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US Agriculture and National Security

R. James Woolsey

Since September 11, 2001 most of us have come to realize that we have become participants, not in just defending ourselves against a single terrorist group, but rather in what Eliot Cohen and Norman Podhoretz have called World War IV (the first three being the two hot wars and one cold one of the 20th century). Three murderous movements from the Middle East essentially consider themselves at war with us: the Shia extremists who control the instruments of power in Iran and their terrorist arms, such as Hezbollah; the Sunni terrorist groups, particularly al Qaeda; and Saddam Hussein's Baathist regime in Iraq. We had best realize that we will be in this a long time, and that one of our major vulnerabilities is the nature of our own technological infrastructure.

We are a society that relies on the smooth operation of hundreds of networks—from the production and delivery of food, to the electrical power grid, to the Internet. Most of these have been put together with an eye toward ease of access, resilience against random failures of components and naturally-occurring risks such as bad weather, and low cost, but without a single thought being given to their vulnerability to terrorism. We have now seen two of these networks—civil air transport and mail delivery—turned into tools to kill Americans. There will be further attempts by clever adversaries to exploit the vulnerabilities of other networks for the same purpose. This will require a fundamental change in our thinking. We will need to redesign many of these networks so that they don't have salient vulnerabilities to terrorist exploitation and so that they are substantially more resilient and decentralized than they are today.

One of the most vulnerable of these networks is our energy distribution system and one of its greatest vulnerabilities is our reliance on petroleum for transportation fuel and for the feedstock used to produce a substantial share of our chemicals, fibers, and plastics. We consume about a quarter of the world's petroleum although we now have only about 3% of the world's oil reserves. Increasingly, as other fields around the world reach peak production and thus see increased production costs, the rest of us will come to rely on the two-thirds to three-quarters of the world's proven reserves that lie in the Middle East. This is not a recipe for stability.

We would be far better served by moving toward using cellulosic biomass (e.g. agricultural and forest wastes, prairie grass) as a feedstock both for our transportation fuel, such as ethanol made from such feedstocks, and for the production of chemicals of all kinds. Other waste-to-energy technologies are available to convert an even wider range of organic wastes—from used tires to chicken manure—into energy and useful chemicals and fertilizers. In this way we can also begin to rejuvenate the economy of rural America, since most such waste products are bulky and expensive to transport and thus the facilities and employees that process them into useful products will ordinarily be relatively near the farms and forests from whence the feedstocks come.

We need to move to forge a coalition between those who care about rural America and its farm communities, those who want to promote development in poor nations overseas whose economies are rooted in agriculture, those who are concerned about the environment, and those who are worried about the security implications of our being dependent on a volatile Middle East—call it a coalition of the farmers, the do-gooders, the tree huggers, and the cheap hawks.

So expanded, such a coalition has a chance of bringing about a transition from an economy rooted in hydrocarbons to one rooted in the productivity of agricultural America—carbohydrates and more. This is a transition that is long overdue. America's scientists have invented the genetically modified biocatalysts that can convert farm and forest wastes into both ethanol for transportation fuel and other useful chemicals. They have also invented processes to convert other organic waste products into energy, fertilizer, and the chemical building-blocks for modern society. Their ingenuity nicely matches the productivity of the American farmer and the glorious expanses of rich land in this country. In light of what our scientists, our farmers, and our natural resources can do when brought together—and in light of the threats to us that were made manifest to all by the events of last September 11—there is no excuse for this coalition's not moving forward, and prevailing.

What in the world are we waiting for?

The New Petroleum*

Richard G. Lugar and R. James Woolsey

Richard G. Lugar
United States Senator, Indiana

R. James Woolsey
Director, Central Intelligence Agency, 1993–1995

WHY CHANGE?

Oil is a magnet for conflict. The problem is simple-everyone needs energy, but the sources of the world's transportation fuel are concentrated in relatively few countries. Well over two-thirds of the world's remaining oil reserves lie in the Middle East (including the Caspian basin), leaving the rest of the world dependent on the region's collection of predators and vulnerable autocrats. This unwelcome dependence keeps U.S. military forces tied to the Persian Gulf, forces foreign policy compromises, and sinks many developing nations into staggering debt as they struggle to pay for expensive dollar-denominated oil with lower-priced commodities and agricultural products. In addition, oil causes environmental conflict. The possibility that greenhouse gases will lead to catastrophic climate change is substantially increased by the 40 million barrels of oil burned every day by vehicles.

