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# Industry Study

## Final Report
## *Biotechnology Industry*


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# BIOTECHNOLOGY 2006

**ABSTRACT:** The United States leads the world in biotechnology, centered on "genetic engineering" at the cellular or molecular level, a process which applies across a range of products in diverse industries, just as computer engineering does. The biotech industry is becoming a major player in many sectors, including medicine, agriculture, energy, defense, the environment, and nanotechnology. Genetically modified (GM) foods are feeding millions. GM bacteria and plants are cleaning up pollution quietly and cheaply. The nation depends on biotechnology for defense against terrorist attacks and pandemic influenzas. Stem cells promise the miracle of tissue regeneration. As an industry, though, biotechnology is still emerging, driven by the promise of research which for many companies has yet to yield products or profits. The industry relies on government to a surprising degree for support of basic science and for regulations that can either free up or stifle growth: property rights (patents), clinical trials, litigation relief, and ethical guidelines. Only an informed public will allow biotechnology to flourish, because it leans so strongly on legislation, because it is pushing into ethical dilemmas no one has faced before, and because it can either develop or defend against biological weapons and environmental risks. However, the shortage of U.S. scientists and engineers with advanced degrees in biotechnology means the industry depends on foreign researchers, which could easily threaten future preeminence. Establishing a National Biotechnology Council would facilitate federal collaboration. Biotechnology has already had an impact on our lives on an unprecedented scale, and there is every indication the future holds much more.

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## PLACES VISITED

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National Institutes of Health, Rockville, MD
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Human Genome Sciences, Rockville, MD
Merial Limited, Duluth, Georgia
Centers for Disease Control and Prevention, Athens, Georgia
U. S. Department of Agriculture, Agricultural Research Center, Beltsville, MD
USAMRIID, Ft. Detrick, MD
Charles River Laboratories, Wilmington, MA
Harvard Stem Cell Institute, Boston, MA
Cambridge BioPartners, Cambridge, MA
TEIBio Sciences, Boston, MA
Genzyme, Cambridge, MA
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### International

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U.S. Embassy, New Delhi, India
Government of India Department of Biotechnology, New Delhi, India
Panacea Biotech Ltd., Okhla, India
Department of Plant Molecular Biology, University of Delhi, New Delhi, India
Ranbaxy Laboratories Limited, Gurgaon, India
Indian Defence Research and Development Establishment (DRDE), Gwalior, India
CIPLA Pharmaceuticals, Mumbai, India

## INTRODUCTION

Biotechnology transcends the traditional definition of industries, like steel or medicine, which are based on a certain line of products or body of knowledge. What unifies biotechnology is a number of techniques or approaches drawn from the same branch of science, often called "genetic engineering," that apply across a range of industries. The methods are the same, whether manipulating organisms to clean up pollution or using them to cure cancer. Government regulations are much the same, as they strike the delicate balance between rewarding companies for innovation and protecting citizens from economic and sometimes physical harm. The ethical issues are the same across sectors, as science pushes the human envelope into dilemmas no one has ever faced before: life versus benefit, collective safety versus individual rights, and public good versus private incentive. Funding issues are the same, as cutting-edge research and careful safety trials based on legitimate concerns stretch out the product development time, which means years without profits. So although the biotechnology industry extends across a number of diverse sectors, they have much in common.

The science of biotechnology is coming of age. It already has an impact on our lives, slowly but on an unprecedented scale. The sequencing of the human genome gave scientists a roadmap of the human body. There is still much to learn about side roads and scenic byways, but we are on our way to discovering the microscopic origins of our species, just as surely as astronomers are probing the origins of the universe. Medical breakthroughs appear quietly, daily, and are adding up. Genetically modified (GM) foods are feeding millions. GM bacteria and plants are cleaning up pollution quietly and cheaply. We are turning to biotechnology for defense against terrorist attacks and pandemic influenzas. Stem cells promise the miracle of tissue regeneration.

This paper takes a broad look at the U.S. biotechnology industry in much of its diversity, with the goal of understanding what it is, the challenges it faces, and the government policies that will help. Since there is increasing competition from biotech ventures overseas, we also draw conclusions from meetings with a wide range of biotech experts in India.

## INDUSTRY DEFINITION

Biotechnology traces its roots back to 8000 BC when the Mesopotamian people used selective breeding practices to improve their livestock and to 6000 BC when the Sumerians began brewing beer. Scientific plant breeding has been producing hybrids for almost 150 years. In 1953, DNA was discovered (BIO, 2006, *Timeline*). But modern biotechnology started less than 30 years ago with the first experiments in genetic modification. A good definition of the science is "...a diverse collection of technologies that manipulate cellular, sub cellular, or molecular components in living things to make products, discover new knowledge about the molecular and genetic basis of life, or modify plants, animals, and microorganisms to carry desired traits" (DOC, 2003, p. 3). The core of biotechnology is genetics and the technology is genetic engineering, inserting genes from one organism into another to produce a different trait for commercial or other purposes. Because it is a process resting on the understanding of genetics, proteomics, and life science, biotechnology has applications in diverse areas, from medicines, treatments, and vaccines to defense, environmental cleanup, crop production, and the development of alternative fuels. In many ways, the "biotechnology industry" itself is still in its

infancy due to very long development times. It requires painstaking and often breakthrough research, time-consuming government clinical trials, regulatory and ethical judgments, and the capital to fund it all. Yet when it does realize its potential, the industry will change life as we know it. In many ways, it already has.

## CURRENT CONDITIONS

Biotechnology is capturing a growing share of the larger pharmaceutical market and—because of the expense of biologics—it may soon pass traditional chemical-based products. It accounted for 14% of all pharmaceutical sales in 2004 ($33.3 billion). R&D expenditures and new drug approvals are showing a shift. Biotech R&D in 2004 came to $19.8 billion, 42% of the total pharmaceutical R&D ($47.6 billion) (PhRMA, 2006). Of this, 69% went to health care, 13% went to agriculture and 1% went to energy and the environment combined (Smith, 2004, p. 12). The biotech sector notched 40 new drug approvals out of a total of 93 (Plunkett, 2005).

More than 250 million patients have already been treated with biotech drugs (Plunkett, 2005). Hundreds of millions of people have enjoyed the use or consumption of bioengineered agricultural products such as cotton, corn, soybeans and papaya. The Miliken Institute estimates that in 2004 more than 400,000 Americans were employed in the biotechnology sector (Plunkett, 2005).

As befits an emerging industry, there are many biotech companies: over 1400, 350 of which are public (BIO, 2006, *Facts*). Most are relatively small: 58% have fewer than 50 employees, and 89% have fewer than 500 (DOC, 2003). These companies as a whole posted losses of $6.4 billion in 2004, making capital investments crucial to the industry (BIO, 2006, *Facts*). Financing for the year totaled $20 billion and came from venture capital (20%), "angel" investors, and debt (42%) (Plunkett, 2005).

The public often cites drug prices as a principal cause of the steady rise in health care costs. Yet, drug expenditures have never risen above 10% of the total health care spending and lag well behind hospital care (30.4% in 2004) and physician services (21.3% in 2004) (HHS, 2005).

