Biotechnology and its Potential Impact on Global Security

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Biotechnology – the ability to understand and manipulate biology at the molecular level – is likely to continue to have a profoundly positive impact on the human condition. For example, we have already seen great advances in the treatment of complex viral diseases such as AIDS, in our understanding of the genetic basis for diseases such as breast cancer, and are beginning to unravel the genetic, molecular and environmental underpinnings of autism and Alzheimer's disease. This trajectory is likely to accelerate in the years to come. In addition to its application to human health care, biotechnology has already had a substantial impact on agriculture. For instance, DNA markers are used to guide the conventional breeding of plants for greater yield and nutritional value, and we have genetically modified corn that is resistant to plant pests.

Biotechnology can also provide the basis for exquisitely sensitive sensors that are already used in diagnostic kits, including those for the measurement of glucose for diabetics and for a wide range of food safety applications. When coupled with nanotechnology and microelectronics, one can imagine ever more accurate insulin pumps, crop management tools and water safety monitors.

Its benefits notwithstanding, biotechnology comes with its own set of complex ethical issues, including cloning, use of fetal stem cells, whether individuals and insurance companies should have access to the knowledge about cancer markers, and the consumers' right to have foods derived from genetically modified organisms so labeled. We must address these ethical issues in a globally responsible way to reap the full promise of biotechnology.

Trajectory of Biotechnology in the Next 20 Years

Many of the intellectual underpinnings of biotechnology are already in place to safely predict that biotechnology will continue to have a very positive global impact over the next 20 years. For example, molecular tools, rapid sequencing technologies, partial libraries of genomes and high speed computational algorithms to mine these libraries are in place. Projection of the future is difficult because discontinuous innovations are required to change the world as we now know it. For instance, it is hard to believe that less than 20 years ago CERN (the European Organization for Nuclear Research) published what is considered the first public face of the world wide web project, which grew out of private, defense and research investments in networks starting in the 1960s. The innovation that gained enormous acceptance was when TCP/IP protocols could adapt to existing communications protocols. Today, it is hard to imagine life without the internet. We now have an entirely new vocabulary including terms such as google, URL, Facebook, Skype, Wikipedia and eBay. We have instant access to information and new means of communicating and performing everyday activities such as buying airline tickets, paying bills and researching our ancestors. It is also hard to believe that Motorola made commercially available the first portable cellular phone only in 1983. Now nearly everyone has one or two, with functionality that includes access to the internet, voice and text communications, GPS, and digital cameras.

As is the case for information technology, discontinuous innovations in biotechnology have changed the world as we know it. For example, DNA fingerprinting was first used in a criminal investigation in 1986. The human genome project officially began in 1990 and a working draft was available by 2000 (five years earlier than projected), spurred by advances in sequencing and computation. Dolly, the cloned sheep, was born in 1996 and introduced to the world in 1997. And in 1996, Roundup Ready soybeans were commercially available; by 2005, 87 percent of the U.S. soybean fields were planted with them.

These examples from the past illustrate two points. First, discontinuous innovations rest on the shoulders of visionary people and take advantage of a strong underpinning of basic knowledge and applied research. Second, the future holds great promise for additional discontinuous innovations in biotechnology if we continue to nurture the underlying intellectual base and build the human capital capable of challenging the status quo.

In this paper we define six global security issues that could benefit greatly from biotechnology approaches over the next 20 years, coupled of course, with informed policy. We set forth challenges in each of these six areas with the goal of changing the world as we now know it. Our goal is a New Secure World.