Ethanol has always provided an alternative to gasoline. In terms of environmental impact and fuel efficiency, its advantages over gasoline substantially outweigh its few disadvantages. But until now it has only been practical to produce ethanol from a tiny portion of plant life—the edible parts of corn or other feed grains. Corn prices have fluctuated around $100 a ton in the last few years, ranging from half to double that amount. Ethanol has thus been too expensive to represent anything but a small, subsidized niche of the transportation fuel market. In spite of recent reductions in the expense of ethanol processing, the final product still costs roughly a dollar a gallon, or about double today's wholesale price of gasoline.

Recent and prospective breakthroughs in genetic engineering and processing, however, are radically changing the viability of ethanol as a transportation fuel. New biocatalysts—genetically engineered enzymes, yeasts, and bacteria—are making it possible to use virtually any plant or plant product (known as cellulosic biomass) to produce ethanol. This may decisively reduce cost—to the point where petroleum products would face vigorous competition.

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The best analogy to this potential cost reduction is the cracking of the petroleum molecule in the early twentieth century. This let an increasingly large share of petroleum be used in producing high-performance gasoline, thus reducing waste and lowering cost enough that gasoline could fuel this century's automotive revolution. Genetically engineered biocatalysts and new processing techniques can similarly make it possible to utilize most plant matter, rather than a tiny fraction thereof, as fuel. Cellulosic biomass is extremely plentiful. As it comes to be used to produce competitively priced ethanol, it will democratize the world's fuel market. If the hundreds of billions of dollars that now flow into a few coffers in a few nations were to flow instead to the millions of people who till the world's fields, most countries would see substantial national security, economic, and environmental benefits.

PAYING FOR ROGUES

Energy is vital to a country's security and material well-being. A state unable to provide its people with adequate energy supplies or desiring added leverage over other people often resorts to force. Consider Saddam Hussein's 1990 invasion of Kuwait, driven by his desire to control more of the world's oil reserves, and the international response to this threat. The underlying goal of the U.N. force, which included 500,000 American troops, was to ensure continued and unfettered access to petroleum.

Oil permeates every aspect of our lives, so even minor price increases have devastating impacts. The most difficult challenge for planners, policymakers, and alternative-energy advocates is the transportation sector, which accounts for over 60 percent of U.S. oil demand. The massive infrastructure developed to support gasoline-powered cars is particularly resistant to modifications. It precludes rapid change to alternative transportation systems and makes America highly vulnerable to a break in oil supplies. During a war or embargo, moving quickly to mass transit or to fuel-cell or battery-powered automobiles would be impossible.

For most countries, excluding only those few that will be the next century's oil suppliers, the future portends growing indebtedness, driven by increasingly expensive oil imports. New demand for oil will be filled largely by the Middle East, meaning a transfer of more than $1 trillion over the next 15 years to the unstable states of the Persian Gulf alone—on top of the $90 billion they received in 1996.

Dependence on the Middle East entails the risk of a repeat of the international crises of 1973, 1979, and 1990—or worse. This growing reliance on Middle Eastern oil not only adds to that region's disproportionate leverage but provides the resources with which rogue nations support international terrorism and develop weapons of mass destruction and the ballistic missiles to carry them. Iraqi vx nerve gas and Iranian medium-range missiles show how such regimes can convert oil revenues into extensive and sophisticated armament programs.

IS OIL RUNNING OUT?

Optimists about world oil reserves, such as the Department of Energy, are getting increasingly lonely. The International Energy Agency now says that world production outside the Middle Eastern Organization of Petroleum Exporting Countries (OPEC) will peak in 1999 and world production overall will peak between 2010 and 2020. This projection is supported by influential recent articles in *Science* and *Scientific American*. Some knowledgeable academic and industry voices put the date that world production will peak even sooner—within the next five or six years.

The optimists who project large reserve quantities of over one trillion barrels tend to base their numbers on one of three things: inclusion of heavy oil and tar sands, the exploitation of which will entail huge economic and environmental costs; puffery by OPEC nations lobbying for higher production quotas within the cartel; or assumptions about new drilling technologies that may accelerate production but are unlikely to expand reserves.