The fact is, the cost of bringing a new drug to market is very high, about $800 million. Out of every 100 drugs that start through clinical trials, just over six gain approval. And because only three out of ten new drugs earn enough revenue to repay the average cost of research and development, less than two of those new drugs will be profitable (Peters, 2004, p. 7). That is a success rate of less than 2%.

The pharmaceutical industry also reinvests approximately 20% of revenues in R&D, compared to an average of 4% for other industries (Plunkett, 2005). Because companies apply for patents at the same time they apply to the Food and Drug Administration (FDA) for approval, the lengthy FDA clinical trials cut into the 20-year patent. New drugs reaching the market average 11.5 years of protection, a relatively short time in which to earn a profit (PhRMA, 2006).

Recent legislation and policy changes have had a mixed impact on the biotechnology industry. The Bayh-Dole Act of 1980 has greatly encouraged public-private collaboration by providing certainty of title for inventions made with federal funding and allowing researchers in the public sector to share in proceeds from patents used in the private sector (Cornell, 2005). The Orphan Drug Tax Credit has encouraged investment in otherwise unprofitable small-market drugs or those targeting disease populations of less than 200,000. However, it can take a year or more for the FDA to designate a drug as "orphan" (BIO, 2006). The Hatch-Waxman Act of

1986, as amended, allows generic drug producers to prove bioequivalency in lieu of clinical trials, which makes their products inexpensive (CRS, 2004). These tests will not work on biologics, so as yet there are no mechanisms to skirt clinical trials and approve biotech generics (Peters, 2004, pp. 14-15).

Some changes have disproportionately affected small companies. Since 2001, companies receiving more than 51% of their funding from venture capital no longer qualify for the Small Business Administration's Small Business Innovative Research (SBIR) grants. This eliminates an important source of funding. Some say complying with the Sarbanes-Oxley Act can cost upwards of $1 million, often doubling small firms' operating costs (BIO, 2006, *Facts*).

While there has been a resurgence in R&D spending over the last three years, continued legislative pressure on drug pricing could discourage the venture capital investment that has been the lifeblood of the biotechnology industry (Plunkett, 2005).

Policy Recommendation:

- Reform policies and legislation—such as the Small Business Innovation Research program and Section 404 of the Sarbanes-Oxley Act—which impose burdens on the biotechnology industry.

## CHALLENGES

The United States now leads the world in the number of biotech companies, spending on research and development (R&D), quantity of patents and products, and amount of revenue. In order to maintain our global advantage, the industry still faces a set of six common challenges across all its sectors. These will determine how much and how fast it will develop in the future and how well we as a nation will do against foreign competition.

- The industry is emerging, driven by the promise of research which for the most part has yielded little in products or profits. Keeping companies financially afloat until the promised earnings are realized is a major challenge.
- The industry relies on government support of basic science to make the discoveries it can then develop into products with applied science. Keeping funding at adequate levels is difficult in a time of shrinking budgets.
- The industry's very existence depends on government regulations: intellectual property rights (patents), clinical trials, litigation relief, and ethical guidelines. They also add to costs and development times. Getting the mix right—and in particular, speeding approval times while maintaining adequate oversight—challenges the government to work out solutions with industry.
- Informing public opinion is a vital task. Biotechnology is a science at the cutting edge of life, and that inevitably raises ethical questions. Government relations are so crucial that voter opposition could cripple the industry.
- Biotechnology is a double-edged sword which can develop or defend against biological weapons and environmental risks. Sufficient governmental control of the technology and development of precautions are essential.
- The shortage of U.S. scientists and engineers with advanced degrees threatens the industry's future preeminence. Depending on foreign researchers means tougher visa restrictions and security measures can have a chilling effect.

Internationally, some countries—India, for example—have seized on biotechnology as a way to leverage a high-quality, low-cost workforce to make economic gains and build a prestigious science sector. In 1986, India created a Department of Biotechnology. Economic reforms begun in 1991 have propelled annual GDP growth rates to around 8%, enabling the biotechnology sector to grow at an explosive rate. The recent draft National Biotechnology Development Strategy charts a decade-long plan to generate $5 billion in revenue and create one million jobs by 2010 (Department of Biotechnology, 2006, p. 2).

Economic and educational advantages, expertise in bioinformatics, and a diverse gene pool have attracted significant international capital. Patent protections begun in January 2005 have further increased domestic and foreign investment in R&D. India's government encourages innovation with Small Business Innovative Research (SBIR) grants, soft loans, biotech parks, and tax breaks to industry. The government is working to simplify India's regulatory regime without reducing consumer protection. It also continues to heavily subsidize university and post-graduate programs (Department of Biotechnology, 2006, pp. 15-19).

In the private health care sector where R&D investment averages 10-15% of revenues, the focus is on the European, Japanese, and American markets—substantial sources of growth and wealth. However, government-industry-academic partnerships concentrate on diseases among the poor in India as well as in the developing world. India has pioneered socially-conscious business models and multiple-licensing arrangements—the requirement that a patent must be licensed to two or more manufacturers—to make drugs available at nominal cost. Patent enforcement and pressure on black markets are the keys to success in this area.

In the agriculture sector, the biotech emphasis is on developing drought and salt tolerant crops to feed the population. Paradoxically, although Indians do not reject GMOs as Europeans do, the "precautionary principle" still applies, and transgenic foods have yet to reach the market.

India devotes the bulk of its collaborative efforts to health care and agriculture, which have the greatest impacts on economic growth and quality of life. Unfortunately, a disintegrating infrastructure, which cannot provide adequate transportation (airports and roads), electricity, sewers, and clean water, will hinder growth. As its economy and infrastructure improve, however, India can be expected to expand its unique collaborative models into environmental biotechnology and other areas.

## OUTLOOK

In the U.S., the biotechnology industry's revenue growth in 2005 continued to be robust, with revenues projected to reach $50 billion, but only ten firms accounted for two-thirds of that ($33 billion). Across the board, sales growth is quite uneven, with some companies projecting 40% gains—Celgene, Genentech, and Gilead Sciences—and many more expecting losses. Only the larger players with several products in the market are able to maintain solid revenue gains year after year (DiLorenzo, 2005. pp. 1-2).

Solid clinical results and strong financial results for some companies reassured investors through November 2005, and the biotech index posted a 23.4% gain over the year. "Standard and Poor's continues to think that the industry's fundamentals are strong and should continue to improve." In line with this, the industry raised $13.9 billion in capital in the first nine months of 2005, which is slightly off 2004's pace but well ahead of 2003's (DiLorenzo, 2005, pp. 1-2).

Clinical and financial news was generally positive for the last half of 2005 and this is expected to continue through 2006, which should be a good year for approvals from the FDA.

Several new biotech medications should be entering the market, and drugs already available will receive approvals for broader uses. Long-term, the performance of the industry depends on the revenue from cancer medications, and it is possible that the FDA will approve several of these in 2007 (DiLorenzo, 2005, pp. 1-2).

