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From Petro to Agro: Seeds of a New Economy

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Overview

Winston Churchill is said to have stopped predicting future events because the future was just "one damned thing after another." Nonetheless, we need to keep an eye on the future and speculate as to what the next damned thing might be. One candidate is the changing raw material base for the economy.

Today, the hydrocarbon molecule is the basic unit of commerce. In a biobased economy, genes will replace petroleum. So, just as we currently demand assured access to sources of hydrocarbon molecules (oil), in the near future we will demand assured access to a broad-based, diverse supply of genes (plants and animals). This shift has security implications. Relations with oil-rich countries will be of less importance, and relations with gene-rich states—mostly the biodiverse regions along the equator—will assume greater significance. Conflicts may arise between gene-rich, technology-poor countries that control the basic raw materials of a biobased economy and gene-poor, technology-rich nations that control the production methods.

American instruments of power will be challenged to meet the demands of a biobased economy. We already see diplomatic challenges with the United Nations Framework Convention on Biological Diversity and controversy with Europe over genetically modified crops. Informational and economic challenges and opportunities will likewise appear. It may be challenging for U.S. land forces, especially the Army, to meet the demands of securing access to large supplies of new genetic material.

Agriculture will become increasingly important as a part of the Nation's industrial base, as it offers the most economical way to produce large quantities of biological materials. Homeland defense will have to consider heartland defense, as agricultural fields will assume the same significance as oil fields.

The Age of Geology

For much of the last century, and particularly since the end of World War II, petroleum has been the primary raw material for U.S. industrial and consumer needs. As a nation, our petroleum use is twice that of our consumption of either coal or natural gas and four times greater than use of nuclear or renewable energy sources.[1]

The bulk of our petroleum use goes to meet energy demands, with approximately 90 percent of a barrel of crude oil going to gasoline, diesel, and other fuels. Since 1949, however, the industrial consumption of petroleum for nonfuel use has increased nearly sevenfold.[2] The chemical industry, for example, relies on petroleum for more than 90 percent of its raw materials to manufacture its myriad of products, ranging from plastics, refrigerants, and fertilizers to detergents, explosives, and medicines. Virtually everything requires petroleum or petroleum derivatives for its manufacture.

We are beginning to see a shift from petroleum, however. As the 20th century was ending, Michael Bowlin, then-president of the American Petroleum Institute, who was also chairman and chief executive officer of ARCO, told industry executives that the world was entering "the last days of the Age of Oil."[3] Estimates of the remaining life of the reserves vary widely, but many experts agree that worldwide oil production will peak between 2010 and 2020. Even if we agree with those who hold that the petroleum supply may be renewable, environmental pressures and economic incentives will remain that will move us to newer technologies.[4] Far from repeating the apocalyptic warnings of the 1960s and 1970s about the end of oil, Bowlin pointed to new technologies that will replace petroleum.

The Age of Biology

Prominent among the replacements for petroleum will be products developed from biological sources. Using biological materials, that is, plants and animals, as raw materials for industrial and consumer products is not a new idea. Before the rise of cheap oil, agriculture was the dominant source of our raw materials. Indeed, when the U.S. Department of Agriculture was established in 1862, its motto proclaimed, "Agriculture is the foundation of manufacture and commerce." Even today, agriculture supplies raw materials for industry; for example, about 8 percent of the U.S. corn crop goes to industrial uses rather than directly meeting food or feed requirements.[5] Moreover, the agricultural industry offers the most cost-effective way to manufacture large volumes of biological materials.

In its vision statement for the 21st century, the National Agricultural Biotechnology Council forecasts agriculture to be the source of not only our food, feed, and fiber, but also our energy, materials, and chemicals.[6] In a 1999 report on biobased industrial products, the National Research Council noted that U.S. farmers already generate annually about 280 million tons of waste biomass—leaves, stalks, and partially used plant portions. That is more than sufficient material to serve as feedstock for all of the domestic industrial chemicals that can be readily manufactured from agricultural sources.[7]

Domestically, resources needed for food and feed production will not compete with resources required to grow our industrial raw materials. Our natural resource base of land and water is more than adequate to meet the demand. The United States has the largest amount of arable land per capita of any country in the world (1.73 acres for the United States versus 0.99 for other developed countries; the developing world average is only 0.49 acres).[8] Additionally, through the U.S. Department of Agriculture Conservation Reserve Program, 35 million acres are left fallow each year, some of which could be used to grow crops specifically for biomass.

