The Fragility of Domestic Energy

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ORTHODOX ENERGY POLICY SINCE 1973 HAS RESTED ON THREE ASSUMPTIONS: (1) Imported oil, especially from the Middle East, is unreliable. (2) Domestic energy supplies are secure. (This assumption is used to justify such diverse projects as arctic gas pipelines, offshore oil drilling, coal leasing, the development of synthetic fuels, and breeder reactors.) (3) Secure energy supplies cost more than imported oil, but are worth it.

The oil shocks of 1973 and 1979 vindicated the first of these assumptions, but at any moment the lesson could become far more emphatic. By attacking the oil terminals at Ras Tanura and Ju'aymah, an Iranian jet or saboteurs in a couple of dinghies could cut off five sixths of Saudi Arabian oil exports for three years, the time that would be needed to rebuild key components; after that, of course, the attack could be repeated. The Persian Gulf's facilities are extraordinarily centralized: on average, each Saudi Arabian well lifts about a thousand times more oil per year than a typical American well does. The supergiant Ghawar field alone—a strip about a dozen miles wide—has, until recently, lifted oil faster than any country except Saudi Arabia as a whole, the U.S., and the USSR. The oil from this field is collected at a single site; in 1977, a fire there, of questionable origin but officially described as accidental, cut off ARAMCO's output for ten days. The Middle East's dense webs of pipelines, pumping and compressor stations, refineries, and natural-gas plants have been prime targets in the battles between Iran and Iraq, and have been subject to sporadic attack by various antagonists in the region for more than a decade.

The lumbering supertankers that bring Middle Eastern oil halfway around the world to Western ports are also insecure. Naval planners shudder at the tankers' vulnerability to submarines, but even pirates in small boats manage regularly to board and rob tankers off the coasts of Singapore and Nigeria. Moreover, it is not at all unusual for such ships to sink or blow up without any assistance.

So manifest is the fragility of Middle Eastern oil that the second and third assumptions listed above have been accepted uncritically as corollaries. The supply has been presumed to be unreliable because the oil is foreign, and a more fundamental defect has been ignored: in reality, the Middle East's political volatility matters mainly because of the extreme geographic concentration of the oil drawn from the region.

Domestic energy, of any kind, from any source, and at any price, has seemed the obvious answer. However, most domestic sources, current and potential, are also centralized—and hence vulnerable to different, but equally serious, kinds of disruption. Amid the enthusiasm for all- American energy, this cause for concern passes unnoticed. Analysts who are quick to note that some 500 miles of pipe in eastern Saudi Arabia carry a sixth of the non-Communist world's oil have failed to observe that three fourths of the oil extracted in the U.S. comes from four states (Texas, Alaska, Louisiana, and California); that more than half the refinery capacity is in three (Texas, Louisiana, and California); that three fifths of the petrochemical capacity is in one (Texas); and that five sixths of the interstate natural gas comes from or passes through one (Louisiana)—3.5 percent of this amount being processed by a single plant equivalent in terms of energy output to twenty giant power stations.

Only a tenth of the total energy supply in the U.S. now comes from imported oil. Making cars and buildings more energy efficient could reduce that fraction to zero within a decade. Nearly all of the remaining 90-odd percent is accounted for by domestic sources. This share, however, can be disrupted about as easily as foreign oil, faster, and in larger increments. Moreover, the vulnerability of American supplies to sabotage, natural disaster, or technical accident is increasing year by year, because successive administrations, wrongly assuming that any domestic source must be reliable, have promoted, with subsidies totaling more than $10 billion a year, those energy technologies that are the least secure.

Already, a handful of people in Louisiana could shut off three fourths of the gas and oil supplies to the eastern states in an evening, leaving them out of action for as long as a year. A small group could black out the electric power to a city, or perhaps a region, for weeks or months. Certain attacks on natural-gas systems could incinerate a city. Low-technology sabotage of certain nuclear facilities could make vast areas uninhabitable. The electromagnetic pulse of a single nuclear explosion high over the Midwest could accomplish most or all of these disruptions simultaneously, by burning out electronic devices throughout the contiguous U.S. that control refineries, gas-processing plants, oil and gas pipelines, power plants, and gas- and electricity-distribution grids.