As people live longer throughout the world, the percentage of elderly people increases, and with that, the demand for medications grows. Drug prices continue to rise steadily, but so does the volume, which could receive a substantial boost in 2006 from the new Medicare prescription drug program. However, government programs and the eventual emergence of biotech generics may offset rising costs from demographic trends (DiLorenzo, 2005, pp. 1-2).

## GOVERNMENT

*Education*

The growth of the biotech industry depends upon R&D, and this depends upon hiring the best and brightest researchers. There currently seems to be no shortage of qualified personnel in the industry, but it depends on overseas hires to fill its ranks and satisfy its needs.

As late as 1975, the U.S. graduated more scientific and engineering PhDs than any other region of the world—three times more than Asia. Today, however, the EU graduates 50 percent more of these PhDs than the U.S. China is graduating almost half the number of PhD scientists the U.S. does and is projected to overtake us by 2010 (Samuelson, 2005, p. 1). Interestingly, after receiving advanced degrees, many Indian students typically seek post-doctorate positions in the U.S. and stay on to join the biotech companies. That trend is slowly changing. The Director of Life Sciences at the University of New Delhi said that although 50% percent of his students still went to the U.S., they were beginning to return after five or six years to take up positions in government, academia, and the private sector.

In the U.S. over the last decade, the number of Americans studying for science degrees has declined and the number of foreign-born students has risen. In 2001 non-Americans received over half of all PhDs in science and engineering (Task Force, 2005, p. 4). Despite visa restrictions, about 68 percent of these say they intend to stay and work in the U. S. (NSB, 2004). Unfortunately, as a consequence of tightened security following 9/11, scrutiny of foreign-born students and researchers seeking to enter the U.S. has increased and caused delays which made them go elsewhere. However, with the streamlining of background checks, in 2005 more foreigners applied to U.S. graduate schools than in the two previous years. The largest increases came from India (23%) and China (21%) (Reuters, 2006).

Americans appear unwilling to pursue careers in biotechnology for three reasons: The economy does not value scientists as much as other occupations. From 1990 to 2000, average incomes for scientists rose 30% from $56,000 to $73,000, lawyers' incomes grew 49% from $77,000 to $115,000, and doctors' incomes swelled 58% from $99,000 to $156,000 (Samuelson, 2005, pp. 1-2).

There is too little emphasis on science education, particularly at elementary schools, where it is often lumped together with other subjects and where most teachers receive no specialized training. It does not help that teachers' salaries are even lower than scientists'.

Biotechnology has not yet become "hot" as software engineering did in the 1990s. It is a complex discipline that is difficult to understand and does not capture the popular imagination.

Policy Recommendation:

- Make developing scientists, and particularly biotech scientists, a presidential priority and provide funding to encourage teachers and students through the liberal use of the media, study grants, awards, and salary incentives.

*Ethics*

As biotechnology pushes science to the edges of life, it increasingly crosses familiar lines and raises ethical issues in agriculture, the environment, embryonic stem cell research, and genetic testing. Professional discussions and government guidelines are playing an increasingly important role in redefining what is permissible, reducing public anxiety, and allowing science to advance.

Scientific plant breeding has produced resistance to drought, pests, and herbicides—to reduce their use—increasing crop yields for a century and a half. Genetic modification (GM) is the next step, but here researchers sometimes insert genes from other organisms to produce hybrids unlikely to occur in nature. This has raised concerns about the long-term impacts of GM plants on air, water, and soil quality, on human health, and on bio-diversity, where the effects of cross-breeding GM and non-GM plants may have unintended consequences. There are consumer issues: some want labeling that will allow them to choose what to buy. There are economic issues: most GM crops belong to Monsanto and patents give it monopolies on seeds that farmers have to buy before each season. Balanced against that are the undeniable benefits—increase in the food supply and decrease in cost. The question is where to draw the line.

Animal rights activists are concerned about using animals for drug testing. Few in the general population want to ban animal testing outright, but nearly everyone agrees that animals should suffer as little as possible.

Embryonic stem cells hold great promise in the regeneration of organs, limbs, or spinal cords, because in theory they can develop into any type of tissue. Harvesting these cells terminates the blastocyst, the ball of embryonic cells not yet attached to the uterus. This has sparked strong opposition from generally religious people on the pro-life side of the U.S. abortion debate, who say embryos should not be destroyed because that constitutes killing human beings. Some argue that adult embryonic stem cells may yield the same results. Proponents hold that blastocysts are the by-products of in vitro fertilization and will never develop into embryos, so there is no life or death debate. Interestingly, opponents in Europe fear this research as it reminds them of Nazi experiments with eugenics.

Through DNA testing, doctors can identify and often treat genetic defects that may reduce quality of life or eventually lead to disease. Couples can also make informed decisions whether to have children. There are ethical concerns about who should see this information, because employers and insurance companies, for example, seek to cut risks and expenses. There are also questions whether screening newborns and carriers should be mandatory, and what and how results should be presented to parents and patients, especially when no treatment may exist. Pre-screening education is key. Guidelines from the Committee on Bioethics (COB) are a first step in resolving these issues (COB, 2001).

*Intellectual Property Rights*

The Constitution empowers Congress "to promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries" (U.S. Constitution, Article 1, Section 8). This exclusive right provides the economic incentive for invention. "The strength and vitality of the U.S. economy depends directly on effective mechanisms that protect new ideas and investments in innovation and creativity" (USPTO, 2006, *Business*).

The U.S. Patent and Trademark Office (USPTO) grants a patent to an applicant who "invents or discovers any new and useful process, machine, manufacture, or composition of matter [chemicals], or any new and useful improvement thereof." (USPTO, 2006, *General*) Protection lasts 20 years from the date of filing, in compliance with international treaties.

The landmark U.S. Supreme Court decision of *Diamond v. Chakrabarty* in 1980 (447 US 303(1980)) launched today's biotech industry by holding that even living things made by man are patentable. The possibility of a substantial return on investment has driven the proliferation of biotech companies which often go years without profits during the long research, development, and clinical trials process.

Critics argue that patents restrict intellectual freedom and benefit only the powerful. They deny use to those without licenses. India's poor farmers save one year's seeds to plant the next year's crops, but patents on genetically modified (GM) seeds make this a crime (Shiva, 2005). Patents also appropriate the traditional use of products India's Neem tree has provided medicinal products for centuries, but in the mid-1980s, U.S. and Japanese corporations patented more than a dozen neem-based materials, leading some to say "…collective local knowledge developed by Indian researchers and villagers has been expropriated by outsiders who have added very little to the process" (Shiva & Holla-Bhar, 1993).

The courts continue to draw the line between public good and private incentives. In a current case, a company has used a certain amino acid—which indicates a vitamin B9 or B12 deficiency—to devise a test and has applied for a patent. A rival company argues such a patent "gives its owners an effective monopoly over a basic principle or natural phenomenon." U.S. patent law also does not permit "patenting a law of nature, natural phenomenon or abstract idea" (Bridges, 2006). The issue is in litigation, and in the meantime, patients are at risk. Future court rulings will almost certainly modify existing patents on living things.