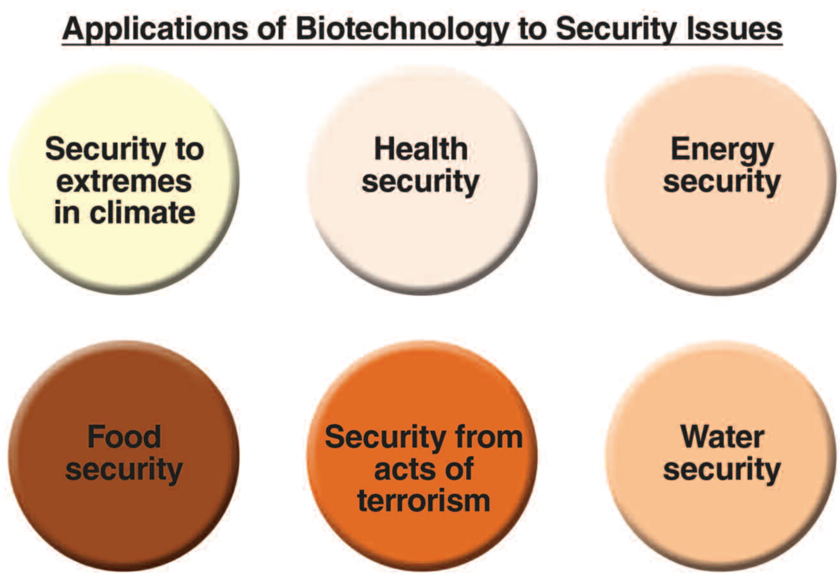

FIGURE 1 Six areas of global security in which biotechnology could have a major impact over the next 20 years

How Biotechnology Might Affect Global Security Issues

Although global security issues are legion, we will focus here on six areas in which biotechnology could have a major impact. These are energy security, security to extremes in climate, health security, security from acts of terrorism, water security, and food security (figure 1, p. 86). Although we will discuss each of these in turn, we show at the conclusion of this paper that these areas are largely interrelated and we advocate a systems approach to them.

Energy Security The world's supply of oil, gas and other fossil fuels is limited, and furthermore, burning of fossil fuels contributes to global greenhouse gas emissions. Although new fossil fuel discoveries continue to be made, considerable uncertainty exists in the amount of reserves and the rate in which they are being depleted. Figure 2 depicts the percent of known oil reserves in 2009 by geographic area. Most would agree that because our supply of fossil fuels is finite, we must do something, whether nuclear energy, alternative fuels, hydrogen fuel cells, or conservation, to continue a sustainable trajectory of global population and economic growth.

In this section we briefly discuss various options for producing biofuels and how advances in biotechnology might accelerate their production in an economically and environmentally responsible way.

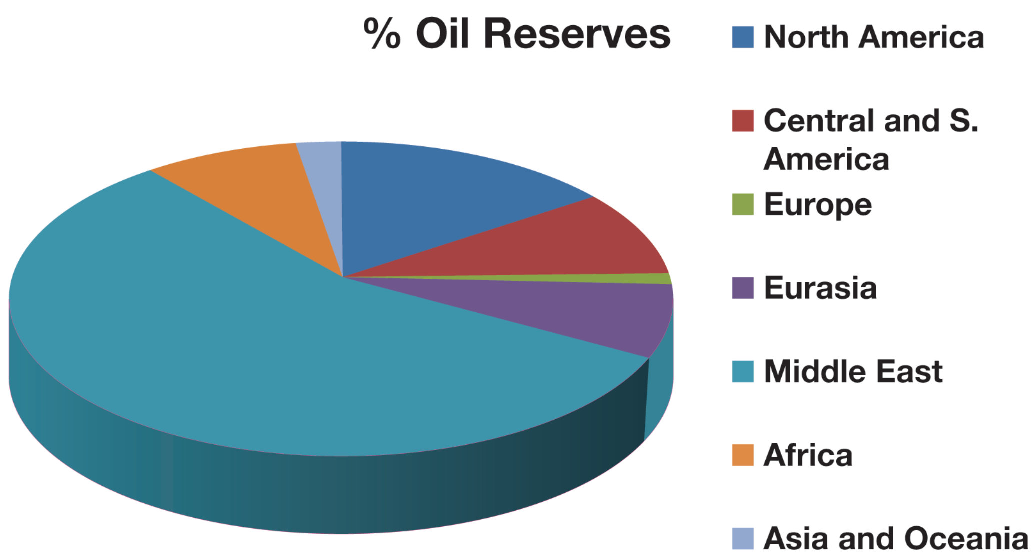

FIGURE 2 Percent of world's known oil reserves, 2009. **SOURCE:** Compiled from data obtained from *http://www.eia.doe.gov/emeu/international/reserves.html*