These loopholes in national security are the work not of enemies abroad but of highly qualified and patriotic engineers who faithfully performed the wrong task: designing a reliable system for supplying cheap energy to a technological paradise, in which everything works according to the blueprints, unsullied by human fallibility or malice.

The result, built up piece by piece without regard to the fragility of the whole, is enormously complex and mostly interdependent networks of aerial wires, shallowly buried pipelines, fuel-storage facilities, gas-processing plants, oil refineries, and billion-dollar power plants—systems that take years or decades to be constructed and whose routine operation very few people understand. The systems depend on split-second computer timing and elaborate, instantaneous communication. Those that govern the distribution of electricity and natural gas—together delivering 41 percent of the energy we use—are tightly coupled and not particularly flexible. Electric-power grids depend on the ability of many large, precise electric generators to rotate in exact synchrony across half the continent. Regional gas grids require the continuous maintenance of minimum pressures. Many of the spare parts for these systems are special-order items that are too expensive to be stockpiled, yet require months or years and unusual skills to be made and installed. Some key components are not built in this country. Moreover, supposedly redundant backup devices can themselves suffer unstoppable, grotesquely cascading failures. (For example, in 1969, technicians at the Oak Ridge Research Reactor tried to deploy a safety system with three redundant channels. The backup devices in each channel suffered seven independent and simultaneous failures, a coincidence that, according to the official postmortem report, was "almost unbelievable.")

When all these traits are considered together, it appears more than conceivable that a well-coordinated attack on electric grids and pipelines, and on the computers that orchestrate their output, could enmesh the U.S. in spreading waves of chaos from which recovery would be difficult at best.

According to the General Accounting Office and private security experts, most energy control and distribution centers are protected by chain link fences or Keep Out signs, or not at all. (An audit done by the GAO in 1979 revealed that only a single locked door protected the computer controlling a pipeline that carries a quarter of the crude oil fed to Midwestern refineries. A public road provided free access to the facility.) Hardening the most vulnerable sites, however, buys little security. Fences, alarms, and guards may discourage the casual or incompetent attacker, but will elicit stronger attacks from serious adversaries, or divert their attention to softer targets. There are far too many soft targets to defend. Vital control centers, pumping and compressor stations, switchyards, and the like—each of which governs huge amounts of energy—number in the thousands. Moreover, energy lifelines are stretched thin over hundreds or thousands of miles. The Trans-Alaska Pipeline System alone spans nearly 800 miles of rough country. America's principal oil and gas pipelines would stretch more than twelve times around the equator; the overhead electrical transmission circuits, more than fifteen times. The total length of gas pipelines in the U.S. exceeds a million miles.

The scale of modern energy systems is such that a relay failure in Oregon can cause a blackout in Arizona (and did so last year). Their concentration is such that the loss of three major domestic oil pipelines would interdict nearly 5 million barrels per day—substantially more than all the imported oil now used in the U.S.

One can hardly imagine a target more ideal than the domestic energy system for easy disruption, widespread catastrophic failure, and slow, difficult recovery. Major failures could produce abrupt backward lurches, of decades if not centuries, in this country's economic progress and in its standard of living. Suddenly, the United States might find itself grappling with problems of daily survival that for years have been confined chiefly to the poorest countries.

When the Pentagon's Defense Civil Preparedness Agency (now incorporated into the Federal Emergency Management Agency) commissioned us in 1979 to analyze the vulnerability of American energy systems and seek remedies, we were unprepared for what we found. Practically no one in government, we discovered, knew or cared about any form of energy insecurity other than interruptions of oil imports. And that problem had been "handled" with the establishment of the Strategic Petroleum Reserve (a huge repository of oil stored by the government in Gulf Coast salt formations), which one person in three nights could render useless. Three pipelines ship the reserve's oil to refineries. Each would have to be cut in only one place for the oil to stop flowing. It could take six months or more to mend a break in pipe running through a swamp or across a river; damage to important pumps or controls could shut off the oil for an even longer period. Pipelines carry three quarters of the crude oil that U.S. refineries use, and about a third of the refined products they produce. A single pipeline system, the Colonial, whose 4,600 miles of main pipe cover 1,600 miles of territory stretching from Texas to New Jersey, handles half of the shipping of these refined products.