Once production peaks, even though exhaustion of world reserves will still be many years away, prices will begin to rise sharply. This trend will be exacerbated by increased demand in the developing world. As Daniel Yergin, Dennis Eklof, and Jefferson Edwards pointed out in these pages ("Fueling Asia's Recovery," March/April 1998), even assuming a substantial recession, increased Asian needs alone will add enough demand by 2010 (9 million barrels per day) to more than equal Saudi Arabia's current daily production.

The nations of the Middle East will be ready to exploit the trend of rising demand and shrinking supply. The Gulf states control nearly two-thirds of the world's reserves; the states bordering the Caspian Sea have another several percent. Barring some unforeseen discoveries, the Middle East will control something approaching three-quarters of the world's oil in the coming century.

A WHOLE NEW WORLD

If genetically engineered biocatalysts and advanced processing technologies can make a transition from fossil fuels to biofuels affordable, the world's security picture could be different in many ways. It would be impossible to form a cartel that would control the production, manufacturing, and marketing of ethanol fuel. U.S. diplomacy and policies in the Middle East could be guided more by a respect for democracy than by a need to protect oil supplies and accommodate oil-producing regimes. Our intrusive military presence in the region could be reduced, both ameliorating anti-American tensions and making U.S. involvement in a Middle Eastern war less likely. Other states would also reap benefits. Ukraine, rich in fertile land, would be less likely to be dominated over time by oil-rich Russia. China would feel less pressure to befriend Iran and Iraq or build a big navy to secure the oil of the South China Sea. The ability of oil-exporting countries to shape events would be increasingly limited.

The recent report by the President's Committee of Advisers on Science and Technology (PCAST) predicted that U.S. oil imports will approximately double between 1996 and 2030, from 8.5 million barrels per day, at a cost of $64 billion, to nearly 16 million barrels per day, at a cost of $120 billion. They estimated, however, that with concentrated efforts in fundamental energy research and investment in renewable fuel technologies, this could be reduced to 6 million barrels per day in 2030. The report concluded:

> *A plausible argument can be made that the security of the United States is at least as likely to be imperiled in the first half of the next century by the consequences of inadequacies in the energy options available to the world as by inadequacies in the capabilities of U.S. weapons systems. It is striking that the Federal government spends about 20 times more R&D money on the latter problem than on the former.*

FUEL FARMERS

Cellulosic ethanol would radically improve the outlook for rural areas all over the world. Farmers could produce a cash crop by simply collecting agricultural wastes or harvesting grasses or crops natural to their region. Agricultural nations with little to no petroleum reserves would begin to see economic stability and prosperity as they steadily reduced massive payments for oil imports. Even more striking would be the redistribution of resources that would occur if farmers and foresters produced much of the world's transportation fuel. We know from the positive results of micro-credit institutions and other such programs that even small increases in income can be a major boost to a subsistence-level family's prospects. If family income is a few hundred dollars a year, earning an extra $50–$100 by gathering and selling agricultural residues to a cellulosic ethanol plant could mean a much improved life. Such added income can buy a few used sewing machines to start a business or a few animals to breed and sell. It can begin to replace despondency with hope.

There are likely to be even larger effects on rural development if biomass ethanol production can lead a shift toward using plant matter for other products as well, such as biochemicals and electrical energy. The cleanliness of renewable fuel technologies makes them particularly attractive to countries that lack a sophisticated infrastructure or network of regulatory controls. At least some facilities that process carbohydrates should lend themselves to being simplified and sized to meet the needs of remote communities. If such towns can produce their own fuel, some of their fertilizers, and electricity, they will be far better positioned to make their way out of poverty and to move toward democracy and free enterprise. Local economic development can promote political stability and security where poverty now produces hopelessness and conflict.

A major strength of the new technologies for fermenting cellulosic biomass is the prospect that almost any type of plant, tree, or agricultural waste can be used as a source of fuel. This high degree of flexibility allows for the use of local crops that will enrich the soil, prevent erosion, and improve local environmental conditions.

Finally, as recession and devaluations overseas move the American balance-of-payments deficit from the 1998 level—$1 billion every two days—toward nearly $1 billion every day, there will be increased calls for protectionism. The best way to avoid the mistakes of the 1930s is to have a solid economic reason for increasing U.S. production of commodities now bought abroad. The nearly $70 billion spent annually for imported oil represents about 40 percent of the current U.S. trade deficit, and every $1 billion of oil imports that is replaced by domestically produced ethanol creates 10,000–20,000 American jobs.