- *Ethanol as a Biofuel* Biotechnology offers the promise of producing sustainable biofuels and biodiesel from plant feedstocks.[1] In Brazil, for example, the fermentation of cane sugar to ethanol, coupled with new infrastructure and policies for cars capable of running on "flex" fuel, has shown that biofuels can be produced in a sustainable way. In 2009, Brazil produced 29.4 billion gallons of ethanol for fuel, or 37.7 percent of the world's supply.[2] Ethanol can be fermented directly from sugar in the sugar cane feedstock, making the process economically viable when the price of gasoline is sufficiently high. Because in the U.S. sugar cane grows only in Texas, Louisiana, Florida and Hawaii, this route to ethanol is less attractive in the U.S. than it is in Brazil or Central America.

To produce ethanol from corn, the cornstarch must be converted into sugars before fermentation. This conversion is expensive and furthermore, the process of making ethanol directly from corn is environmentally less desirable and competes with corn as a source of food. In the absence of an inexpensive source of sugar, the conversion of cellulosic feedstocks into ethanol or biodiesel is more likely, ultimately, to be an economically viable and sustainable route to biofuels.

- *Cellulosic Feedstocks for Fuel* Cellulosic feedstocks such as switchgrass and corn stover can be converted into sugars and lignins and then fermented into ethanol, or converted via pyrolysis into biofuels. Biotechnology is being used to optimize both scenarios. For example, lignins interfere with the fermentation process and scientists are examining ways to remove them. In addition, cultivars of perennial grasses are being improved, just as turf grasses were, by selective breeding using genetic markers. Finally, one could imagine learning about new processing enzymes from termites, whose guts are capable of digesting cellulose.

- *Algae to Create Biodiesel* Biodiesel is produced in the U.S. from soybeans and in Europe from canola oil. Both are expensive propositions. An alternative approach is to harvest biodiesel from algae grown in high density.[3] This has been pioneered by a number of demonstration projects, among them the Redhawk power plant near Phoenix, Arizona, in which algae were maintained in plastic bag-like containers.

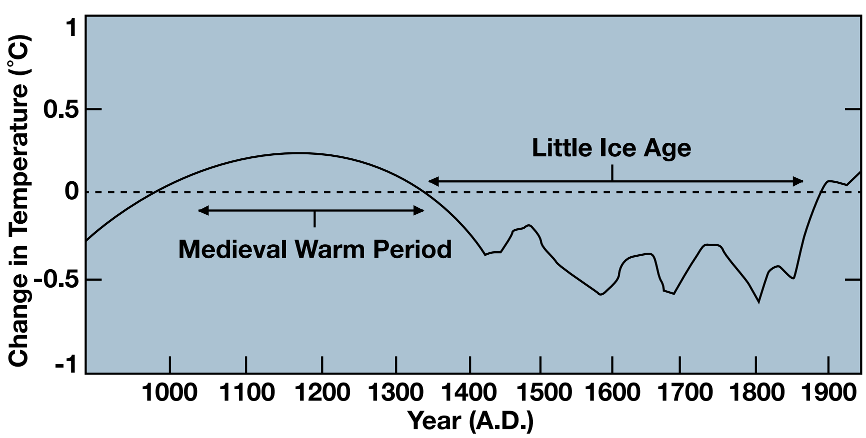

FIGURE 3 Smoothed and averaged regional proxy data illustrating the Medieval Warm Period and the Little Ice Age.
SOURCE: *http://www.geocraft.com/WVFossils/ice_ages.html*

Security to Extremes in Climate Although the exact predictions about global warming have recently been called into question[4] and debate continues over the degree to which anthropogenic activity has influenced global climate,[5] several issues are clear. First, the earth's climate has previously undergone warming and cooling periods (figure 3), although the global extent of these temperature swings is unclear, as historical records and proxy measurements were used to construct the analyses.[6] Nevertheless, the Medieval Warm Period (ca. AD 950 - 1250) is one in which Europe was balmy and grapes grew in England. During the subsequent Little Ice Age the Thames repeatedly froze over. In addition, between 1900 and 2005, where actual temperature measurements were recorded, temperatures at Earth's surface increased about 0.8 degrees Celsius.[7]

Potential impacts of global climate change include weather extremes, changes in sea level, ocean warming, flooding, new regional rainfall patterns, new temperature extremes, threats to human health and reduced crop yields. It is appropriate and timely that we develop contingency plans for the global security issues described here, should recent climate change predictions come to fruition. Failure to adapt to these changes could be a source of national and international instability particularly in climates and geographical areas most affected by climate extremes.