Our research revealed a comprehensive denial of reality: policy-makers tend to be so preoccupied with Persian Gulf oil that they fail to consider the frailty of their favorite alternatives. The Trans-Alaska Pipeline, for example, carries a seventh of all the crude oil fed to American refineries.

Its failure would cost more than $700 per second, and in three winter weeks could turn the line into "the world's biggest Chapstick," as 9 million barrels of hot oil congealed inside. (The pipeline's proprietors believe that the pumps are powerful enough to get the oil moving again, but no one knows for sure.) It would take as long as seven months to replace a large section of the labyrinth of forty-eight-inch pipe at the system's north end. The line has already been bombed twice, incompetently and with only light damage. The most accessible and dispensable of its pumping stations was blown up accidentally, in 1977.

Although the Army has declared the Trans-Alaska Pipeline indefensible, the system's owners seem to perceive no security problem. The Reagan Administration wants to augment the oil pipeline with a still more vulnerable arctic gas pipeline, which would carry half as much fuel at three and a half times the cost. In fact, the new line's estimated cost is so high that even though Congress has waived all legal impediments, it probably will not be built. If it ever is built, however, it will hardly enhance energy security.

Other federal proposals invite similar concern. Consider, for example, the government's hope that by the year 2000, mining in Wyoming's Powder River Basin will yield 500 million tons of coal a year—three-fifths as much as is now mined each year in the U.S. as a whole. The coal would be carried out of the basin along the Burlington Northern rail lines; its concentration would make it as easy a target as the oil shipped through the Strait of Hormuz, in the Persian Gulf. What if the U.S. did come to depend on all this coal? Coal trains and bridges have been bombed frequently in Appalachia during labor disputes; why not in Wyoming, and by attackers with larger motives?

Consider, too, the Department of Energy's encouragement of the electric utilities to build more than 400 giant coal and nuclear plants. The DOE forecasts that otherwise the current overcapacity of electric power plants will turn to shortage. The electricity generated by the new plants would have to be distributed by longer, higher-voltage lines than are now typical, requiring more-specialized and more-vulnerable switchgear and controls. Investors do not seem to share the DOE's enthusiasm for another trillion dollars' worth of power plants: no nuclear plant has been ordered in the U.S. since 1978, and more than a hundred have been canceled since 1972; no large power plant of any kind has been ordered since 1981. For the DOE's projections to be fulfilled, the plants would have to be ordered at an average rate of one a week, starting now. If built, the plants will make blackouts more likely and bigger than they have been thus far.

Offshore oil is favored by the secretary of the interior, James Watt, as a secure substitute for Persian Gulf oil. The Coast Guard says that in good weather it could put a vessel alongside a threatened platform in the main Gulf of Mexico fields in eight hours. Only an incompetent saboteur could fail to destroy the platform in eight minutes.

Twenty billion dollars in federal subsidies are being offered to yet another component of energy security—giant synthetic-fuel plants. Only two countries have ever substantially relied on such plants: Germany, during World War II, and, more recently, South Africa. The German plants were bombed by Allied aircraft, the South African plants by African National Congress saboteurs. Synthetic fuel plants, like refineries, are dense clusters of high-pressure tanks and pipes carrying flammable liquids and explosive gases, such as hydrogen, interlaced with sources of heat to ignite any fuels that escape. Their configuration makes the saboteur's task easy. Such plants also require prodigious amounts of water and power—supplies that are not hard to interdict.

In sum, all of the energy sources currently being promoted as the backbone of American energy supplies into the twenty-first century are precisely those least suited to surviving the uncertainty and violence that seem likely to characterize the future.