*Biodefense*

Biodefense targets acts of biowarfare as well as bioterrorism, "the deliberate release of viruses, bacteria, or other germs (agents) used to cause illness or death in people, animals, or plants [crops].…Terrorists may use biological agents because they can be extremely difficult to detect and do not cause illness for several hours to several days" (CDC, 2006, *Bioterrorism*). The goal is "to harm people or to elicit widespread fear or intimidation of society for political or ideological goals" (Fauci, 2002, p. 1). The 2001 anthrax attacks which killed five Americans signaled the arrival of the age of bioterrorism (Sutton, 2005).

The incubation period for biological agents can be up to 60 days and they may spread widely before health professionals notice. "Early inhalational anthrax symptoms are similar to those of common illnesses such as the flu (Meadows, 2004, p. 1). Focusing on "earlier detection of epidemics and a more timely public health response," the CDC has ties with 100 sites

monitoring illness syndromes or events that might indicate bioterrorism (Buehler et al, 2003, p. 2).

The United States is stockpiling anthrax and smallpox vaccines against a bioterrorist attack. Among the bioagents, anthrax is the easiest to manufacture in stable amounts. There are two types: antibiotic-sensitive (easy to make) and antibiotic-resistant. The Soviets claimed to have six different classes of antibiotic resistant anthrax (Peters, 2003), and stocks have vanished from the country (The Times of India, 2001). Though harder to produce, there are many other agents as deadly as anthrax: plague, smallpox, viral hemorrhagic fevers (Marburg, Ebola, Lassa, and Machupo), bacterial infections (glanders and melioidosis), and various encephalitises (The Times of India, 2001). New generations of biotech viruses and bacteria have no known antidotes and mutate continuously.

The Project BioShield Act of 2004 "strengthened partnerships to develop and improve medical countermeasures—human and animal drugs, vaccines and other biologics, blood and blood products, diagnostic tests and devices that can prevent, diagnose, and treat illnesses related to a terrorist attack." ((Meadows, 2004, p. 1). It provided DHS with $5.6 billion over 10 years, but only $1.1 billion has since been committed, most of it to a single program to buy 75 million doses of anthrax vaccine. Critics point to delays and inertia at the Department of Health and Human Services (HHS) and the lack of protection against litigation (Gillis, 2006, p. A11). Even so, BioShield has been modestly successful in encouraging small companies to develop anti-bioterrorist drugs. but larger firms looking for growth to satisfy stockholders are going elsewhere (Salinsky & Werble, 2006, p. 22).

Preventing or controlling biological threats requires the various federal agencies involved to have clear roles. The Department of Homeland Security (DHS) has the lead. The Food and Drug Administration (FDA) approves the drugs aimed at bio-agents. The CDC would detect and define an attack and develop defensive public health policies (CDC, 2006, *Mission*). The U. S. Department of Agriculture (USDA) monitors crops and animals, possible economic targets of a bioterror attack (USDA, 2006). The Environmental Protection Agency (EPA) might well play a part in detecting as well as cleaning up after an attack. During an attack, USNORTHCOM would take the lead in managing the disaster: The Department of Defense (DOD) has added $2.1 billion to its budget to improve defenses against emerging chemical and biological threats (DOD, 2006). Of course, many other government agencies—federal, state, and local—are also involved in detection.

There are still more players. The National Institute of Allergy and Infectious Diseases (NIAID), has a strategic plan for biodefense and is cooperating with the U.S. Army in building the National Interagency Biodefense Campus at Fort Detrick, Maryland. One of the National Institutes of Health (NIH), NIAID also works closely with the U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID) also at Ft. Detrick, making use of its bio-safety level 4 laboratories for the most dangerous agents, which allow "researchers to test the effectiveness of biodefense vaccines, drugs and diagnostics by permitting aerosol challenges on animals" (*The Standard*, 2005, p. 1).

Policy Recommendations:

- Develop a detailed interagency national biodefense plan to clarify responsibilities, decision-makers, and lines of communication, and to take advantage of expert scientific knowledge in the private sector.

- Accelerate Project BioShield funding for research and development, detection tools, training, vaccines, and other capabilities.
- Commit to purchasing significant amounts of anthrax and other biodefense vaccines to build surge capability.
- Offer litigation protection to companies participating in Project BioShield and establish a compensation program for claimants.

## SCIENCE

*Curing and Preventing Disease*

There has been tremendous progress in medical-related biotech applications, with the launching of new drugs and vaccines, improved and accelerated drug discovery, and better diagnostic capabilities (DOS, p. 11). Many believe this is only the beginning and that biotechnology will lead to a new era in disease prevention and cures.

More than 370 biotech drugs and vaccines were in clinical trials in 2005, targeting more than 200 diseases including various cancers, Alzheimer's disease, heart disease, diabetes, multiple sclerosis, AIDS, and arthritis (Ghadar & Spindler, 2005). In the last ten years, more than 160 new medicines have been approved for the treatment of conditions such as cancer, arthritis, and multiple sclerosis. According to the 1100-member Biotechnology Industry Association (BIO), "Biotech drugs are often the only effective treatment for many life-threatening diseases" (BIO, 2006, *Healthcare.).*

Strong public sector support for U.S. biotechnology has been critical to U.S. progress. The National Institutes of Health (NIH) is encouraging academic institutions to pursue biotechnology, distributing grants totaling $27.9 billion to researchers and universities in 2004. Over recent years, however, NIH has been unable to meet the growing need for medical research due to a straight-lined budget, which has resulted in program cuts and tough choices.

Many believe that embryonic stem cells hold great promise for curing and treating diseases, but due to federal limitations on funding, institutes like the Harvard Stem Cell Institute have had to actively raise private funds. The institute draws on the expertise of Harvard University and its affiliated hospitals to address five principal diseases (HSCI, 2005).

Due to the large amount of funding necessary to continue biomedical research, public-private collaborations are often key in fighting diseases. One cooperative model is found in the campaign against type 1 diabetes, an autoimmune disease in children and young adults that destroys the insulin-producing cells in the islets of the pancreas. The disease strikes 13,000 people each year.

Congress provided funding for type 1 diabetes research in a special appropriation passed in 1997, which provides $1.14 billion over the period FY 1998 through FY 2008. As the lead institute at the NIH in pursuing this research, the National Institute of Diabetes & Digestive & Kidney Diseases (NIDDK) administers these funds and collaborates extensively with other government agencies including CDC and FDA, with the two major diabetes voluntary organizations, and with industry. One of NIDDK's most promising programs aims at developing an artificial pancreas, which senses blood glucose levels and secretes insulin in response.

Private foundations are often crucial in these efforts. The Juvenile Diabetes Research Foundation International (JDRF), has awarded more than $900 million since its founding in

1970, including over $98 million in FY 2005 alone. Its lobbying efforts have been even more effective, spurring government to increase funding in type 1 diabetes to unprecedented levels.

If the United States wishes to maintain a leadership position in curing and preventing chronic and life-threatening diseases, it will require collaborative national efforts, dedication of resources, and constant vigilance.