Biotechnology can address many of the uncertainties predicted by climate change including: the development of plants either bred or engineered to adapt to extremes in temperature, crops that can withstand stress and are tolerant to drought or saline. Adaptive strategies could also involve developing agricultural cropping systems that require reduced water and nitrogen inputs and sequester more carbon than is currently the case.

Over the past several decades biotechnology and plant breeding approaches to drought tolerance have been the subject of intense investigation. We now have a better understanding of the roles of regulatory networks, gene expression and signal transduction.[8] Nevertheless, the commercial production of drought resistant plants is in its infancy and we may well need a discontinuous innovation to bring it to reality.

Health Security The future of biotechnology is bright when it comes to predicting its impact on human health.[9] We are likely to see advances in areas such as personalized medicine, drug delivery, gene therapy, vaccines and regenerative medicine. Many of these advances will stem from molecular diagnostic tests now capable of interrogating specific points in the chain: "DNA makes RNA makes protein" as markers relate to disease progression and personal response to treatment.

While these advances in healthcare will greatly improve quality of life, some are also directly applicable to global health security issues. For example, outbreaks of pandemic diseases and chronic debilitating diseases create economic disruption and place heavy demands on medical and social services. In this section we focus on three areas in which medical biotechnology, both diagnostic and therapeutic, can have a large impact on global security. The ultimate goal is to use biotechnology to move from treatment of disease to prevention of disease.

- *End to Chronic Debilitating Diseases* Many countries, particularly ones in tropical zones, face the security threat that chronic debilitating diseases impact people of working age, creating a population of non-working and medically needy people. Diseases include chronic conditions such as schistosomiasis, Chagas disease, AIDS, dengue, and West Nile virus.

A similar situation, but ethically difficult to discuss, pertains to countries that face a rapidly aging population. As our average lifespan continues to increase, so too will the number of people requiring advanced care for conditions such as Alzheimer's disease, dementia, hip replacements and artificial heart valves. Unless properly managed, this situation, coupled with new and expensive medical procedures, costly diagnostic tools and heroic treatments, conspires to create an unstable economic situation. We anticipate that biotechnology will contribute diagnostic and preventative tools to ease the security burden of chronic debilitating diseases.

- *Regenerative Medicine* Replacement tissues and organs derived from stem cells may one day make it possible to replace organs such as kidneys and livers and to treat diseases such as muscular dystrophy and Parkinson's disease. Research at the interface between biotechnology and materials science is now making it possible to grow cells on artificial scaffolds.

- *Shift from Treatment of Disease to Prevention* Ultimately biotechnology will make it possible to shift to disease prediction and prevention from our current modality of treating diseases after they have occurred. Microarray technology of increasing sophistication will make it possible to shift from the treatment of disease to its prevention. For example, over 10 million single nucleotide polymorphisms (SNPs) have been identified in the human genome. SNPs can predict genetic disease, which can be treated or prevented.

Water Security Access to clean water is a major issue, particularly in developing countries. Waterborne diseases are the second most frequent cause of death in children under five years of age.[10] Dr. Rita Colwell summed up the national security issues surrounding access to clean water when she discussed her life-long work on the waterborne disease cholera leading to receipt of the 2010 Stockholm Water Prize: *"Infection by waterborne diseases, parasites, bacteria and viruses causes a reduced capacity for work and daily functions, which creates economic and social disruption and a reduction of capacity of a country. Safe drinking water is critical to economic stability, social stability and even national security."*[11]

Colwell, whose lifelong work has used molecular and other techniques to understand the transmission of waterborne diseases, advocates simple improvements in water treatment in developing countries. She also warns that climate change could increase water temperatures, perhaps leading to increased geographical distribution and seasonality of waterborne pathogens.