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While water does present some local and regional challenges, groundwater depletion rates in the United States have slowed overall during the last 20 years. As the need for affordable water increases, improvements in irrigation technology and the development of new water resources are likely to follow. One estimate suggests that improvements in irrigation technology alone can reduce the anticipated worldwide demand for additional water resources by one-half during the next 25 years.[9] Thus, while a concern, water availability is not likely to present a barrier to expanded agricultural production.

Technological innovations in agricultural production probably will continue to increase yields. Corn yields, for example, gained an average of 1.0 bushel per acre per year during the last century. In the last half of the century, the average increase was 1.8 bushels per acre per year. Depending on soil characteristics and water availability, even something as simple as the spacing between cornrows can be used to maximize yields. In the late 1990s, corn yields in the United States averaged 134 bushels per acre. Some researchers believe that within the next 20 years, technology and cultural practices can increase yield averages to nearly 260 bushels per acre.[10]

The United States clearly has the production capacity to produce and process the raw materials for a biobased economy. Still, in most current industrial practices, the cost of the conversion process—turning biomass into energy, materials, and chemicals—is not competitive with petroleum. Consider five common industrial products: adhesives, acetic acid, pigments, inks, and plastics. A comparison of their cost when derived from petroleum with their cost when derived from plant materials generally shows not only a greater cost for plant-derived materials but also great disparity in the spread, based on which product is being considered.[11]

A key problem with making cost comparisons is that the production costs are based on using existing facilities designed for petroleum feedstocks. When using biomass, some of the end products can be made through direct physical or chemical processing; others can be produced indirectly through fermentation (using microbial agents) or by enzymatic processing. What is needed are "biorefineries."[12] Like an oil refinery, a biorefinery would take carbon and hydrogen and produce desired products. The biorefinery's economic advantage will emerge from its dual capability. Along with the desired end products, foods, feeds, and biochemicals could be produced.

Prototypes of the biorefinery already exist in our industrial base in the form of corn wet mills, soybean processing facilities, and pulp and paper mills. While the prototypes of full-scale biorefineries are only in the planning stage, two facilities designed for specific biobased end products are presently coming online. Earlier this year, Cargill Dow opened a $300-million facility in Nebraska to manufacture a bioplastic made from sugars found in corn kernels.[13] As the technology improves, the company plans to extract the sugars from less costly agricultural waste, such as corn stalks, wheat straw, and rice hulls.

Similarly, DuPont announced last year that it had successfully manufactured a key ingredient for one of its new polymers, using corn sugars instead of petrochemicals.[14] The conversion was done in a pilot plant using a fermentation technology. Anticipating the eventual cost competitiveness of biological materials, the company has built a full-scale production plant for the polymer and designed it to use either petrochemical feedstocks or biobased feedstocks.

Is this biobased economy just a vision with a few immediate examples, or is there a long-term probability for its success? In its 1999 report on biobased industrial products, the National Research Council argued that a competitively priced, biobased products industry eventually would replace much of the petrochemical industry. As an intermediate goal, the report suggested that by 2020, a biobased economy could provide 25 percent of the 1994 levels of the Nation's organic carbon-based industrial feedstock chemicals and 10 percent of liquid fuels. The report suggested that, ultimately, 90 percent of the U.S. organic chemical consumption and 50 percent of our liquid fuel needs could be met by a domestic biobased economy.