*Stem Cells*

Stem cells—particularly human embryonic stem cells (HESC)—hold great scientific promise in treating spinal cord injuries, diabetes, cancer, Parkinson's disease, diabetes, neurodegenerative diseases (like Alzheimer's and Parkinson's), blood diseases (including AIDS), and cardiovascular disease. Labs use therapeutic cloning to grow stem cell colonies ("lines"), multiple copies of the same cell (Paarlberg, 2005, p. 1). Despite their tremendous potential, embryonic stem cells have drawn fierce opposition from religious conservatives who believe the process kills babies and that the therapeutic cloning involved may quickly lead to reproductive cloning of human beings (Plunkett, 2005).

In response to those who urged him to outlaw embryonic-stem cell research, President Bush announced in 2001 he would only allow federal funding for research on the 78 stem cell lines then in existence, "where the life and death decision had already been made" (Mann, 2005). Because lines degrade over time as cells accumulate random genetic mistakes, because some of the original lines never differentiated, and because some lines were not in the public domain, there have never been more than 18 of these lines actually available (Powell, 2006). Unfortunately, labs need hundreds of lines to be able to test for genetic and racial variations.

President Bush's decision rendered 11,000 embryos donated from infertility clinics untouchable (Readme, 2005). It also made new research much more expensive. Strict separation from federally-funded projects requires researchers working with the new lines to either set up separate labs with dedicated equipment and supplies or to create new facilities. No one who works on these projects—even part time—can be receiving federal funding, even for unrelated research (Cook, 2004).

The federal limitation has ignited competition among some states which are concerned about losing scientists, revenues, and infrastructure (Russo, 2005). In November 2004, voters in California approved issuing bonds for $3 billion over ten years to finance HESC research, although right-to-life and anti-taxation groups have been successful in tying up the funding in courts. New Jersey has set aside $380 million, Connecticut $100 million, and Maryland $15 million in similar efforts. Three other states have passed laws aimed at promoting HESC. On the other side of the ledger, six states have banned therapeutic cloning and one (South Dakota) has banned all stem cell research, embryonic and adult (States, 2006). The lack of federal leadership is starting to create a patchwork of research labs, each responding to separate state regulations and funding.

One of the fears the states have is that stem cell research may go overseas. Singapore, Australia, Israel, and Sweden—with 32% of the harvested stem cells worldwide—are the major players. Japan and China also have significant programs (Plunkett, 2005).

India is a good example of what happens in a permissive environment when there are no religious and moral qualms (Mishra, 2005). The government supports embryonic stem cell research, but conflict between the Indian Council of Medical Research (ICMR) and the Department of Biotechnology (DBT) has left it relatively unsupervised. Project proposals are

not peer-reviewed for scientific validity or for subject safety. In the first use of HESC for human treatment, Dr. Greeta Shroff, a private physician, claimed in 2005 that she injected stem cells into nearly 100 patients suffering from degenerative brain disorders with positive effects, but she failed to provide verifiable scientific evidence (Mudur & Kidwai, 2005). Clinics from both the private and public sectors have since been making unsupportable claims that stem cells are available to treat a range of diseases. In response, the ICMR and DBT have begun negotiating a single set of guidelines for clinical practice (Jayaraman, 2005).

This is in line with the draft of India's national biotechnological guidelines (Datta, 2006), which proposes to decentralize regulatory clearances while placing safety controls on clinical practices. Clearances fall into three categories—prohibited, restricted (approved at the national level), and permitted (approved at the institutional level) (Datta, 2006). Reproductive cloning is in the prohibited category, while embryonic stem cell research is restricted, meaning that procedural and ethical guidelines have to be met.

While India seems to be well positioned to emerge as a significant player in stem cell research (Basu, 2005), its current unregulated practices may lead to unethical methods of harvesting stem cells, jeopardize human subjects, and allow false scientific and therapeutic claims (Sook, 2006). Even though it has a very large pool of scientific talent, India currently lacks the regulatory standards and governmental organization to take the lead in stem-cell research.

*Vaccines*

The few vaccine makers may not be up to combating a bioterrorist attack or controlling an avian flu epidemic. Weakness in that sector is structural, and government may have to lend a hand to develop the surge capacity such events would require.

Unlike the other nine classes of biotech drugs, vaccines prevent diseases rather than treat them. Typical vaccines simulate disease-causing agents, which cause the immune system to produce antibodies. The body then "remembers" the cause (the antigen) and will produce antibodies each time it senses the antigen's presence (Salinsky & Werble, 2006, pp. 3-4).

The vaccine market is small. Annual sales are between $4.8 and $6 billion globally, with about $1.5 billion of those in the U. S.—1.5% of the total for all pharmaceutical drugs. About 70% of U. S. sales are in pediatric vaccines. The vaccine market has increased 10% annually since 1992, mostly due to polio eradication campaigns in developing countries and more expensive vaccines getting approvals elsewhere. The market is set to grow. In 2004 there were about 200 vaccines in Phase II and Phase III FDA trials, and analysts expect 30 new and more expensive products to appear by 2010, including standard vaccines for human papilloma virus (which causes cancer in female organs including the cervix) and human immunodeficiency virus (HIV). Making their debut will also be therapeutic vaccines—for specific patients based on specimens taken from those individuals—which initially will target melanoma (skin cancer) and rheumatoid arthritis (Salinsky & Werble, 2006, pp. 6, 12).

The vaccine business has high barriers to entry, which include the cost of research and development and the requirement for highly educated workers. Constructing a sterile vaccine manufacturing plant costs upwards of $300 million and takes five years, largely because of the specialized equipment and the detailed FDA inspections. Starting up production of a new vaccine is costly as well, because each has specific requirements (Calfee & Gottleib, 2004, p. 4).

The first step in all vaccine production is cultivation of a microorganism in living cells while maintaining a constant environment to increase yields and avoid contamination, which requires costly monitoring and adjustment. Steps such as purification and packaging follow, with stringent and expensive quality controls throughout.

Manufacturers normally have to make vaccines for the FDA in the same plant with the same methods as the approved product. FDA standards are higher than for other drugs, because vaccines are meant for healthy people and even small side effects can tip the risk-benefit balance. Vaccines also target the broad population, so clinical trials need to be very large (Salinsky & Werble, 2006, p. 7-8).

All of these factors contribute to high fixed costs, which run around 60%. Another 25% of costs are fixed for each batch of vaccine. This leaves only 15% in variable costs. Companies cut prices to increase sales and seek economies of scale by increasing production (Salinsky & Werble, 2006, pp. 10, 13-15).

If costs are high, prices are low. Governments purchase most childhood vaccines in bulk. The demand for adult vaccines is less dependable, since healthy people usually regard vaccinations as optional and thus are sensitive to price (Salinsky & Werble, 2006, pp. 15-16).

This combination of perishable product, expensive and time-consuming production, static demand, high fixed costs, and low prices means only the most determined and efficient producers can remain profitable. They must also be savvy enough to predict the market a year in advance. It is not surprising many vaccines have only one supplier (Salinsky & Werble, 2006, p. 17).