Security from Acts of Terrorism Although the absolute number of deaths from terrorist incidences is small (figure 4) compared to deaths from hunger or waterborne diseases, terrorist activities introduce a high level of uncertainty and chaos. The disruption from terrorism is encumbering in its disruption of travel and its requirement for resources. Furthermore, in the wrong hands and weaponized, biological agents such as ricin, aflatoxin, botulism toxin, saxitoxin, smallpox, anthrax, ebola, Marburg virus, plague and Rift Valley fever could generate enormous damage. Although treaties are in place prohibiting the use of biological agents, it is nevertheless prudent to be prepared to detect and prevent such an attack. Terrorists are not bound by treaties and rogue scientists could provide access to biological agents.

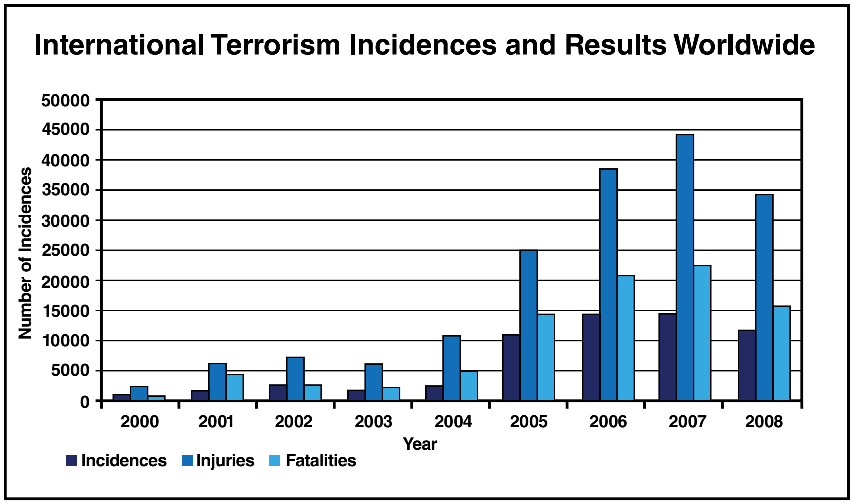

FIGURE 4 International terrorism between the years 2000 and 2008.
SOURCE: U.S. Department of Defense, *http://www.project.org/info.php?recordID=178*

Biotechnology offers the advantage of producing exquisitely sensitive sensors for detection of both biological and non-biological threats. One could imagine sensors for airborne threats, multi-array sniffers at airports and public buildings, and perhaps routine screening in hospital emergency rooms to detect early victims.

Food Security According to the World Food Programme, about one person in six or seven regularly suffers from hunger.[12] As figure 5 (p. 92) shows, most of the world's hunger is concentrated in Africa, India, Mongolia, Bolivia and Central America. Biotechnology, either as a guide to conventional breeding programs or via genetic engineering, can be used to enhance the production of foods, both plant and animal. Goals include higher yields, shorter time to market, resistance to pests and pathogens, and greater nutrition.

While the goal of eliminating world hunger is noble, not everyone is willing to embrace a solution that involves genetically modified organisms (GMOs). For example, the European Union has not been widely accepting of GMO crops and requires labeling for foods and food products that still contain the DNA or protein derived from GMOs. Similarly, in September 2010 the U.S. Food and Drug Administration was unable to reach a decision on whether to allow genetically engineered Atlantic salmon to be used for human consumption.[13] The salmon, AquaAdvantage, was raised from eggs injected with DNA from the Pacific salmon and genetic material from the ocean pout eel. If approved, this would have been the first genetically modified animal in the food supply.