In this new economy, plants and animals will be specifically bred and farmed to produce desired raw materials. For example, if an industrial process requires a chemical to have certain tolerances to heat, a protein may be available to provide that tolerance. The protein, which would be the product of a gene, could be derived from plants. If the protein occurs naturally in animals or in plant species that are not easily farmed, genetic engineering offers the ability to transfer the gene to a plant species more suited to agricultural production. (The product of moving genes from one species to another

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Production Costs (dollars per pound)		
Product	Petroleum-derived	Plant-derived
Adhesives	1.65	1.40
Acetic acid	0.33	0.35
Pigments	2.00	5.80
Inks	2.00	2.50
Plastics	0.50	2.00

is called a *transgenic*.) Once introduced into an agriculturally desirable plant, the protein can then be produced more cost-effectively and made available on a commercial scale.

Fueling the Biobased Economy

As the biobased economy matures and issues of production and processing are improved, the demand for new products will grow. New products will require new raw materials. In a biobased economy, the basic raw material will be genes, and novel genes will be the source of novel products. Thus, as we shift from an economy based on geology to one based on biology, the basic unit of commerce will shift from the hydrocarbon molecule to the gene. The Quadrennial Defense Review 2001 cites access to key markets and strategic resources as part of our enduring national interests.[15] Just as we currently demand assured access to sources of hydrocarbons, in the near future we will demand assured access to a broad-based, diverse supply of genes.

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As with any resource vital to our economy, the location of large supplies of genes will become important to our national security concerns. In our petroleum-based world, the resource is concentrated in various pockets distributed worldwide in nearly all climate regions. Obviously, genes are distributed worldwide, as there is life in every nook and cranny of this planet. However, the overwhelming majority of genes are concentrated in the equatorial regions.

Biologists refer to a region's biodiversity when commenting on the range of life forms present. The more life forms present (that is, the more genes present), the greater the biodiversity. The general biological principle of *latitudinal diversity gradient* contends the closer to the equator, the greater the biodiversity. The amount of solar energy present, the lack of seasonal climate fluctuations, and the expanse of land explain the gradient's existence. By way of illustration, consider the results of a study that used comparable sized plots of land at different latitudes to compare the number of different bird species found at each latitude: Greenland, 56 species; New York state, 195 species; Colombia, 1,525 species. Plants show a similar degree of biodiversity. For example, in all of Canada and the United States, there are only 700 native tree species. In one census involving about 25 acres in Borneo, more than 1,000 different tree species were cataloged.[16]

International Implications

In a biobased world, our relations with Ecuador (to use a representative country that takes its very name from the equator) will be more important than those with Saudi Arabia. The United States must consider what controversies could arise over another nation's genetic treasure and how best to secure access and provide compensation to the regional owners. These are not new issues.

A classic example that illustrates the potential issues is the rosy periwinkle plant of Madagascar. In the early 1950s, a plant biologist working for the U.S. drug firm Eli Lilly extracted two cancer-fighting compounds from the flower. During the course of the patents on the two compounds, Lilly earned hundreds of millions of dollars from the sale of the drugs. Madagascar received no compensation whatsoever.[17]

By the early 1990s, two documents were ready for international agreement that sought to address cases like that of the periwinkle, among other things. The Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement—part of the Final Act of the Uruguay Round of Multilateral Trade Negotiations—sought to strengthen international intellectual property protection in order to promote world trade. The United Nations Framework Convention on Biological Diversity, known commonly as the Biodiversity Treaty, sought to preserve agrarian societies and promote sustainable development.

Throughout the Uruguay Round, the United States strongly supported the TRIPS notion of protecting international intellectual property. Emblematic of the problems associated with that position were the 1993 riots in India directed against W.R. Grace, a U.S. chemical firm. Indian farmers were protesting that Grace had a patent on an insecticide derived from the neem tree, even though the farmers had a traditional method to extract the compound from the leaves. Although Grace's process gave the compound a shelf life and allowed it to be transported to areas where neem trees were not available, the farmers accused Grace of "gene piracy."

