current energy crisis in the United States, have become an important topic in US agriculture. In recognition of this, biofuels and energy sustainability will be the subject of the NABC meeting to be held at South Dakota State University in 2007. With close to a hundred ethanol plants and an annual capacity of nearly 4.5 billion gallons (Karnowski, 2006), agriculture is beginning to have an impact on US energy problems. About 39% of ethanol capacity is farmer-owned. Another thirty-five ethanol plants and nine expansions—with a combined capacity of more than 2.2 billion gallons—are being built in 2006.

Currently, 90% of the US ethanol production uses corn kernels as feedstock, contributing to a decrease in corn exports and a further decline in the agriculture balance of trade. In the first quarter of 2006, agricultural exports exceeded imports by only 5%, and corn prices rose from $2 to $2.50/bushel. Clearly, as oil prices continue to increase, corn and ethanol prices will also increase, as will the acreage of corn planted.

Approximately 2% of today's transportation fuels are derived from biomass and blended fossil fuels; Shell Oil has predicted that "the global market for biofuels such as cellulosic ethanol will grow to exceed $10 billion by 2012" (Greer, 2005). A recent study funded by the Energy Foundation and the National Commission on Energy Policy, entitled *Growing Energy: How Biofuels Can Help End America's Oil Dependence*, concluded that, if the United States follows an aggressive plan to develop cellulosic biofuel, farmers could see profits of $5 billion/year by 2025, with the need to import Persian Gulf oil decreased by two-thirds. At the same time, increased biofuel usage could reduce US greenhouse-gas emissions to 1.7 billion tons/year (22% of 2002 emissions) (Greene *et al.*, 2004).

As the United States has been forced to develop new energy strategies, the federal government and general public, unlike most areas of agriculture, have taken a serious interest in the biofuels industry. In order to promote the industry, the federal government currently subsidizes ethanol at $0.51/gallon. In addition, because of the cheap sugarcane ethanol available from Brazil, the US government has placed importation tariffs on ethanol. According to Kenneth Cook, president of the Environmental Working Group, corn is America's No. 1 subsidized crop (Grist, 2006); the federal government paid $37 billion in corn subsidies between 1995 and 2003. These actions point to the long-term importance that biofuels will play in future US energy plans.

In the meantime, a debate continues over the scope and impact of biofuels, their sustainability, and their potential impact on greenhouse-gas emissions. Part of this debate centers on the use of starch vs. cellulosic feedstocks and fermentation vs. gasification/syngas processes. In addition, there are debates regarding food vs. fuel consumption, price supports and import tariffs. The bottom line for US agriculture is that biofuels hold great potential value for the nation, socially, environmentally and economically. Hopefully in the next few years the scientific, economic and political issues surrounding biofuels will be resolved. Clearly, the biofuels industry will continue to be a growing segment of the US farm industry because of contributions to energy security, potential to reduce greenhouse-gas emissions, and support for agriculture (Koonin, 2006).

Biobased Industrial Materials

While biofuels and prices at the gas pump have been responsible for a public recognition of solutions to energy problems through corn, the public is much less aware of other industrial uses of farm crops in replacing petroleum imports. For instance, corn sugar and other agricultural raw materials are also being used to replace petroleum-based products to produce polyhydroxyalkanoate (PHA) plastics. In February of 2006, Archer Daniels Midland Company (ADM) and Metabolix announced that ADM will build the first commercial plant to produce a new generation of natural plastics that are eco-friendly and based on sustainable, renewable resources; the plant will have a capacity of 50,000 tons/year. Corn feedstocks are also being used to produce the polyester fabric Sorona® and polylactic acid (PLA) plastics. These are just three of the many manufactured goods for which plant-derived materials can be substituted for the petroleum products required hitherto for their production.

Contributions to Healthcare

In addition to prices at the gas pump, the American public is particularly interested in scientific advances in human health. Agricultural research at NABC and other agricultural research institutions is also making important contributions in the area of human health. Americans pay a higher percentage of their gross domestic product for healthcare than does any other developed nation (Cowling *et al.*, 1996). Many such advances have their foundations directly or indirectly in the findings of studies originally aimed at agricultural problems. For instance, using an animal model, Michigan State University veterinary researchers are using biotechnology to find the genes responsible for human asthma (Ewart *et al.*, 2000), which currently affects about 20 million Americans (ALA, 2006). These studies, which are elucidating the common molecular pathways that result in asthma, can open the way to treatments directed at the basic mechanisms of this disorder.