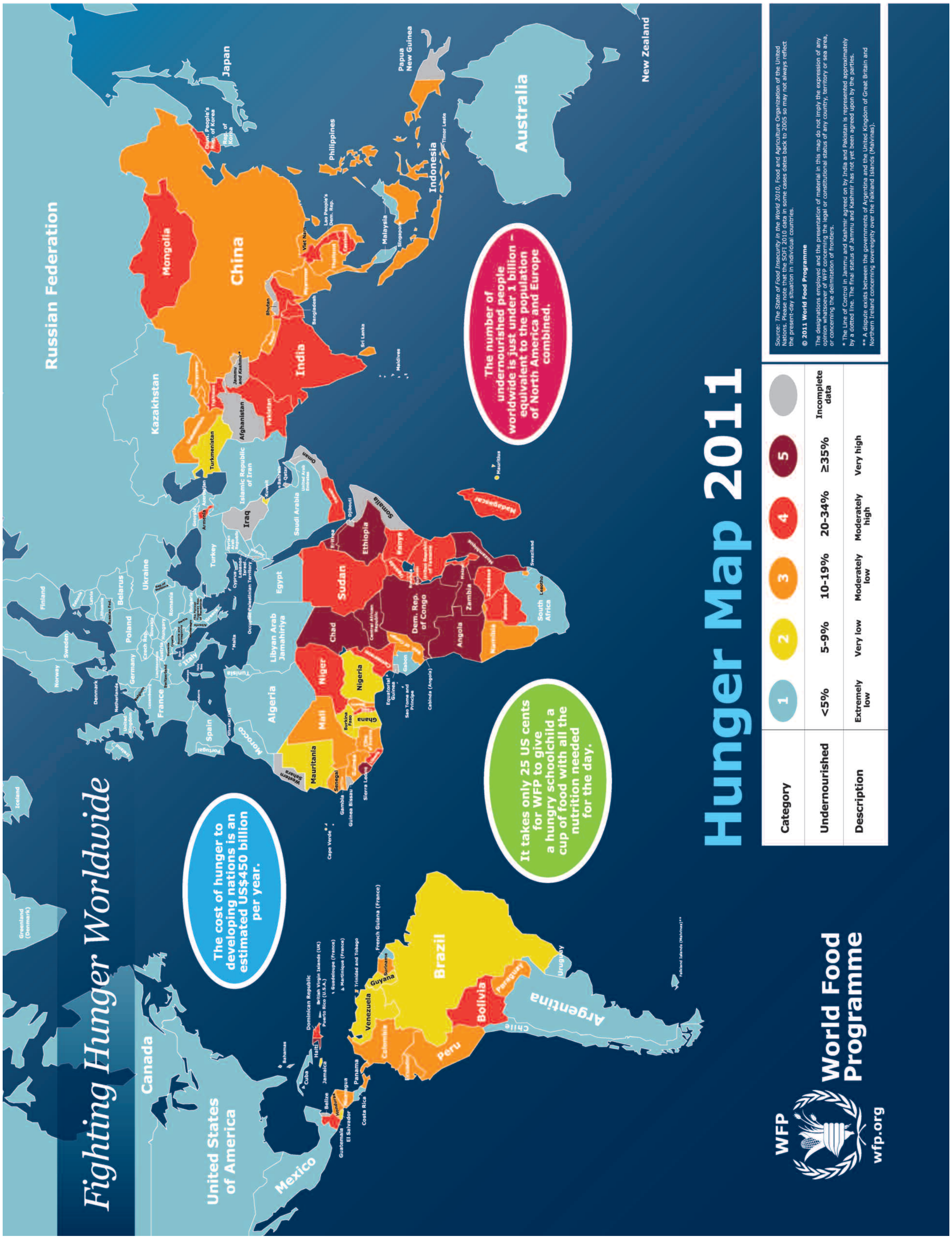

FIGURE 5 World Hunger Map. **SOURCE:** World Food Programme, *http://www.wfp.org/*
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How are we adapting/responding to these global security issues?

It is important to note that none of the six security issues we have identified exists in isolation. For instance, access to plentiful and clean water is directly related to health security, to security from terrorism, to food security, or to security to extremes in climate, and indirectly to energy security. Consequently, a systems approach seems appropriate.

The U.S. is currently engaged in a number of activities to address these global security issues – issues even more important in the context of a growing world population. In 2010 the world's population is estimated at 6.87 billion people (U.S. Census Bureau). While population growth has slowed to about 1.1 percent in many developed countries, the world's population is not expected to peak for at least 20 more years, at which time estimates range from an additional 0.63 – 2.13 billion more people (figure 6). It is likely that this population growth will add additional stress to the system.