The Biodiversity Treaty was seen by many to be in conflict with the U.S. position on TRIPS. The Biodiversity Treaty sought to address the issue of the biodiverse-rich underdeveloped countries seeking compensation for the resources taken and used by the technology-rich developed countries. Provisions of the treaty require biodiverse-rich countries to provide access to genetic material in return for the developing countries providing a fair and equitable share of the benefits. U.S. pharmaceutical and biotechnology firms initially opposed the treaty. Eventually, however, they dropped their opposition, out of fear that it might ultimately preclude their exploration for genetic resources in underdeveloped countries. The treaty was signed by President William Clinton in 1993 but was never ratified.[18]

Although the treaty was not ratified, the business sector moved forward with an agreement that serves as a model for such arrangements. In 1991, Merck and Company signed an agreement with the Costa Rican Institutio Nacional de Biodiversidad (INBio) for a 2-year renewable contract, in which INBio supplied Merck with extracts from plants, insects, and micro-organisms for its drug-screening program. In exchange, Merck paid INBio $1,135,000 and royalties on any resulting commercial products.

Thus, even a decade ago, the business sector was quite aware of the potential for genes as raw materials. This is especially true in the pharmaceutical industry at the moment, as about one-fourth of all prescription drugs contain an active ingredient derived from plants.

In a biobased economy, with many players seeking access to the biodiversity treasures of developing countries, the possible international scenarios that might arise are limitless: conflicts between developed countries over who had access to what gene at what time; conflicts between developing and developed countries over access to genes and compensation; conflicts between developing countries over territory, and thus ownership, of particular stores of genes.

In this context, a serious dilemma could surface if a state set out to destroy large amounts of diverse genetic material. This is not a hypothetical situation. It is estimated that some 31 million hectares of rainforest are destroyed annually.[19] Article 3 of the Biodiversity Treaty states that countries have the "sovereign right to exploit their own resources pursuant to their own environmental policies."[20] If genes were the basic unit of commerce, would we tolerate another state's environmental policies that allowed for the continued destruction of the rainforest?

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Another likely point of international friction will be the use of transgenics. Moving genes from one species to another provides for tremendous diversity and the opportunity to create new products. It also raises safety and ethical concerns about introducing such genetically modified organisms (GMOs) into the environment. (A distinction is drawn between GMOs that are nonliving end products that would have no effect on the environment—for example, the heat tolerance protein theorized above—and living modified organisms [LMOs], such as seeds, that may have some environmental consequences.)

Current Department of Agriculture figures cite a continuing increase in acreage planted with genetically modified crops in the United States. In 2002, nearly one-third of all corn acreage will use genetically modified (GM) seed, while GM cotton will account for just over 70 percent of acreage and GM soybeans will be planted in approximately three-fourths of soybean fields.[21] The use of GMOs only will increase as the biobased economy matures, and, likewise, the potential for disputes will increase.

These are not hypothetical issues for the distant future but are present day concerns. The European Union (EU), for example, has had a moratorium on approving the importation of GM crops for the past 4 years. While it appears that the EU may be moving toward approval by summer 2003, the moratorium has been a cause of controversy between the EU and the United States. As recently as February 2002, the Secretary of Agriculture noted that the United States had not ruled out the possibility of filing a formal complaint with the World Trade Organization (WTO).[22] At the same time, however, environmental activists in Europe are encouraging EU governments to ban GM crops of beet and oilseed rape. In Australia, the Insurance Council of Australia has stated its reluctance to insure farmers, biotechnology companies, or food companies in cases involving GMOs.[23]

Significant multilateral international efforts have been made to address specific concerns surrounding LMOs. In January 2000, the Biosafety Protocol to the Biodiversity Treaty was signed. Known as the Cartagena Protocol on Biosafety, it is the first protocol to the Biodiversity Treaty. Its intent is to provide countries the chance to obtain information about LMOs before they are imported. Moreover, it acknowledges each country's right to regulate bioengineered organisms and provides a framework to help the developing world to protect its biodiversity further. Although the United States is not a party to the Biodiversity Treaty and thus cannot be a party to the Protocol, it participated in the negotiations as a member of the so-called Miami Group, a coalition of leading agricultural exporters that included Argentina, Australia, Canada, Chile, and Uruguay.[24]