Finally, there are liability issues. Healthy people who notice changes may blame inoculations. The National Vaccine Injury Compensation Program (VICP) compensates those harmed by childhood vaccines, using funds collected through an excise tax on covered vaccines. However, plaintiffs can still sue for pain and suffering, and the VICP does not cover all vaccines (Salinsky & Werble, 2006, pp. 20-21).

Policy Recommendations:

- Expand funding for basic research under the National Institutes of Health (NIH) and the National Science Foundation (NSF).
- Increase research and development subsidies up through Phase II FDA trials for some products, particularly vaccines.
- Increase government R&D of biologics that the market does not support: medicines for developing countries, biodefense, and some orphan diseases. Offer guaranteed purchase agreements to manufacturers. Guide price discrimination that allows developed countries to subsidize drug costs in developing ones.
- Shorten the FDA's clinical trials by using new direct testing. Define and analyze the molecular structure of biologics to assure quality or directly test the antibody levels a vaccine produces. To identify promising compounds quickly, the FDA now allows companies to produce a tiny amount of a compound and test it in less than 20 subjects for up to seven days, using advanced imaging and testing technology to see if it produces the desired changes (Wechsler, 2006).
- Build surge capacity for vaccine production:
  - Extend the liability protection of the National Vaccine Injury Compensation Program (VICP) to all vaccines, childhood and adult.

- Make advance purchase agreements, guarantee markets, or offer tax incentives to encourage companies to build excess vaccine production capacity for use in a pandemic or a bioterrorist attack.
- Offer longer patents to manufacturers of critical vaccines or extensions on other drugs in a manufacturer's lineup—a major incentive for entry-level vaccine producers to get into the anti-bioterror drug business.

*Avian Flu*

The world is bracing itself for a pandemic, this time caused by the avian influenza virus (H5N1). Predictions based on models of the most recent pandemic (1968) indicate it may result in 2 million to 7.4 million deaths globally and cost $70 billion to $165 billion (Luke & Subbarao, 2006, p. 67). Even though the person-to-person transmission that would signal the beginning of a pandemic has not yet occurred, it may be a matter of time. Infected migratory birds are expected to reach the U.S. within the next year (HHS, 2005).

Influenza is a group of four types of RNA viruses. Influenza A is what the public normally thinks of as flu, widely found in nature and the cause of pandemics. Scientists identify flu strains by two surface antigens, hemagglutinin (HA) and neuraminidase (NA). There are 16 HA and 9 NA subtypes known to exist, all of them affecting aquatic birds. In the 20$^{th}$ Century, H1, H2, and H3 subtypes and N1 and N2 subtypes of influenza A have circulated in people (Luke & Subbarao, 2006, p. 67).

An influenza pandemic strikes when a new HA subtype appears, and there are no anti-bodies in the human immune system for defense. There has never before been an H5 flu virus in humans. That is why the medical community was alarmed when in 1997 the H5N1 virus jumped directly from birds to people in Hong Kong. A mass culling of poultry stamped out that outbreak, but in 2003, the H5N1 virus appeared again. Asian countries reacted by culling more than 120 million birds, which was costly to their economies (Luke & Subbarao, 2006, p. 68).

Quick action may have slowed the disease in humans, but it has begun to spread in birds and bird-to-human transmission is rising. As of May 23, 2006, there have been 218 cases of avian flu in humans resulting in 124 deaths, most of which have been in Southeast Asia, but some occurring as far away as Egypt, Turkey, and Iraq (WHO, 2006). Most of those affected had direct contact with sick birds.

In the early stages of a pandemic, no vaccine will be available. Development of a vaccine against the H5N1 virus cannot begin until the contagious strain emerges and could easily take six months or longer. The initial focus must be on treatment (Lister, 2005, p. 25). There are currently two types of antiviral drugs for treating flu, but H5N1 is resistant to one, so the focus is on the two neuraminidase inhibitors now available: oseltamivir (Tamiflu tablets) and recently approved zanamivir (Relenza inhalants) (Lister, 2005, p. 30). Although from different families with different side effects, both drugs can treat the severely ill or prevent illness in high risk patients—though there are indications that prolonged use builds viral resistance. It is yet to be seen whether either drug will be effective against bird flu. Even so, the U.S. has bought 4.3 million 5-day courses of Tamiflu, enough for 1.5% of the population. The goal is to treat 25% of the population (75 million courses), but there is a supply shortage (Lister, 2005, pp. 30-31).

Because worldwide vaccine production capacity is now estimated at only 300 million doses, a possible pandemic makes it imperative to find methods to increase production. The traditional way to grow a vaccine is in a medium of fertilized hen eggs, which takes at least six

months—but H5N1 threatens poultry stocks. It may be possible to extend a future vaccine with a response-boosting adjuvant, but one under investigation may cause Gulf War Syndrome (Gillis, 2006, p. A1). Using cell cultures cuts production time to four months and vastly increases the yield (Piller, 2005). The fourth avenue is to use genetic engineering and DNA cloning, which could eventually produce as many as 500 million doses in as little as three weeks. A "gene gun" would then inject the vaccine into patients (Piller, 2005), but this method is unlikely to have FDA approval before a pandemic hits.

*Agriculture*

Agricultural researchers can genetically modify (GM) crops to survive in dry environments, bear fruit that is more nutritious and bountiful, and resist diseases and pesticides. However, market acceptance outside the U.S., particularly in Europe, has been problematic. The world's largest importer of agricultural crops, the European Union (EU), and the world's largest exporter, the U.S., need to end the mismatch of standards and overcome the uneasiness about genetically modified organisms (GMOs) (Trarieux, 2006). The EU GMO regulatory process hinges on science, but ends up being highly political, reflecting pubic opposition from traditionalist and "green" camps. It starts with European Food Safety Authority (EFSA), which has six months to respond to an application (GMO, p. 1). If the scientific data (or lack of it) cannot prove harmlessness, approval is doubtful (Trarieux, 2006). Unfortunately, in most cases, the science of biotechnology cannot offer the required detail. EFSA's opinion goes to the European Commission and then to the Council of Ministers for comment and decision, a political process (GMO, pp. 1-3).

The U.S. regulatory process is more bureaucratic and scientific. For governmental protections to work, however, the three agencies involved must cooperate closely. The Animal and Plant Health Inspection Service (APHIS), part of the USDA, regulates the importation, interstate movement, and field testing of GM plants and organisms. Once APHIS has tested a product, it will go before customer panels for the decision on "unregulated status" (Becker, 2005). The FDA regulates food, animal feed additives and human and animal drugs. It holds GM crops to the same standards as non-GM or conventionally generated foods and feeds (Becker, 2005). The EPA regulates all pesticides, including those genetically engineered into plants (Becker, 2005).

Currently, three issues face the GM industry: labeling and tracing, the "terminator" seed, and adventitious presence. The EU requires labels and origins on foods and feeds containing 0.9% of GM ingredients (GMO, p. 3). Because of the inability to trace crops to their origins and a lack of scientific data, in 1998 the EU placed a moratorium on the approval of new GM crops (Becker, 2005). U.S. farmers claim this has cost them $300 million per year in corn exports alone (Pew, p. 3). Bowing to pressure from its own markets and farmers, however, the EU is slowly backing down. Since 2004, it has approved a variety of GM corn for import and four varieties of GM maize, three of canola and one of soybeans for planting.