These risks are frighteningly real: so real as to make us ask whether they should be studied at all. Might it not be better to hope that they will simply pass unnoticed? Unfortunately, it is already far too late for that, as a glance at the newspapers reveals. Worldwide, significant attacks on energy systems are now occurring about once a week (not counting the ones in El Salvador, which occur more or less daily). In the past decade or so, they have occurred in twenty-six states in the U.S. and in more than forty other countries. Such attacks are becoming more frequent, more intense, and more sophisticated.

Since 1972, 117 countries have suffered terrorist attacks of some kind, and ten of these—all advanced countries—account for more than half of the incidents. So far, the U.S. has been very lucky, but few experts on terrorism expect our luck to hold for long. According to the Federal Bureau of Investigation, from 1972 until 1978, minor facilities of American electric utilities were bombed, on average, every two weeks, mainly by political-protest groups. Someday, however, attacks on the country's utilities may become more common, and they may have consequences more severe than the local and symbolic effects that have so far been typical.

Because the risks are real, we have taken great care that our analysis not provide a cookbook. Formal government classification review and extensive peer review have reinforced our own sense of discretion. Yet we feel that the only thing more dangerous than publicly discussing these previously unrecognized forms of energy vulnerability is not discussing them, for if the vulnerability increases, while remedies languish unused, everyone's security will suffer. Since the record of attacks shows that terrorists already know that energy systems are a soft target, it seems time that political leaders and the public be informed of the hazard, and of what they can do about it.

Our work for the Defense Department led the General Accounting Office last year to reiterate its warnings that the U.S. is poorly prepared to deal with assaults on its electrical-power system. Three congressional hearings have been held, a committee on energy vulnerability has been established at the Georgetown Center for Strategic and International Studies, and further analyses have been undertaken at Los Alamos National Laboratory and by some energy companies. Our work seemed to be welcomed by the military and security communities, but not by the Department of Energy. And our final report to the Federal Emergency Management Agency, delivered in November of 1981, seems to have sunk without trace.

The government's limited interest may be owing, at least in part, to the natural assumption that experts have every thing under control. After all, the energy supplies of advanced industrial countries are ordinarily quite reliable. Unfortunately, modern energy systems are so complex that nobody can foresee all the ways in which they might fail, even accidentally. Each major failure has been a surprise to the designers. Further, designing energy systems to be reliable in the face of predictable kinds of technical failures—as the engineers have done with commendable thoroughness—does not provide, and may even discourage, a more vital characteristic: resilience in the face of unpredictable kinds of failures (especially from sabotage). Energy engineers tend to design highly centralized, monolithic systems. On their own, they do not fail often, but when they do fail, they fail big. Thus, if a relay failure blacks out New York, the normal response is to improve the relay—but at the same time, the centralized architecture that caused the cascading grid failure in the first place is not only preserved but expanded. Thus the next crash is not prevented, it is enlarged.

Someone unacquainted with the hundreds of actual incidents that we have compiled might reasonably suppose that the country's energy supply could never be seriously jeopardized—just as a regional blackout was considered implausible until 1965; as the hijacking of three jumbo jets in a day was until 1970; as the seizure of more than fifty embassies was until the 1970s; and as an air raid on a nuclear reactor was until 1981 (when Israel destroyed one in Iraq). But, given the stakes, nobody would wish to be in the position of the British intelligence officer who, on retiring in 1950, after forty-seven years of service, reminisced: "Year after year the worriers and fretters would come to me with awful predictions of the outbreak of war. I denied it each time. I was only wrong twice."

Energy vulnerability in its widest sense—the potential for interruptions of any form of energy supply, by any means, on any scale, at any time and place—has serious political implications. The threat of terrorism can fundamentally alter the political balance between large and small groups in society. This may in turn erode the trust and the civil liberties that underpin democratic government.

Modern energy supplies depend on technicians with specialized skills. Strikes that disrupted electric power helped to unseat the ruling party of Britain in 1974 and (with the aid of oil and gas workers) deposed the Shah of Iran in 1978. Similarly, power strikes, or threats of them, have been used as political instruments in Argentina, Australia, Israel, Puerto Rico, and elsewhere. Coordinated attacks on electric-power systems hastened the fall of President Salvador Allende, in Chile; in 1972, they disrupted a presidential inauguration in Portugal and frustrated a coup they were meant to precipitate in El Salvador (where the blackout prevented the plotters from communicating with one another or with the public).