While the various treaties and scenarios described above depict potential conflicts, not all international implications of a biobased economy will be filled with peril. For example, consider the implications for job creation. As a raw material, petroleum has considerably more energy per unit volume than biological materials. Thus, it is economical to transport petroleum from its source to distant refineries for processing and then further to ship the refinery products for use as end products or industrial intermediates. With biological materials, however, the economics will not support shipping the raw materials much farther than 250 to 300 miles from their point of origin. Biorefineries will have to be built close to the source of their raw materials. A regionalized agriculture will likely develop, with certain areas growing specific crops to supply regional biorefineries. Additional processing and manufacturing of value-added biologically based products can economically take place farther from a biorefinery, but there will be limits to the distances involved. The significance is the likely creation of nonfarming jobs in rural areas.

Urbanization in the developing world is often noted as a major issue of strategic concern for the 21st century. Currently, there are approximately 40 cities in the world with populations of 5 million or more. By 2015, it is anticipated that nearly 25 more will join the ranks. Only 11 of these 65 will be in the developed world.[25] Moreover, the demographic structure of societies in developing countries is heavily weighted toward people 25 years of age and younger. Unemployment among large numbers of young urban males in developing countries is frequently cited as a root cause of the terrorism that we are fighting today. A biobased economy ultimately could help stem the flow of urbanization and provide rural employment opportunities.

Domestic Implications

Just as new international issues will surface as a result of our transition to a biobased economy, new domestic considerations will likewise arise. For example, most homeland defense planning currently focuses on the protection of urban populations and infrastructure, while the safeguarding of agricultural areas does not receive much consideration.[26] Agriculture simply does not enter into the thinking of most people. Throughout most of the last century (from about 1930 to 1999), agriculture as a percent of U.S. employment declined nearly 90 percent—from 23 percent to 2.6 percent. The number of farms declined from 6.3 million to 2.2 million. Agriculture was not even included among the eight critical national infrastructures in Presidential Decision Directive (PDD) 63, "Critical Infrastructure Protection." Interestingly, however, agriculture is included as a subgroup of the Weapons of Mass Destruction Preparedness Group resulting from PDD 62, "Combating Terrorism."

In fairness, it has not seemed particularly necessary to include agriculture as critical infrastructure, since croplands have not surfaced as likely terrorist targets. Terrorists usually aim to score immediate to near-term effects by striking high-profile targets. While a present-day attack on our field crops could have a large economic price tag, it certainly would not affect our ability to feed ourselves. Food is plentiful worldwide, and the marketplace easily could meet any immediate or near-term demands. (Even with the growing world population, per capita food production has actually increased during the last 30 years from 2,360 calories per day to 2,740 calories per day.[27])

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In addition to field crops, farm animals, food in the processing or distribution chain, food at wholesale or retail establishments, and agricultural facilities are all potential targets.[28] Presently, an attack on any link in the chain would result in large economic losses, as well as likely loss of human and animal life. It is estimated that a natural outbreak of foot and mouth disease on just 10 farms would result in a $2 billion loss.[29] Losses from last year's outbreak of foot and mouth disease in the United Kingdom were estimated at $30 billion.[30] However, if we relied upon agriculture to provide the raw materials for our economy, the potential disruption could be orders of magnitude greater.

Consider this hypothetical scenario. What if, as the National Research Council report suggests, we did derive 50 percent of our liquid fuels from agriculture? At present, agriculture provides only 1.2 percent of our "gasoline" supply in the form of ethanol, much of which is blended with gasoline as an oxygenate to reduce seasonal pollution effects. As new biotechnologies improve the processing of biomass, ethanol will become an economically viable option, and it will become a larger source of our liquid fuel supply. At that point, destruction of a large portion of U.S. farmlands would be tantamount to an invasion of Kuwait.