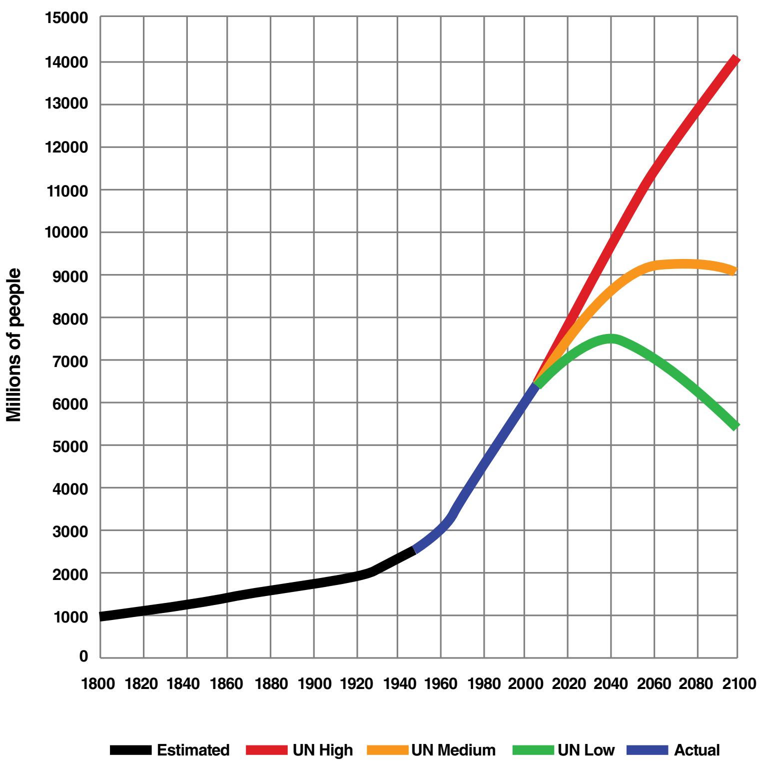

FIGURE 6 Projections for world population
SOURCE: *http://en.wikipedia.org/wiki/World_population*

The U.S. is engaged on a number of fronts to address these security issues. For example, Congress recently passed the Energy Independence and Security Act (2007). Its goals are "to move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes." Among other provisions, it calls for the amount of biofuels added to gasoline to increase to 36 billion gallons by 2022, up from the 4.7 billion gallons in 2007, and that most of this increase comes from non-cornstarch feedstocks such as sugar and cellulose.

In addition, the National Science Foundation, the National Institutes of Health and the Department of Energy commissioned the National Research Council to produce a report *"New Biology for the 21st Century"* which defined four major societal challenges:[14]

- generate food plants to adapt and grow sustainably in changing environments;
- understand and sustain ecosystem function and biodiversity in the face of rapid change;
- expand sustainable alternatives to fossil fuels; and
- understand individual health.

These four challenges are now driving part of the biotechnology research agenda. For example, the U.S. Department of Agriculture has issued competitive grants in five broad areas: 1) keep American agriculture competitive while ending world hunger; improve nutrition and end child obesity; 3) improve food safety; 4) secure America's energy future; and 5) mitigate and adapt to climate change.