The vulnerability of cities and factories to even simple kinds of energy sabotage invites a particularly debilitating kind of economic warfare, such as is now being waged in El Salvador, Peru, Afghanistan, and South Africa. Key power lines and plants are periodically destroyed in all four countries. (In South Africa, the attacks provoke what appear to be retaliatory raids on oil facilities in Angola and elsewhere.) All over the world, valuable energy targets are typically clustered in exposed positions. The burning of the main oil depot in Salisbury, Rhodesia, in 1978 destroyed nearly half a million barrels of oil, which the embargoed regime had painstakingly accumulated from Iran and from South Africa's synthetic-fuel plants. Thus a raid with simple munitions increased Rhodesia's budget deficit by 18 percent within a few minutes. The value destroyed was at least a million times that expended in rockets and tracer bullets. Attacks on oil depots have succeeded in Italy, have partly succeeded in the Netherlands, West Germany, and the U.S., and have been narrowly foiled in Chile and Israel.

The expense can entail lives as well as money. Modern liquefied-natural-gas (LNG) facilities often store flammable inventories equivalent in energy to megaton-range strategic warheads. Some such facilities are sited near cities—Boston, London, and Tokyo, among others—even though a major leak could cause a firestorm. Just the radiant heat from a large LNG fire can cause third-degree bums a mile or two away. There have already been near misses: for example, an LNG terminal on the River Thames near London has almost been ignited three times by oil spills and fires. An audit done by the GAO in 1978 found that LNG trucks—each potentially a portable, quarter-kiloton firestorm—had only slightly better security than potato trucks; unauthorized people could readily enter the terminals where the trucks are filled and drive them away. Finally, if a saboteur cut off a city's piped natural-gas supply long enough to extinguish the pilot lights, and then turned the gas on again, any errant spark would ignite a conflagration.

The huge radioactive inventories in nuclear reactors and spent-fuel facilities place the fallout potential of a sizable nuclear arsenal in the hands of anyone with the simple means required to cause a major release. Various attempts at sabotage of nuclear facilities—bombings, arson, and destruction of equipment, rather than the more minor incidents that can take place during anti-nuclear demonstrations—have already occurred in Spain and France, and less frequently in other European countries, the U.S., Argentina, and Brazil. By 1980, more than 400 acts or warnings of violence (mostly telephoned bomb threats) had occurred at U.S. nuclear facilities; each year, several more actual incidents and dozens of new threats are reported. Worldwide, more than a hundred attacks or significant breaches of security have occurred at nuclear facilities. Fissionable materials stolen from a nuclear plant can be made, directly or indirectly, into crude nuclear bombs, which might, in turn, be aimed at a nuclear facility. The long-term, long-range radiological consequences of exploding such a sub-kiloton bomb in a public area near a large reactor would probably be similar to those of a one-megaton groundburst.

Because attacks on the energy system can be devastating, yet cheap, pointed, and deniable, they offer an attractive means of clandestine or surrogate warfare, against which a free society has no effective means of defense. It is hard to see why any of the conventional means of overt warfare—costly, indiscriminate, and inviting retaliation—should be preferred to clandestine attacks on a country's energy infrastructure (or, for that matter, on equally vulnerable targets in telecommunications, data processing, food, water, and so forth). From this point of view, the U.S. is spending about $10,000 per second on military defenses for the front door while the back door stands ajar unnoticed.

Deterring attacks by thousands of nuclear missiles does not provide security if a few satchels of high explosives have, in the meantime, upset the national economy by blacking out New York City for upwards of a year. Just as the delivery vehicle of choice for a nuclear warhead may now be a tramp freighter, rental van, or parcel-service truck—modes that can be anonymous and therefore undeterrable—so future strategic attacks may occur in the form of abrupt, complete, but seemingly accidental breakdowns of infrastructure vital to national life. Energy vulnerabilities have broad implications for NATO, too. For example, even if no nuclear bombs were used to counter a Warsaw Pact thrust across the north German plain, collateral damage to the four large reactors now sited there could readily release about as much radioactivity as would issue from the groundburst of many thousands of tactical nuclear warheads.