"Terminator" seed cannot reproduce, which lessens the chance for GM crops to spread into conventional fields. It forces farmers to purchase new seeds each season instead of saving some from the harvest. There are also fears the trait could spread to other crops, causing them to "terminate" as well (Tortato, 2006).

Adventitious presence happens when trace amounts of GM seed appears in conventional seed, in non GM fields nearby, or in products. Cross-contamination can occur through cross

pollination, seeds from previous crops on the same land, or the mixing of grain in silos. One gene with untested and unapproved traits could "impugn the entire industry," resulting in major financial losses for the responsible company (Innovest, p. 32).

In 2001, widely sold food products were found to contain "Starlink," a GM corn variety containing an insecticidal protein developed by Aventis, which the FDA had not approved for humans due to allergy concerns. More than 10% of the U.S. crop was contaminated and Japan, the top importer of U.S. corn, also reported its presence. The recall cost Aventis over $1 billion. There was also a $110 million settlement to farmers who claimed damages (Innovest, p. 33).

The U.S. and the EU are not alone in trying to deal with GMOs. Countries around the world are trying to keep their citizens safe while many face food shortages. Interestingly, India is more accepting of GMOs than the EU. Some countries will disregard dangers and charge ahead, raising the possibility that unmanaged GMOs could find their way to our shores. Others will be cautious and the markets will leave them behind. There is a real need for a world regulatory system to harmonize the various standards and protocols, perhaps under the World Trade Organization or the United Nations (Nair, p. 4).

Policy Recommendations:

- Set up an international regulatory system to harmonize GMO standards and protocols under either the WTO or the UN.

*Biofuels*

Oil prices are shooting upward, driven by demand which by 2015 is expected to double in China and increase 75% in India (EIA, 2005, *World Oil*). This will make home-grown biofuels—ethanol or biodiesel—increasingly profitable as well as politically attractive. The global biofuel market is already responding. In 2005 it hit $15.7 billion and over the next decade, it is expected to reach $52.5 billion (LaPedus, 2006).

Brazil has shown the way in ethanol production. Economically battered by the 1973 oil shock (Luhnow & Samor, 2006), it turned to sugarcane and developed capacity until in 2004 it was producing 15 billion liters (Unica, 2005). Even though ethanol gets less mileage than gasoline, costs are significantly lower—about $1 a gallon, as compared with the international wholesale gasoline price of $1.50. Brazil takes advantage of subsidies, of its abundant sugar which—unlike corn in the U.S.—converts directly to ethanol, and of research which has sequenced sugarcane's DNA and produced high-yield, pest-resistant varieties (Luhnow & Samor, 2006).

Novel biotechnologies could bring down the costs of making ethanol. Iogen Corporation has genetically modified a fungus to produce enzymes which break down straw (cellulose) into sugars necessary for the fermentation of ethanol (Elias, 2006). BRI Energy is using a bacterium discovered in chicken wastes to produce ethanol from carbon monoxide (BRI Energy, 2006).

Optimists claim the U.S. could produce enough ethanol to meet "between 54 and 96 percent of all our transportation gasoline needs in 2050" (Green, 2004, p. 34). The U.S. Department of Energy (DOE) has more conservative goals of providing 10% of transportation fuels by 2020 (DOE, 2003).

Europe is the world leader in the other biofuel—biodiesel—generally made from vegetable oils or animal fats. It produces 17 times more than the U.S. European tax policies and

regulations have stimulated demand and the rapeseed (canola) it widely grows yields over 2.6 times more biodiesel than the soybeans which are the U.S. source (Lovins & Datta, 2004).

Another possible source of biodiesel is algae with more than 50 % oil content, which could grow on ponds at wastewater treatment plants (Briggs, 2004) or on gas emissions from power plants (GreenFuel, 2006).

The switch to biofuels will bring many benefits. They are bio-degradable, non-toxic, and have low emissions (Queddeng, 2005). The U.S. would gain $250 billion dollars a year as world energy prices dropped (Bergsten, 2005, p. 57). Higher crop prices could increase farm income by 30% and farmers would cultivate more land, saving $10 billion a year in government subsidies (Greene, 2004). Even the 34 U.S. ethanol plants now under construction will create 153,725 jobs and increase tax revenues by over $3.5 billion (Urbanchuk, 2006, p. 3).

On the downside, environmentalists are concerned about the effects of biofuel crops on water resources, biodiversity, and natural habitats (Holland, 2005). Using switchgrass—a native American grass that grows in wasteland—will minimize this impact (Greene, 2004, p. 27-32). Bio-fuel stocks are also dependent on the weather. Ethanol production dropped significantly in mid-1996 because of wet weather conditions (Dipardo, 2002).

Policy Recommendations

- Begin a national campaign for energy independence (President).
  - Set new biofuel replacement goals of 15% of transportation fuel by 2015 and 50% by 2025 (USDA and DOE).
  - Direct government vehicles to use biofuel blends.
  - Provide consumer incentives to use of E85 cars (a blend of 85% ethanol).
- Provide incentives to gasoline stations to offer ethanol and biodiesel blends—at minimum a blend of 10% ethanol and 90% gasoline (E10).
  - Tax only the gasoline portion of a biofuel blend.
  - Triple the federal gasoline tax (now 18.4¢/gallon) and use the proceeds to promote research and development into new production technologies and plants.

*Environment*

Environmental biotechnology reduces or eliminates hazardous industrial wastes, treats these wastes, or cleans up polluted sites (bioremediation). It is potentially much less expensive than conventional cleanup because it works *in situ*, taking advantage of naturally occurring processes and avoiding expensive chemical or physical treatment. It is also "green," a plus in the public eye. And when integrated with other biotechnologies, it can create useful byproducts such as energy—methane, ethanol, and biodiesel—from biomass, compost, and carbon sequestration.

In treating polluted sites, bioremediation may use genetically engineered microorganisms which break down pollutants by feeding on them. Phytoremediation, a subset, uses plants "to remove, transfer, stabilize, or destroy contaminants in soil, sediment, and groundwater" (EPA, 2004, p. 5). Both bacteria and plants can also absorb and sequester contaminants for later recycling (Smith, 2004, pp. 175-177).

Despite the more than $1 trillion cost of cleaning up the 12,000 Super Fund and 450,000 brownfield sites, actual U.S. remediation revenues were just $6.3 billion in 2004, down slightly from 2003. Only 30% of that went to site remediation, and bioremediation was only a small portion of that, making it a tiny fraction of the $60.8 billion U.S. biotech market (IBISWorld,

2006, Remediation, pp. 6, 9, 12). In the past, projections of bioremediation growth have been wildly optimistic: "ten-fold over the following five years" (Evans & Furlong, 2003, p. 5). Realistically, bioremediation's share of the cleanup market will increase by a percent or two per year over the next several years.