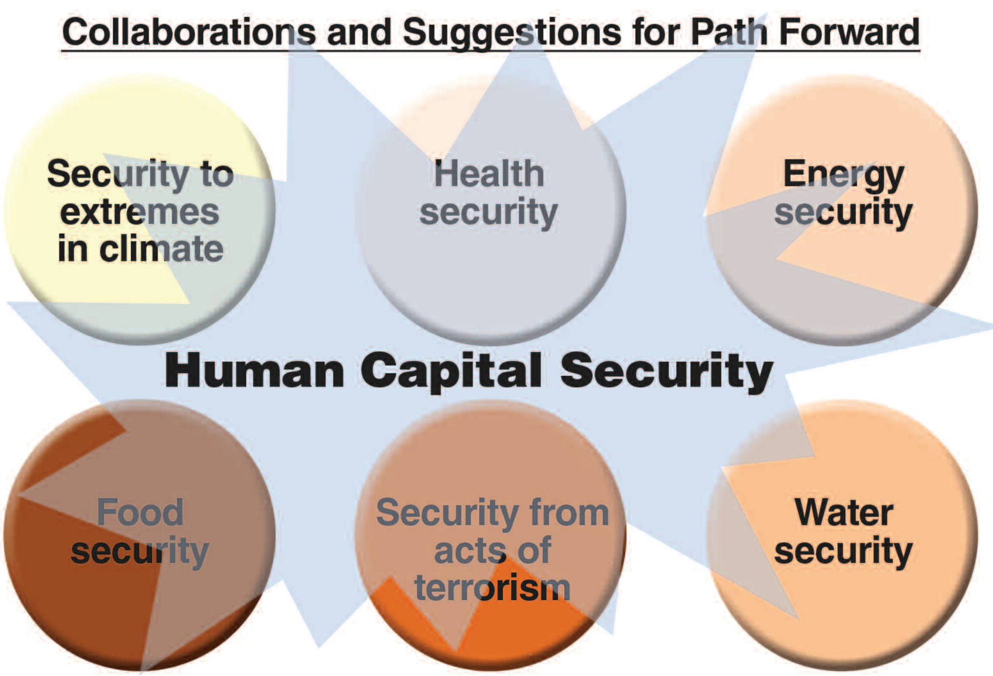

FIGURE 7 Emphasis is on the value of human capital

Way Forward: Recommendations for Strengthening and Improving Global Security

The six biotechnology security issues are not unique to the U.S.; many other nation-states have the same issues. Solutions to these issues will overlap, and cooperative effort will produce superior results.

With our focus on potential applications of biotechnology to security issues we have ignored perhaps one of the most important areas of all: human capital security (figure 7, p. 94). As we go forward to define collaborations and areas of join interest, it is essential to recognize that our greatest security will ultimately come from a highly educated, technically and scientifically literate population.

To fully utilize our human capital to solve the security issues faced jointly by nations, We set forth the following recommendations to build collaborations around mutual issues of global security:

- for each identified issue selected for multinational effort, face-to-face meetings are important first steps and memoranda of understanding are useful to formalize collaborations;
- leaders should go beyond meetings and discussions and create hands-on opportunities for genuine intellectual exchanges, including visiting professorships, laboratory internships and joint field work;
- leaders should define several focused areas of mutual interest and expect mutual contributions and time commitments from each nation;
- the efforts should include cultural as well as scientific exchanges;
- there must be a substantial effort to follow up on issues identified and to ensure mutual contributions occur as anticipated; and
- to continue to build human capital, it is essential that students are exposed to the value of global teamwork.

Notes

1. World Bank, "Biofuels: The Promise and The Risks," *World Development Report 2008,* 70-71.

2. Renewable Fuels Association, "2010 Ethanol industry outlook: climate of opportunity" (2010).

3. Joel K. Bourne, Jr., "Green dreams – making fuel from crops could be good for the planet – after a breakthrough or two," *National Geographic Magazine* (October 2007): 38-59.

4. M.E. Mann, et al., "Global-scale temperature patterns and climate forcing over past six centuries," *Nature* 392 (1998): 779-787.

5. Monte Heib and Harrison Heib, "Global warming – a chilling perspective," 2007, *http://www.geocraft.com/WVFossils/ice_ages.html*.

6. National Research Council, "Surface temperature reconstructions for the last 2,000 years" (Washington, DC: National Academies Press: 2006), 3.

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8. T. Umezawa et al., "Engineering drought tolerance in plants: discovering and tailoring genes to unlock the future," *Current Opinion Biotechnology* 17 no. 2 (2006): 113-122.

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10. R. A. Rahman, "Water is imperative to economic and national security – 2010 Stockholm Water Prize interview with Rita Colwell," *Water Front Magazine* 2 (2010): 8-9.

11. Ibid.

12. *http://www.wfp.org/*.

13. Kim Carollo, “Surprise: FDA Panel Unable to Rerach Conclusion on Genetically Modified Salmon,” ABC News, September 21, 2010, *http//abcnews.go.com/m/story?id=11682586&sid=26.*

14. National Research Council, “A new biology for the 21st century: ensuring the U.S. leads the coming biology revolution” (Washington, DC, National Academies Press: 2009).