Military history teaches important lessons about energy vulnerability. Hermann Goering and Albert Speer stated after World War II that the Allied Forces could have saved two years by bombing the Nazis' central power plants early. (The Allies had mistakenly believed that the German electric grid could reroute power flexibly enough that a few plants or switching centers would not be missed.) Japan's power system, however, did successfully withstand heavy assault during the war, because it was decentralized. Its thousands of small and dispersed hydroelectric plants, which were thus all but impregnable militarily, generated 78 percent of Japan's electricity Those plants sustained 0.3 percent of the bombing damage. Japan's large power stations, which supplied only 22 percent of the country's power, sustained 99.7 percent of the damage.

The accidental blackout of virtually all of France in 1978 showed that substituting domestic energy (nuclear power, actually based on imported uranium) for foreign oil does not necessarily protect people from freezing in the dark, and may even cause large numbers to do so at one stroke. This lesson was repeated with the accidental blackout of Israel in 1979, of most of southern Britain in 1981, and of Quebec in 1982 (the most recent of many there). Several countries—notably Sweden, the People's Republic of China, and Israel—are already pursuing energy decentralization as a national-security measure. The Red Army is reportedly anxious to follow suit, but the Politburo forbids this on the grounds that any sort of decentralization would threaten its own authority.

Energy insecurity is not necessary; it is not even economic. Cheaper alternatives exist. Design lessons from biology and from many engineering disciplines—computer theory, aeronautics, naval architecture, nuclear science—can be embodied in practical, available, and cost-effective energy technologies. Systematic use of these principles can make the energy system so resilient that major failures, from any cause, become impossible. Investing in a resilient energy supply would enhance American military preparedness, minimize the threats to be prepared against, and make defense costs less onerous. Best of all, such an investment would be paid back. According to a study released by the Solar Energy Research Institute in 1981, the U.S. could double its energy efficiency and convert at least a third of its energy supply to renewable sources within the next two decades. The institute's data suggest that such a shift could save several trillion dollars, make the energy sector deflationary, and provide as many as a million jobs.

A resilient system is one that has many relatively small, dispersed elements, each having a low cost of failure. These substitutable components are interconnected not at a central hub but by many short, robust links. This configuration is analogous to a tree's many leaves, and each leaf's many veins, which prevent the random nibblings of insects from disrupting the flow of vital nutrients.

Such dispersed, diverse, and redundant systems can yield striking economic savings. For example, when a power engineer in Holyoke, Massachusetts, saw the blackout that struck most of the Northeast in 1965 rolling toward him, he was able to separate the city from the collapsing grid and power it instead with a local gas turbine. Within four hours, the money saved by not having to shut off electricity to the city repaid the cost of building the turbine. In 1978, the residents of Coronado, California, were not aware that the surrounding San Diego grid had been blacked out, because their power was supplied by an independent cogeneration plant. In the bitter winter of early 1977, when Midwestern factories and schools were closed by natural-gas shortages, rural New England was unaffected, because its supply was bottled, rather than delivered through the nexus of pipelines; as a result, systemwide collapses could not occur. In 1980, officials from the Department of Energy were cutting the ribbon on a West Chicago gas station powered by solar cells when a violent thunderstorm blacked out the city. The station's power was not interrupted. Likewise, a Great Plains farmer who uses wind power was once watching the television news and saw a report that his whole area was blacked out. He went outside and, sure enough, all his neighbors' lights were off.

All of these examples illustrate the architectural principle of resilient energy supply. But the last two also show the security advantage of harnessing natural energy, which cannot be depleted or disrupted by wars, strikes, embargoes, sabotage, and the like.