EASY BEING GREEN

To be politically and economically acceptable, changes in fuel must be understood by the American public to be affordable and not disruptive. Most other countries require the same tough criteria—U.S. difficulties in convincing developing nations to reduce greenhouse gas emissions are directly related to the cost and the damage this would have on their development plans. But if one of the most effective ways to reduce greenhouse emissions also produced an improved balance-of-payments deficit and opportunities for rural development, economic benefits would suddenly far exceed the costs. The political acceptability of reducing emissions changes substantially when the economics change. A shift to biomass fuels stands out as an excellent way to introduce an environmentally friendly energy technology that has a chance of both enjoying widespread political and economic support and having a decisive impact on the risk of climate change.

Renewable fuels produced from plants are an outstanding way to substantially reduce greenhouse gases. Although burning ethanol releases carbon dioxide into the atmosphere, it is essentially the same carbon dioxide that was fixed by photosynthesis when the plants grew. Burning fossil fuels, on the other hand, releases carbon dioxide that otherwise would have stayed trapped beneath the earth.

If one looks at the complete life cycle of the production and use of ethanol derived from feed grains, the only addition of carbon dioxide to the atmosphere results from the use of fossil fuel products in planting, chemical fertilizing, harvesting, and processing. But this fossil fuel use can be substantial—up to seven gallons of oil may be needed to produce eight gallons of ethanol. When ethanol is produced from cellulosic biomass, however, relatively little tilling or cultivation is required, reducing the energy inputs. It takes only about one gallon of oil to produce seven of ethanol. There is a virtual consensus among scientists: when considered as part of a complete cycle of growth, fermentation, and combustion, the use of cellulosic ethanol as a fuel, once optimized, will contribute essentially no net carbon dioxide to the atmosphere.

According to a 1997 study done by five laboratories of the U.S. Department of Energy, a vehicle powered by biomass ethanol emits well under one percent of the carbon dioxide emitted by one powered by gasoline. More surprising; however, is that ethanol produced from biomass emits only about one percent of the carbon dioxide emitted by battery-powered vehicles, since the electricity for those is commonly produced by burning fossil fuels at another location. Although local air quality is improved, total carbon dioxide emissions are not curtailed; they are merely exported—for example, from Los Angeles to the Four Corners. Unless the electricity to charge the car’s batteries is produced by renewable fuels or nuclear power, electric vehicles are only 20 to 40 percent better as carbon dioxide emitters than gasoline-powered cars. Biomass ethanol beats both by a factor of about 100, fundamentally changing the global-warming debate.

FRINGE BENEFITS

Cellulosic ethanol is the only alternative fuel that requires, at most, very modest changes to vehicles and the transportation infrastructure. One need not spend money retooling Detroit, nor spend years awaiting the gradual replacement of older vehicles by those with new technology. Nor does one need to modify or construct pipelines and storage tanks to hold hydrogen as an alternate to petroleum. This compatibility with today’s infrastructure saves billions of dollars and not just years, but decades. Moreover, there is nothing incompatible between using ethanol now in internal combustion engines and using it later in more efficient power systems, such as hybrids or fuel cells.

Essentially all automobiles currently on the road can use fuel containing up to ten percent ethanol. But strict fuel economy standards have encouraged the development and production of flexible fuel vehicles (FFVS) that can use up to 85 percent ethanol. FFVS are already in dealers’ showrooms, containing (at no added cost to the consumer) the minor engine modifications—a computer chip in the fuel system and a fuel line made out of slightly different material—that make large-scale ethanol use possible. Even pure ethanol vehicles are quite practical. Brazil has 3.6 million on the road.

Corn ethanol will continue to serve an important role as ethanol production shifts to cellulosic biomass. Commercialization of corn ethanol has provided a base of industrial experience, talented people, and infrastructure from which a much larger cellulosic ethanol industry may be launched. For corn farmers, biomass is no threat; it will probably be a boon. Indeed, there is likely to be a continuing, perhaps even an expanding, market for corn ethanol because of the value of its byproducts, such as animal feed. In general, the transition from corn to cellulosic biomass and from a few producers to many is likely to expand opportunities for American farmers.

BIOENGINEERED BUGS

Ethanol's economic viability depends on making it cheaper to produce. This can be achieved by making it out of cellulosic biomass, which includes essentially anything that grows or has grown: agricultural and forest residues, prairie grass, kudzu, waste wood, used paper products, even much of urban waste. Last year, about 95 percent of the ethanol produced in the United States came from corn. But agricultural residues and other wastes have low or even negative cost—some you are paid to haul away—while crops like prairie grass cost only a few tens of dollars a ton. This represents a substantial savings in the raw material used in ethanol and puts it within the range of oil, even inexpensive Persian Gulf oil.