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A procedure now widely used to produce proteins of medical importance was originally discovered by entomologists at Texas A&M University in the course of studies on the use of naturally occurring insect viruses as alternatives to chemical insecticides. They discovered a method for introducing foreign genes into insect viruses and producing large amounts of foreign protein when the virus replicated in insect cells (Smith *et al.*, 1983); the baculovirus expression vector system (BEVS) is now used in thousands of research laboratories and more than seventy commercial licenses have been issued (TAMU, 2006). The BEVS has been used to produce many pharmaceutical proteins including vaccines to treat Hong Kong "bird-flu" virus and SARS; most recently it was used to produce a highly effective vaccine against human papilloma virus, a known cause of cervical cancer.

Other human vaccines are also being produced in agronomic plants. Worldwide, two billion humans are infected with hepatitis B and an estimated one million die each year from it and its complications (HBF, 2006). Researchers at the Boyce Thompson Institute and Arizona State University have developed plants that produce several recombinant proteins including vaccines against Norwalk virus (Mason *et al.*, 1996) and hepatitis B (Thanavala *et al.*, 1995).

Tremendous advances in the assessment of fertility have been made by scientists at South Dakota State University through the development of the sperm chromatin structure assay (SCSA) (Evenson and Wixon 2006). Using bovine sperm models, these researchers developed the first computerized, instrument-based test capable of measuring the genetic integrity of thousands of sperm cells in just seconds. More than 10% of US couples experience infertility problems (WebMD, 2006), and this method, which can be used to rapidly measure abnormalities that relate to defects in paternal genes, is now becoming widely used at human fertility clinics.

Researchers at Washington State University are elucidating the enzymes and processes involved in taxol biosynthesis. Taxol, a drug isolated from the bark of the slow-growing Pacific yew in the early 1960s, has been proven effective in the treatment of breast, ovarian and other cancers. The researchers are in the process of determining the metabolic pathway of the drug, isolating the pathway genes, and investigating the use of yew tissue culture as a means of producing the drug (Jennewein *et al.*, 2004). The development of a high-yielding, low-cost production system for taxol would be a major accomplishment.

A plant physiologist at the Boyce Thompson Institute discovered that vitrification (a type of sugar crystallization) is responsible for long-term maintenance of seed viability. The vitrification protects seed proteins from denaturation and inactivation (Sun and Leopold 1994). This protective factor has been applied to many other proteins. Most recently it was discovered that insulin could be stabilized by vitrification, making it possible to replace injection therapy with inhalation therapy (Potera, 1998). According to the American Diabetes Association approximately 21 million US adults and children deal with diabetes every day.

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Technological Advancements

Agricultural research has made many contributions to biotechnology beyond enhancing food and fiber production. For example, Cornell University researchers invented the gene gun, a "biolistic" method of transforming plant tissue by shooting DNA-coated metal particles into cells. It allowed the transformation of plant species that at the time were recalcitrant to transformation by the widely utilized Ti-plasmid method (Ye *et al.*, 1990). Having been used to successfully transform agricultural as well as non-agricultural plants, animal cells, insect and fish embryos, algae, fungi, pollen, bacteria, and intracellular organelles, it has proven to be a very significant technological advancement in biotechnology.

Another extremely significant agriculture-based technology that promises to have a great impact on society is the discovery of RNA silencing in plants through RNA interference (RNAi). Discovered initially by researchers at the John Innes Centre (Baulcombe, 1996), this has opened the door to blocking the expression of nearly any eukaryotic gene. The potential uses, particularly in the treatment of human diseases, are enormous and a large number of human clinical trials testing RNAi-based drugs are currently underway. The 2006 Nobel Prize in medicine was awarded for the discovery of RNAi; however, the vital groundwork in plants was ignored.

Spreading the Word

These are a few of the more recent examples of significant contributions to society through agricultural research with application beyond food and fiber production. Except for possibly the plant-made vaccines, the general public and—possibly more importantly—Congress are unaware of these products of agricultural research. The agricultural industry does not have a lobbying group such as the health industry's Research!America (www.researchamerica.org), which refers to itself as "an alliance for discoveries in health" and advertises the latest discoveries in health science, particularly to legislators. Research!America claims that its educational activities are responsible for the recent doubling of the NIH budget. But, if Research!America were to advertise the new human papilloma virus vaccine or the new insulin-inhaler therapy, the key contributions of agricultural research would probably not be emphasized; to the best of the author's knowledge, only one newspaper, the *Ithaca Journal*, has carried a report of the agricultural connection to the insulin inhaler technology to the general public.

The agricultural community would benefit greatly by emulating the public relations strategy of NASA's space program. NASA promotes its research by advertising and promoting discoveries and products that have affected society beyond space travel (NASA, 2006). Among the dozens of spin-off products and technologies are charged coupled device (CCD) chips for digital imaging breast biopsies, a device to control chronic pain, new golf-ball designs, enriched baby foods, water-purification systems, freeze-dried food technology, home-security systems, smoke detectors, flat panel television sets, *etc*. As briefly listed above, agricultural research has similar spin-off products that could be used to enhance the public's recognition of its broad value to society beyond food and fiber.