The whole issue of agricultural bioterrorism is complex, but for the purpose of this argument, let us focus solely on croplands. How vulnerable are our croplands? In 1970, without planning or assistance from any organized terrorist group, a naturally occurring epiphytotic, an epidemic in the plant world, destroyed 15 percent of the U.S. corn crop with an estimated value of $1 billion.[31] Although we have diversified the genetic base of corn in an effort to avoid another such disaster, crops are still vulnerable to disease. Any number of organisms, including various molds, fungi, viruses, and bacteria, can cause epiphytotics. These organisms are easily grown in laboratories, at no threat to humans, and can be transported worldwide without detection.

At present, our crops present a relatively simple target set for anyone wishing to do them harm. The U.S. crop base is fairly uniform, with 8 of every 10 acres planted to just 3 crops: corn, wheat, or soybeans. There is genetic diversity within each crop, offering some disease resistance. Predicting the actual loss for any given attack would be based on several assumptions, as epiphytotics are dependent on multiple variables. Moisture and temperature are the most complex variables involved and are extremely difficult to predict in any long-term fashion.[32] Nonetheless, well-coordinated simultaneous attacks in many areas, using multiple pathogens, would no doubt result in significant losses. (Significant in this case could be analogous to the 1970 corn epiphytotic. This would have the net effect of reducing our annual supply of raw materials by 15 percent.)

The U.S. Department of Agriculture is responsible for the Animal and Plant Health Inspection Service (APHIS). Under APHIS, the Plant Protection and Quarantine (PPQ) Division is charged with protecting our crops from the national and international spread of diseases and pests. Since 1982, PPQ has conducted a nationwide survey on crop health and is responsible for dispatching rapid response teams to control any disease outbreak. In the face of a concerted attack, however, one could envision PPQ requiring the assistance of large numbers of people to help man the response teams. It is not inconceivable that military troops could be requested, in much the same manner as they are today to aid with firefighting.

From a plant protection perspective, the shift to a biobased economy will have some positive aspects. To provide new materials for industry, there will be a demand for new genes and their products. If novel genes are found in plants that can be easily grown in this country, then their direct cultivation would be the preferred method rather than creating a transgenic with corn, wheat, or soybeans. With direct cultivation, the overall U.S. crop base would be broadened and thus provide a more challenging target set for terrorists. Also, the construction of regional biorefineries would complicate targeting more than the current groupings of petroleum refineries.

While a biobased economy will no doubt bring the United States the same benefits of slowing urbanization and rural revitalization as anticipated for the developing world, the net effect most likely would be marginal. We will remain a predominantly urban society. As we reconsider the terrorist threat in the wake of September 11, however, it is important to note that agriculture will assume a greater significance as a potential target.

Challenges to U.S. Instruments of Power

Converting to a biobased economy will present new but not totally unfamiliar challenges on all fronts. This is not the first time we have developed and used new resources. Nor will it be the first time we have sought to obtain resources from other nations or wanted to trade finished products. None of these changes will happen quickly or without warning. Nonetheless, it is worth considering some possible effects on our diplomatic, informational, economic, and military instruments of power.

Diplomatic and Informational

Already, diplomatic challenges are being presaged by topics such as the Biodiversity Treaty and possible WTO action for our GMOs. Such issues may well become the norm, requiring a diplomatic corps well trained in scientific and technical skills. Water warrants some extended discussion, as it will be at the heart of diplomatic concerns in the 21st century, regardless of the world's resource base. A biobased economy, though, may well intensify the issue.