Only recently have scientists developed the means to convert cellulosic biomass efficiently into ethanol. The edible portions of corn and other grains easily ferment into ethanol because of their chemical make-up. Most biomass, however, consists of more recalcitrant hemicellulose and cellulose, requiring both the breaking up of these two fibers as well as the fermenting of both five- and six-carbon sugars. This all happens in nature, but two parts of it—fermenting five-carbon sugars and breaking up cellulose quickly—are technically challenging. The first is now done by genetically engineered microorganisms; this tool and other new techniques are now being brought to bear on the second problem.

How far along are these developments? The current efficiency of ethanol processing is somewhat analogous to that of petroleum refining in the early 1900s: after the invention of thermal cracking made it possible to use a major share of the petroleum molecule for gasoline production but before the invention of catalytic cracking opened up an even larger share of petroleum to exploitation. In short, we have come a long way, but still have some inventing to do. The new, genetically engineered microorganisms have already taken us far toward the fermentation of ethanol from a wide range of plant material, laying the groundwork for reductions in processing costs as well.

The new microorganisms, combined with other improvements in processing, fundamentally change the equation for considering ethanol a major transportation fuel. According to a recent study by Dartmouth engineering professor Lee Lynd, utilizing only some of the nation's agricultural and forest residues, with no additional land use, could supply over 15 billion gallons of ethanol a year—more than ten times the amount now produced from corn, and enough to replace around eight percent of the nation's gasoline. (Not all residues would be used, of course, since some must be left for long-term fertility.) Lynd also calculated that taking a little over half of the 60 million acres of cropland historically idled by federal programs for conservation and other purposes, and using for ethanol production the mown grasses with which much of this acreage is ordinarily planted, would produce enough ethanol to fulfill around 25 percent of the country's annual gasoline needs. These calculations use current automobile mileage. Lynd notes that, further mileage improvements, achieved through a shift to hybrids or fuel cells, could obviate the need for gasoline entirely, without taking land from food crops or nonagricultural uses. The coproduction of animal feed and biomass residues from alfalfa and switchgrass is especially promising. There is, in short, no basis for the argument that America does not have the land to produce enough ethanol to make a very large dent in U.S. gasoline consumption.

Biofuels must be produced in ways that enhance overall environmental quality. Sound land-use policies certainly must be followed, to protect wildlife habitat and address other environmental concerns. But professional land-use techniques should readily accomplish this. Alternative fuels are often seen as an unpalatable necessity representing a retrenched standard of living, forced upon us in an age of limits. The opposite may be true. Utilization of renewable fuels will make it possible for us to continue enjoying the freedom afforded by private cars, even as the production of petroleum begins to decline.

THE RIGHT STUFF?

Early this century, Henry Ford expected that ethanol, not gasoline, would be the fuel of choice for automobiles. His reasons are evident. The two fuels can be compared by examining three basic parameters—energy content, octane, and vapor pressure. Pure ethanol contains 69 percent of the energy of gasoline. A lower energy content translates into fewer miles to the gallon; in order to travel the same range, about a 30 percent larger fuel tank is needed (as is used in Brazil). Many scientists believe that optimizing engines for ethanol use will largely compensate for this difference, in part because ethanol is a simple combination of carbon, hydrogen, and oxygen. It is vastly less complex than gasoline, which means that fine-tuning an engine to squeeze every last drop of energy from ethanol is potentially easier.

Octane is the measure of a fuel's ability to oxidize hydrogen and carbon molecules within a fraction of a second. When the reaction is not simultaneous, "engine knock" and inefficient combustion result. Ethanol has an octane rating 15 percent higher than gasoline's. In the 1920s ethanol was briefly considered as a large-scale additive to gasoline to stop the knocking of the new higher compression engines. However, to the detriment of public health, ethanol lost out to highly toxic tetraethyl lead, for three reasons: in contrast to ethanol, only a small amount of lead was needed as an additive; some were concerned that corn-derived ethanol would compete for land and threaten the feed grains market; and since Prohibition was in effect, many were also worried about the security problems associated with maintaining large volumes of what is essentially 200-proof vodka. Ethanol's ability to be an effective fuel, however, was never an issue.