Renewable energy sources are often dismissed as unreliable. Yet several analysts have shown that a variety of renewable sources in combination can be more reliable than nonrenewable sources. Stormy weather, bad for direct solar collection, is generally good for windmills and small hydropower plants; dry, sunny weather, bad for hydropower, is ideal for photovoltaics. A diversity of sources, each serving fewer and nearer users, would also greatly restrict the area blacked out if a grid connecting them failed. And when renewable energy sources do fail, they fail for shorter periods than do large power plants. Windmills in appropriate sites might stand becalmed, at reduced output, for tens of hours; but reactors typically fail for 300 hours, at zero output. It can be cloudy (not a serious impediment to properly designed solar systems) for days or weeks; but a total eclipse lasting several months—the natural analogy to an oil embargo—is most unlikely.

Finally, while the intermittence of renewable supplies is caused by well-understood effects that are fairly predictable (rotation of the earth, calm, cloudiness, drought), the nonrenewable supplies are intermittent for reasons that are much harder to predict (terrorism, reactor accidents, strikes, and international politics). One can have greater confidence that the sun will rise tomorrow than that no one will blow up Ras Tanura today.

The most resilience per dollar is achieved by the most productive use of energy, whatever the source. For example, if America's car fleet averaged 65 miles per gallon (fifteen fewer than an advanced diesel *Rabbit* tested two years ago), the cars could run for hundreds of miles on half-filled tanks. The stocks of oil extracted from the ground but not yet sold would run the fleet for about a year whereas now, if the pipeline feeding a refinery is cut, the refinery must shut down in a few days, and its customers would run out of products in about a week. Thus, using energy more efficiently diminishes fuel stocks more slowly, buying precious time to mend what is broken or to improvise new supplies.

Fuel-efficient cars are only one of many ways to make the failure of an energy supply less critical. If, for example, the heating system of a superinsulated house in Montana were to fail in midwinter, it would probably take days or weeks—not hours—for the indoor temperature to drift down into the mid-fifties. The warmth from people and from sun shining through windows (and, if the electricity were on, from lights and appliances) would make lower temperatures physically impossible. The body heat from a few neighbors, coming in to take refuge from their sievelike houses, would restore the superinsulated house to a comfortable temperature. If they brought along a large dog, the house would overheat unless the windows were opened. Alternatively, the house could be evenly heated by any small, improvised source of heat, such as burning junk mail in a large tin can. If well-designed, the house need not have been equipped with a heating system at all.

If electricity were consumed more efficiently, the country's large hydropower plants could team up with smaller units of supply—micro-hydropower plants, industrial cogeneration equipment, windmills—to meet the demand. New technologies for saving electricity can perform the tasks of existing technologies more cheaply. Heat-saving renovations of buildings and passive solar systems can reduce or even eliminate the demand for electric heating and air-conditioning; changes in the configuration of motors can drive industrial machinery twice as efficiently; household appliances can be designed in ways that cut their demand for electricity by at least 75 percent; improved bulbs, fixtures, and electronic controls and the creative use of daylight can reduce light bills by between 60 and 90 percent.

Analyses by an energy study group at the Harvard Business School and by the Solar Energy Research Institute have shown, and market experience is confirming, that renewable sources, chosen carefully and acquired sensibly, are generally cheaper—many by several times—than the centralized, nonrenewable sources that they stand ready to replace. Within decades, resilient energy sources could wholly supplant the vulnerable supplies, both domestic and foreign, on which the U.S. now depends. Using energy in an economically efficient way can buy the country enough time to complete the transition comfortably.

The transition is already well underway. Since 1979, the United States has gotten more than a hundred times as much new energy from savings as from all the expansions of the energy supply combined. Of those expansions, more new energy has come from renewable sources, which account for about 8 percent of the total U.S. supply, than from any or all of the nonrenewables. That is, sun, wind, water, and wood have been adding to the American energy supply at a faster rate than oil, gas, coal, and uranium, singly or combined. Higher energy efficiency is far outpacing them all. The amount of energy needed to make a dollar of GNP has fallen by a fifth in nine years, and is still falling by several percent per year.