Globally, the renewable fresh water supply has fallen by nearly two-thirds in the last 50 years. During that same period, the human population has increased nearly 250 percent. Two-thirds of the world's water demands are for agricultural use, and while irrigated agriculture accounts for only 20 percent of farmland, 45 percent of the world's food supply is grown on irrigated land. By 2025, it is estimated that nearly 3 billion people—40 percent of the projected world's population—will find it difficult or impossible to satisfy basic water needs.

water will be at the heart of diplomatic concerns in the 21st century

The potential international points of conflict over water are also significant. Two or more countries share 261 of the world's rivers. Some 51 countries, within 17 international river basins, are at risk of water disputes during the next decade. An analysis of 1,831 international water-related disputes over the last 50 years revealed that about one-fourth resulted in violence.[33]

Although water will be a problem, it will not be an insurmountable one. In a 1999 National Academy of Science report on the future of water in the Middle East, it was noted that additional supplies could be obtained by using a variety of techniques. Some involve improved management of watersheds and collection of water that now is lost as runoff. Other techniques use current technologies and include wastewater reclamation and desalination. Some of these can be made even more productive and economical with further improvement. Conservation still remains a significant factor in extending water supplies. Between 1985 and 1993, for example, Israel reduced its water consumption by more than 200 million cubic meters per year, almost entirely through improvements in irrigation and water delivery restrictions.[34]

Former U.S. Senator Paul Simon is a strong advocate of desalination. In his 1998 book on the world's coming water crisis, he noted the progress being made in desalination technologies and use. About 11,000 plants are in operation in more than 125 countries. Desalination is most widely used in the Middle East, which accounts for about 60 percent of the world's plants. In fact, Saudi Arabia built the first modern desalination plant in the late 1930s. To be certain, the economics of desalination are still not competitive, especially for agriculture, but continued development will ultimately drive down the price. That will be especially true as the price of water from other sources rises.[35]

The informational element of the biobased economy is of particular interest and is worthy of a separate study. It is probably unprecedented that both government and business sources are being required by the general population to provide such large amounts of detailed technical information on procedures and products. This issue will only become more complicated, as nontechnical societies will demand data, and bioethics considerations will have to consider differing cultural views.

Economic

The economic forces of globalization at work today will not be affected by the biobased economy (with the possible exception of urbanization, as previously discussed). Thomas Friedman points out that the driving force of globalization is free market capitalism.[36] While a discussion of agricultural trade may well question how much it follows the rules of a truly free market, it is instructive to note our position in that arena. According to the Department of Agriculture Economic Research Service, the United States accounted for 19.2 percent of the world's agricultural exports in 2000. In that same year, we accounted for 13.7 percent of worldwide agricultural imports.[37]

Friedman also notes that globalization has its own set of defining technologies, which includes computerization, miniaturization, digitization, satellite communications, fiber optics, and the Internet. Those are the same technologies American farmers use in a technique called *precision agriculture*, which enables them to integrate all available data and to make the most efficient and economical decisions concerning a crop. For example, using data collected from field sensors, a farmer may detect a developing pest problem. Rather than treating an entire field, as would have been the solution in the past, very targeted treatments can be applied, saving time and money.

In an economy dominated by products derived from agriculture, it is unlikely that we would lose our position of trade or production capability. In fact, our position only will be strengthened, as the defining technologies used in agriculture are the very ones also used in biotechnology. Thus, we would likely achieve an economic advantage through our combined biotechnology skills—which will allow us to identify and use novel genes more quickly—and our agricultural production capacity.

The National Corn Growers Association, an industry trade group, has coined the phrase that the United States is the "Saudi Arabia of Corn." In a globalized, biobased economy, we will be the new Persian Gulf.

Military

Of all the instruments of national power, the military is the one most likely to be affected by a shift in our resource base. The instruments of diplomacy, information, and economics do not require long lead times to research, develop, and acquire their tools of the trade. Nor are the consequences potentially as serious if an initial misstep is made in exercising one of those instruments of power. The international consequences of launching military operations, however, can be long lasting and potentially fatal to those directly involved.

It can be argued that there is less likelihood of exercising the military instrument of power in a biobased economy than in our current petroleum-based economy. That may be true, especially in terms of needing to ensure a daily supply of new raw material—genes rather than oil. Nonetheless, demand for new raw material will remain considerable. Novel genes will be the source of novel products in the biobased economy. While the other instruments of power may play a greater role in securing access to novel genes, the military must still be prepared to operate in areas of enduring U.S. interest.