There are five reasons for the slow growth of bioremediation. Firms view cleanup as a "necessary inconvenience" rather than a contributor to the bottom line (Evans & Furlong, 2003, p. 2). In the absence of heavy fines from the EPA, the private sector is reluctant to spend the money.

Government is the principal customer. Today, the public sector generates about 70% of the demand for remediation services (IBISWorld, 2006, Remediation, p. 10). Thus, revenues ebb and flow in accordance to public interest and legislative pressure.

Some environmentalists oppose bioremediation, citing the dangers of releasing engineered microorganisms into the environment and lumping bioremediation in with more ethically charged biotechnologies.

The bioremediation industry is significantly less mature that the rest of the biotech sector. It is made up almost entirely of very small, specialized companies (Evans & Furlong, 2003, p. 7), unaccustomed to operating within the regulatory framework that drives the market. Many lack business models, have little marketing expertise, and do not collaborate well with each other—which hurts public appreciation of their potential. The dearth of recent press coverage underlines the industry's inexperience with public relations.

Finally, bioremediation experts have not educated the government about the industry. EPA deadlines often rule out bioremediation, which can require several years to run its course. As a result, many polluters simply transfer waste to landfills rather than clean it up.

Policy Recommendations:

- Initiate an industry-government dialogue aimed at reforming regulatory cleanup timelines to encourage the use of bioremediation.
- Educate the public about the safety and effectiveness of bioremediation.
- Provide incentives to industry to combine environmental biotechnology with industrial processes—which will minimize waste while generating useful byproducts.

*Nanotechnology*

Nanotechnology is the study and development of structures, devices, or systems through manipulating matter at the atomic or molecular levels—at dimensions between one and 100 nanometers. (A nanometer is one billionth of a meter or about one-thousandth of the width of a human hair.) Such very small particles behave very differently from either individual atoms or their aggregations. This is because Quantum effects dominate Newtonian physics and traditional chemistry, due to the combination of dimensions, surface properties, surface area, structure, and shape. This can lead to counterintuitive effects.

Nanotechnology's future is promising but still speculative. In 2004, the worldwide combined private and government investments in this 15-year-old science reached $8.6 billion, $3.4 billion of which was in the U.S. (Nordan, 2005). A significant part of this effort, the National Nanotechnology Initiative (NNI) is a federally funded research initiative managed by the National Science and Technology Council (NSTC), a cabinet-level council which coordinates

science, space, and technology policies across the federal government. Twenty agencies currently participate in NNI (NNI, 2004).

Researchers now apply nanobiotechnology to areas such as bio-information (medical imaging, genomics, and rapid DNA sequencing); engineered cells and organs (cell biology and manipulation, stem cell research, artificial cells, tissue, organs, and cloning); and nanomaterials (biosensors and targeted delivery of drugs to fight cancer and infections) (Freitas, 1999).

The scientific community also anticipates a wide variety of biological applications in the future to include molecular medicine (detection and treatment of disease, body part replacement and regeneration, nanoscale surgery, and synthesis of drugs), nano-pollution control; agriculture (enhancing agriculture output, filtering clean water, and improving storage); human performance (enhanced physiology and sensorial capability), and nanorobots (which can swarm to specified sites and take action.) (Roco, 2003).

The risks of nanotechnology are uncertain and regulation is underdeveloped. Research shows that nanoparticles penetrate the human skin, migrate and accumulate in other parts of the body, and spread in the environment. There is a potential for accidental nanoparticle exposure through the air, the surroundings, or water, but no one is certain what that will mean. Current toxicity models and regulations are based on material mass and do not adequately cover the unique qualities of nanoparticles. The EPA, FDA, and USDA are currently the leading U.S. regulatory agencies for nanotechnology, but they need to focus on this risk.

Policy Recommendations:

- Make research into the toxicity of nanoparticles top priority, because of the possible consequences to health, safety, and the environment.
- Double or triple NNI's current $38.7 million research budget.
- Establish a new government regulatory structure that can oversee and control what could be a very dangerous technology in the wrong hands.
- Wage a joint government-industry information campaign to inform the public about nanotechnology, reduce misperceptions, and increase confidence in safeguards.

## GENERAL POLICY RECOMMENDATIONS

If the U.S. is to maintain leadership in biotechnology—mount an effective national biodefense, remain on the pioneering edges of medicine, digest toxins from pollutants, and generate alternative fuels—the federal government must address the challenges facing both science and industry. Harmonizing the efforts of the many governmental agencies involved and encouraging research and business efforts must become a sustained national priority. Here are the over-arching recommendations:

- Establish a National Biotechnology Council to oversee the national strategy, advocate for the sector, and act as a resource for information.
- Negotiate a national interagency strategy for biotechnology, addressing everything from education and biodefense to health implications and safety/oversight issues.
- Promote public-private partnerships among all the players—academia, nonprofits, industry and government—to build support for biotech programs.
- Create a National Vaccine Production Facility at the National Interagency Biodefense Campus to develop and produce vaccines for biodefense and for unprofitable markets, mainly in the developing world.

- Encourage educated decision-making by consumers and voters through an information campaign aimed at improving public understanding.
- Enact legislation that removes obstacles, promotes innovation, expands funding for biotechnology research funneled through National Institutes of Health (NIH) and the National Science Foundation (NSF).
- Streamline FDA procedures, cutting development time and costs while guaranteeing safety.
- Allow federal funding for embryonic stem cell research to keep key researchers and funding at home and avoid fragmentation into separate state efforts.

## CONCLUSION

The biotechnology industry is of great strategic importance to the U.S., as it is directly involved in defending against bioterrorist attacks and warding off pandemics such as avian flu which could attack public health, kill hundreds of thousands, and damage the economy. Biotech is key in producing biofuels and making the U.S. energy independent. It is the future for an agricultural sector in which GMOs will be called upon to feed a burgeoning worldwide population. Bioremediation is an inexpensive and effective way of cleaning up pollution. Nanotechnology represents the next step, still mostly a dream, of manipulating materials at the atomic level to deliver medicines directly to the disease and to perform microscopic medical procedures.

But it is in the field of medicine where biotechnology holds out the hope of curing the incurable and healing the unhealable. Research into embryonic stem cells may make it possible to regenerate damaged organs and tissues. Therapeutic vaccines aim at using white blood cells from a patient to create an individually tailored cure.

Because biotechnology is pushing science to the frontiers of life, it raises profound ethical issues as to where to draw the lines and how to involve the public to build support. Government decisions on regulations have the power to weaken or kill businesses as fragile as many of these are. Patents and FDA approvals can stifle innovation. The lack of American student interest in this vital field points to a possible future weakness, when the U.S. can no longer attract the scientists industry depends on from overseas.

Due to long-term product development, many biotech companies must find funding for the years it takes to become profitable. Government funding will not build a viable industry, but it can supply the basic research these firms need to take off. It can also pass the laws to create the environment this nascent industry needs to develop, while protecting the public from unintended consequences. For perhaps more than any other industry, biotechnology depends on a tight public-private partnership to flourish.

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