These savings reflect only a tiny fraction of those that are technically possible and economically attractive. Energy technology is advancing with extraordinary speed. Many of the most important innovations have been developed within the past two years: windows so heat-conserving that they can capture more solar heat than they lose, even facing north; refrigerators using an eighth as much electricity as a standard model; ships and jetliners twice as fuel-efficient as today's fleet; light bulbs that cost $25 but that yield better light than standard bulbs, use a quarter as much electricity, last ten times as long, and return their cost within a year or two; moderately priced heat exchangers that bring copious amounts of fresh air into tightly built houses, yet capture four fifths of the heat or coolness from the air they withdraw; ice ponds that cool buildings using a tenth of the energy that air conditioners require;

ways to make existing buildings so heat-tight that they don't need heating—the list goes on.

Renewable sources of energy, too, are penetrating the market. Since 1979, more new electric generating capacity has been ordered from small hydropower and wind-power plants than from coal or nuclear plants or both. Woodburning, though seldom done in the best way, now delivers about twice as much energy as nuclear power, despite the government's outlays of more than $40 billion in nonmilitary nuclear subsidies. The rate of practical progress is similarly impressive in Europe, Japan, and a few developing nations.

In 1980, Americans spent some $15 billion on energy saving devices and renewable sources (not including purchases of fuel-efficient cars)—about a fifth of the total U.S. investment in energy equipment. A manifestly imperfect market is working remarkably well, proving that in a large and diverse society, energy security does not require, and may not even be able to tolerate, central management. The problem of secure and affordable energy supplies is starting to be solved, by individual and community action—from the bottom up, not from the top down. Washington will be the last to know.

More than $400 billion a year is spent nationwide for conventional fuels and power, and this huge sum is a keen spur to local initiative. Typically, between 80 and 90 percent of the dollars spent on energy leave a community, never to return. This drain can be equivalent, in a town of 100,000 people, to the loss of about 10,000 jobs. In contrast, higher energy productivity and the harnessing of renewable energy, using local skills and manufacturing capacity, can keep the money, the jobs, and the economic multipliers at home. Thousands of communities are already moving with remarkable speed to capture these opportunities. They would not act so quickly if resilience cost more than vulnerability. Energy security and price are *inversely* related. The resilient technologies are what a truly free market in energy services would reward, if one existed.

These technologies would enter the market even faster if the severe price distortions created by federal subsidies were removed, and if people were not prevented from responding to price signals by many silly rules and customs left over from the cheap-oil era (3,000 obsolete building codes, conflicting incentives for landlords and tenants, restrictive lending and zoning regulations, inequitable access to capital and information, and so forth). But this will require greater willingness than the Reagan Administration has shown to expose all technologies—even synthetic fuels and nuclear power—to free competition.

Since we cannot afford (and do not need) to do everything, we must compare investment alternatives. Consider, for example, five ways to spend $100,000 to save oil:

- Catalyze a program of door-to-door citizen action to weatherize the worst buildings, as Fitchburg, Massachusetts, did in 1979, and as dozens of towns have done since. Experience shows that over the first ten years, the investment of $100,000 in such a program can save 170,000 barrels of crude oil, at about $.60 a barrel.

- Pay the extra cost (at the highest published estimate) of making forty-four cars achieve 60 mpg. The first decade's savings: 5,800 barrels at about $17 a barrel.
- Buy about 3,000 barrels of foreign oil, put it in a hole in the ground, and call it a "strategic petroleum reserve." After ten years, the oil may be available, but the storage and carrying charges—probably between $50 and $70 a barrel—will be unrecoverable.
- Buy a small piece of an oil-shale plant. After ten years, it will have produced nothing. After that, if it works, it will produce up to 9,000 barrels of synthetic oil per decade, probably retailing at between $70 and $120 a barrel, in 1982 dollars.
- Buy a tiny piece of the Clinch River breeder reactor. After ten years, it will still be under construction. After that, if it works, the $100,000 investment will yield up to 500 "barrels" of energy (as electricity) per decade, retailing at over $370 per barrel, in 1982 dollars, and probably uncompetitive even with roof-mounted photovoltaic cells.

By having failed to allow a truly competitive marketplace to operate and make the alternatives clear, the U.S. has pursued these options in reverse order, choosing the worst buys first. Energy security will come slowly until we take economics seriously.

Note: This PDF was corrected in November 2010.