To be certain, the U.S. military is not ignoring biology and is particularly aware of the potential benefits of new biological technologies. In a 2001 National Research Council report on future biotechnology opportunities for the Army, the five areas of sensors, electronics and computing, materials, logistics, and therapeutics were identified as significant.[38] Additional work done by the Office of Net Assessment (Office of the Secretary of Defense) has further identified a number of specific areas that could enhance soldier performance and provide greater protection on the battlefield. One particularly intriguing notion is the idea to use biological evolutionary processes to create more effective battlefield systems.[39]

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Advances in any or all of these areas will benefit the Nation's 21st-century military, regardless of how it is organized or which wars it is prepared to fight. However, the likely missions and the force structure required for those missions need to be considered.

Special Challenges for the Land Force

The Army's current transformation process and its efforts to find the proper mix of heavy and light forces should be considered in the context of the country's transformation to a biobased economy. Gas and oil undeniably will remain important resources through the first part of this century. Given the geography of a scenario envisioning armor and infantry battling over petroleum and gas resources—a possible replay of Operation *Desert Storm* or an even larger future conflict over Eurasia's untapped gas and oil—multi-ton vehicles, whether part of a legacy force or new acquisitions, are no doubt indispensable. Thirty years from now, however, biology may well have simultaneously reduced the need for fossil fuels and increased the need for access to highly diverse genetic resources.

The Army's transformation to its new Objective Force also should be completed by then. Of its many attributes, the new force is to be agile and deployable. Legacy vehicles such as the multi-ton Abrams tank and Bradley infantry fighting vehicle will still be supplementing the force until about 2030. The Interim Force will be fielded as a bridge between our current force and the final Objective Force that will also have multi-ton armored vehicles. An important question to ask is whether such an army will have the necessary equipment to conduct a forcible entry into an equatorial region to secure the genetic resources contained in a given 5,000-square-mile patch of rainforest. The significance of the question lies in the long lead time needed for research, development, and acquisition of weapons systems.

The Chief of Staff of the Army, General Eric Shinseki, recently made the following comment:

> *We [the Army] must be able to project power anywhere in the world, not just in the easily accessible areas with multiple air and seaports of debarkation, but in the most remote, desolate, landlocked and infrastructure-poor areas as well . . . The one map in the Chief's office is a map of the Caspian Basin. The reason the map is there . . . [is that] . . . it's the one part of the world we didn't know how to get to, and nobody else could, either. For the last two years, the Army War College has conducted its war game in the Caspian Basin.*[40]

General Shinseki certainly has the right idea. He simply needs to add a map of the Amazon Basin to his wall.

Despite all the possible considerations surrounding the shift from geology to biology, it is important to recognize that "war's ultimate stakes," as retired U.S. Army War College Commandant Major General Robert Scales calls them, will not change for the warfighter, whether organized as heavy, light, or something in between. Land, people, and resources will remain the primary focus of warfare.[41] Moreover, it is important to note that biological technologies will not provide the next and final wave for the revolution in military affairs and deliver some sort of ultimate weapon to ensure our future victories. Again, to quote General Scales: "2,500 years of history confirm that ambiguity, miscalculation, incompetence, and above all chance will continue to dominate the conduct of war. In the end, the incalculables of determination, morale, fighting skill, and leadership, far more than technology, will determine who wins and loses."[42]

Despite the war on terrorism, we are at one of those periods in history in which we are not burdened by pressures of such imminent danger that our very existence is threatened. We have time to ponder the distant future. We have an opportunity to shape our relationships with those countries that will be strategically important to us. We have an opportunity to invest in those technologies that will be important to our economic advantage in a biobased economy.

We also have the chance to prepare now for the type of warfare that we may encounter in a world run on biological resources. Sir Michael Howard, the noted historian and military theorist, commented, "You can rest assured, whatever doctrine you are working on in peace time, you probably have it wrong. What counts is making sure that you're not so wrong that you can't get it right when the time comes."[43] Before progressing much further in our current thinking, pausing to take stock of the next damned thing may prove to be a damned smart thing.

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