A third important fuel measurement is vapor pressure, or how readily a liquid evaporates. A fuel's vapor pressure is directly linked to the quantity of vehicle emissions, since over 40 percent of automobile emissions result from evaporation, not tailpipe emissions. Substituting ethanol for gasoline in any amount reduces tailpipe emissions and thus reduces urban smog. Pure ethanol, and any gasoline-ethanol mixture that is more than 22 percent ethanol, has a lower vapor pressure than gasoline and would therefore reduce the amount of evaporative emissions.

Somewhat confusingly, however, blends of ethanol and current gasoline have a slightly higher vapor pressure than pure gasoline when the mixture contains less than 22 percent ethanol, because of the unique mixing properties of the liquids. Some studies show that low-level blends of ethanol and gasoline (like gasohol, which is ten percent ethanol) can actually worsen local air pollution, especially the formation of low-level ozone. Consequently, in cities in the Northeast and California, proposals to encourage the use of ethanol blends have often fallen on deaf ears. Some environmentalists see them as camouflaged subsidies for Midwestern corn growers at the expense of the cities.

But although low-level ethanol blends present complex issues, blends with more than 22 percent ethanol—which can be used in FFVS—do not have the vaporization problem. Moreover, with different approaches to refining and blending gasoline, a solution to the vaporization problem may well exist even at mixtures below 22 percent. Finally, ETBE—an oxygenate made from ethanol that improves gasoline combustion—improves air quality both in tailpipe emissions and vaporization, although its use means the fuel contains five to ten percent ethanol.

Choosing to use cellulosic ethanol is not a choice to forsake more advanced automobile propulsion technologies, such as hybrids and fuel cells. Ethanol is compatible with both. Jeffrey Bentley, vice president of Arthur D. Little, Inc., a company recently honored by the U.S. government for its novel fuel-cell technology, stated that "*ethanol provides higher efficiencies, fewer emissions, and better performance than other fuel sources, including gasoline… Where ethanol is available, it will be the fuel of choice by consumers.*" As both hybrids and fuel cells continue to improve, automobiles powered by them may dramatically reduce air pollution. Ethanol's compatibility with both makes moving toward cellulosic ethanol as a transportation fuel much more desirable.

If government policies promote FFVS, moreover, a large fleet of ethanol-compatible vehicles will be available much earlier than would otherwise have been feasible. This is because FFVS can burn gasoline now but can use cellulosic ethanol as it becomes available. Introducing FFVS into the national fleet differs radically in timing from other changes in transportation. Even if an ideal hybrid or fuel-cell vehicle came on the market, the slow rate of turnover in the nation's cars would mean that it would be many years before its introduction would make a dent in overall fuel use. But moving now to substantially increase the number of FFVS being produced would create the capability to shift to cellulosic ethanol as soon as it is available at attractive prices.

In addition, insofar as U.S. security and environmental concerns are more with the consumption of problem-causing petroleum fuel than with fuel in general, substituting cellulosic ethanol for gasoline improves relevant "mileage" radically, even in internal combustion engines. For example, an average automobile gets approximately 17 miles per gallon and is driven approximately 14,000 miles per year, thus using 825 gallons of gasoline annually. Suppose that same automobile were an FFV using a mixed fuel containing 85 percent cellulosic ethanol. Because of ethanol's lower energy content, it would use about 1,105 gallons of fuel, but only 165 would be gasoline. Such a vehicle could be said to be getting, in a sense, over 80 miles per gallon—of national-security-risk-increasing, carbon-dioxide-producing gasoline.

The one remaining barrier to widespread replacement of gasoline with ethanol is production cost. Relying on feed grains makes this cost comparatively high and volatile, since corn is subject to the caroming behavior of feed markets. In 1995, its price of $100 a ton nearly doubled, forcing a sharp curtailment in ethanol production. A partial shift to biomass should circumvent such instabilities. Over the past 15 years, the cost of producing a gallon of ethanol has been cut in half, to just over $1 a gallon wholesale. If, as predicted, the new biocatalysts, low and steady raw material costs, and improved processing let costs fall another 50 percent or so, ethanol could compete with gasoline at today's prices. If oil prices rise in the next century, gasoline could actually be at a substantial price disadvantage.