When it comes to recognition of scientific value, the most widely accepted measure of excellence has been the Nobel Prize awards. In agricultural academic circles, the awards to Wendell Stanley for plant viruses in 1946, to Norman Borlaug (the "father of the Green Revolution") in 1970, and to Barbara McClintock for mobile genetic elements in 1983 are well known. Most of the additional fourteen awards listed in Tables 2 and 3, involving discoveries in the plant and animal sciences—with significant impacts in other areas of human health and well-being—are not generally recognized by the public.

Table 2. Agricultural research in plants: Nobel Prize awards.

1910	Otto Wallach	Chemistry	Plant smells and tastes
1915	Richard M. Willstatter	Chemistry	Plant pigments, especially chlorophyl
1930	Hans Fischer	Chemistry	Structure of haemin & chlorophyl
1937	Albert Szent-Gyorgyi	Physio/Med	Structure of vitamin C
1937	Paul Karrer	Chemistry	Carotenoids, flavins & vitamin A
1945	Artturi I. Virtanen	Chemistry	Nutrition & fodder preservation
1946	Wendell Stanley	Chemistry	Plant viruses
1949	John Boyd Orr	Peace	Global production and distribution of food
1950	Robert Robinson	Chemistry	Plant products: alkaloids
1961	Melvin Calvin	Chemistry	Carbon pathway: photosynthesis
1970	Norman E. Borlaug	Peace	The Green Revolution
1983	Barbara McClintock	Physio/Med	Mobile genetic elements

Table 3. Agricultural research in animals: Nobel Prize awards.

1966	Peyton Rous	Physio/Med	Rous sarcoma virus induced tumors in chicken
1975	Dulbecco, Temin & Baltimore	Physio/Med	Transformation via RNA-dependent DNA polymerase
1989	Bishop & Varmus	Physio/Med	Cellular origin of retroviral oncogenes
1990	Murray & Thomas	Physio/Med	Organ and cell transplantation
1997	Stanley Prusiner	Physio/Med	Prions: scrapie of sheep

While many scientists are familiar with the Rous sarcoma virus and the Nobel Prize awards for research with this virus, few realize that it was an agricultural research problem. The Rous sarcoma virus, which affects chickens, served as an ideal model for many important discoveries including the first identification of viral-induced tumors and the discovery of RNA-dependent DNA polymerase. Obviously, research on this chicken disease has had significant impact in the field of human-cancer research.

The public is also aware of mad cow disease (bovine spongiform encephalopathy, BSE) and, to lesser degrees, of kuru and Creutzfeldt-Jacob diseases. Stanley Prusiner was awarded a Nobel Prize for his discovery that these diseases are mediated by prions. Less well known by the public is that the discovery of prions and their diseases began with research on scrapie disease of sheep, another agricultural research problem that led to significant contributions to human health.

In Conclusion

Agricultural research in the United States continues to contribute substantially to feeding the world and in making significant societal contributions beyond food and fiber. In this changing world, strategic planning in US agriculture needs to become more global and inclusive in nature. And, in this flattened world, there is need to increase investment in the development of new products and technologies in order to keep US agriculture strong and competitive and to move the agricultural sciences to the next level.

This could lead to an understanding of the national and global importance of US agriculture and its breadth of impact, and an appreciation of its many past and future contributions to society beyond food and fiber.

To achieve these goals, the value and significance of US agricultural production and research must be effectively communicated to the public and to legislators. This could lead to an understanding of the national and global importance of US agriculture and its breadth of impact, and an appreciation of its many past and future contributions to society beyond food and fiber.

And finally, I think it is worth considering that, from a global standpoint, discoveries by US agricultural research can play a role in improving the productivity of subsistence farmers and combating hunger in developing countries; well-fed populations foster political stability and can contribute to our national security.

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Dr. Wood's research defined the interactions of the components of the cowpea mosaic and bean pod mottle viruses, developed methods for purification and characterization of fungal viruses, and elucidated the molecular biology of insect viruses. In 1989, he conducted the first US field release of a genetically engineered virus in Geneva, New York, which led to the optimized production of pharmaceutical proteins with insect viruses.

Based on his patented discoveries, he was a co-founder and chief scientific officer of AgriVirion, which produced pharmaceutical proteins in insect larvae. He is a member of Phi Beta Kappa, Gamma Sigma Delta and Sigma Xi, and was awarded a Fulbright Fellowship in 1981.