Such a reduction of ethanol cost is entirely plausible for two reasons. First, a simple comparison of energy content reveals that a dry ton of biomass crops—$40 is a reasonable current average cost—is comparable to oil at $10–13 a barrel. Agricultural wastes, in many cases, are considerably cheaper than either: many are free or have negative cost. So the overall costs of cellulosic biomass are likely to at least be in the same ballpark as those of crude oil. Second, further reductions in the cost of processing seem quite achievable. The current cost of processing ethanol is significantly higher than the equivalent price per barrel for oil. But this discrepancy reflects the maturity and sophistication of the petroleum industry, developed over the past century, as compared to the fledgling biofuels effort. Producing ethanol is not inherently more complex than refining petroleum—in fact, just the contrary. The world has simply invested far more effort in the latter.

JUMP-START

While the private sector will provide the capital and motivation to move toward ethanol, the federal government has a vital role to play. Market forces seldom reflect national security risks, environmental issues, or other social concerns. The private sector often cannot fund long-term research, despite its demonstrated potential for dramatic innovation. Hence, the federal government must increase its investment in renewable energy research, particularly in innovative programs such as genetic engineering of biocatalysts, development of dedicated energy crops, and improved processing. The very small sums previously invested by the Departments of Energy and Agriculture have already spawned dramatic advances. Every effort should be made to expand competitive, merit-based, and peer-reviewed science and to encourage research that cuts across scientific disciplines.

Research is essential to produce the innovations and technical improvements that will lower the production costs of ethanol and other renewable fuels and let them compete directly with gasoline. At present, the United States is not funding a vigorous program in renewable technologies. The Department of Energy spends under two percent of its budget on renewable fuels; its overall work on renewable technologies is at its lowest level in 30 years. Because private investment often follows federal commitment, industrial research and development has also reached new lows. These disturbing trends occur at a time of national economic prosperity when America has both time and resources for investing in biofuels. The United States cannot afford to wait for the next energy crisis to marshal its intellectual and industrial resources.

Research alone will not suffice to realize cellulosic ethanol's promise. The federal government should also modify the tax code to spur private investment. The existing renewable alcohol tax credits have recently been extended by Congress through 2007—which will help the growth of the new biofuels industry and offer some protection in the transition from grain to cellulosic biomass. But the tax credit structure should facilitate the gradual adoption of cellulosic ethanol—in time, it should not need subsidies. Government incentives to produce FFVS should also be increased.

Finally, there must be a coordinated effort across the many different federal agencies that oversee government laboratories and regulatory agencies. The analogy to the semiconductor industry is instructive. In 1987, Congress authorized the creation of a government–industry partnership, the Semiconductor Manufacturing Technology Association (SEMATECH). Under the direction of the Department of Defense's Advanced Research Projects Agency, SEMATECH pursued fundamental research in semiconductor components and manufacturing processes. Private firms with innovative ideas were encouraged to devote research dollars to transform the idea into a commercial reality. The few domestic semiconductor manufacturers were brought together in forums where the companies could discuss technical hurdles without sacrificing competitive advantage. Today, the success of SEMATECH is evident, as the high-technology sector demonstrates. Biofuels offer a similar opportunity.

Cellulosic ethanol is a first-class transportation fuel, able to power the cars of today as well as tomorrow, use the vast infrastructure already built for gasoline, and enter quickly and easily into the transportation system. It can be shipped in standard rail cars and tank trucks and is easily mixed with gasoline. Although somewhat lower in energy content, it has a substantially higher octane rating than gasoline, allowing for more efficient combustion. It can radically reduce the emission of global warming gases, help reduce the choking smog of our cities, and improve air quality. It is far less toxic than petroleum, far less likely to explode and burn accidentally, and far simpler physically and chemically, making possible simpler refining procedures. If a second Exxon Valdez filled with ethanol ran aground off Alaska, it would produce a lot of evaporation and some drunk seals.

Our growing dependence on increasingly scarce Middle Eastern oil is a fool's game—there is no way for the rest of the world to win. Our losses may come suddenly through war, steadily through price increases, agonizingly through developing-nation poverty, relentlessly through climate change—or through all of the above. It would be extremely short-sighted not to take advantage of the scientific breakthroughs that have occurred and that are in the offing, accelerate them, and move smartly toward ameliorating all of these risks by beginning to substitute carbohydrates for hydrocarbons. If we do, we will make life far less dangerous and far more prosperous for future generations. If we do not, those generations will look back in angry wonder at the remarkable opportunity that we missed.