An Integrated National Energy Research and Development Program

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The energy crisis has spawned its fair share of polemics, but on one aspect there is virtually unanimous agreement. Everyone seems to favor spending more money on energy research and development (R & D). Last summer President Nixon proposed spending $10 billion over the next 5 years and requested the chairman of the Atomic Energy Commission (AEC), Dixy Lee Ray, to prepare an integrated plan for the nation's energy R & D program. Even as Ray's report was being readied, Senator Henry Jackson (D–Wash.) submitted a measure that called for spending $20 billion over a 10-year period on nonnuclear energy R & D. The Senate passed this bill late last year without a dissenting vote.

The rhetoric of the energy crisis includes such phrases as "massive spending" on R & D, "crash programs," and "another Manhattan Project" or "Apollo Project." The implications are loud and clear. American know-how and technological superiority will soon triumph over adversity. Few would care to dispute these sentiments; nevertheless, a cautionary note may be in order. Whatever the causes of our present energy situation, they are deeply rooted in the way our society has chosen to live and conduct its business in the past. The issues that face us now cannot be resolved in terms of clearly defined objectives, such as build an atomic bomb or place a man on the moon. The basic problem is to devise means for bringing energy supply into balance with energy demand in such a way that various economic, international, environmental, and societal factors are taken into consideration, in spite of the fact that there may be conflicts among them.

Scientific and technological R & D have a very proper and significant role to play in our future course of actions, but it would be foolish to consider them as the principal instruments for achieving solutions to problems at hand. Scientific discovery and engineering innovation are usually essential ingredients for a novel or improved commercial enterprise. The decision about whether to place a technological option into commercial practice, however, lies largely outside the proper domain of R & D.

Energy R & D activities should be viewed as but one tier of a larger structure embracing overall energy policy formulation and implementation. Some degree of coordination will be required among all these tiers if we are to have an effective program. Thus, at any given time, the structure and aims of the R & D program should reflect the goals and objectives of stated policy. At the same time, there must be sufficient breadth and flexibility in R & D activities to accommodate evolutionary changes in policy. Another way to express this guiding principle is to recognize that short-term requirements always tend to dominate attention and priority allocation; yet, in order to avoid possible bankruptcy in the future, the interests of projects addressing long-term objectives must be protected.

Policy Considerations

We should first identify national energy policy before embarking on the formulation of an R & D program. This in itself is no easy task, since there are many components of a national policy. We can, of course, examine the Administration's views, the views prevalent in Congress, the federal laws and practices on record, and so on. However, even though the federal government may act in various ways to influence and regulate the energy industries, it is the private sector that, in very large measure, determines the final course of action. The privately controlled energy industries, on the other hand, tend to state that their actions are simply a consequence of government policy.

This can lead to circular arguments. For example, most, if not all, of the gasoline and fuel oil shortages which have developed here during the past 12 to 18 months have been conventionally equated with the lack of domestic refinery capacity. The major oil companies have been busily constructing refineries, but not in this country. Part of the blame is placed on the fact that, until a year ago, we maintained a tight import quota system. Yet this quota system was as much a creature of the major oil companies as of the federal government. What should we conclude —that for some 5 years national policy dictated that domestic refinery capacity should not be increased? Who set this policy?

The ways of the energy business are complex; cause-effect relationships often cannot be determined unambiguously. The voice of the federal government is but one, and sometimes not even a single one, in a chorus. Determining what is policy at any given time can be difficult. One can take the President's statements as an indication of the Administration's policy; it is to be hoped that this policy will reflect in some measure national policy as well. For the time being, the essence of the Administration's policy is contained in President Nixon's Project Independence. Interpretations of Project Independence will vary from the literal to the symbolic. We may expect, nevertheless, that the federal government will embark on a serious attempt to bring energy supply and demand into balance, such that our reliance on imports, primarily crude oil and refined petroleum products, can be drastically reduced within this decade. As a consequence, the primary goals of federal programs must be to restrain the growth of energy demand and expand domestic energy supply, subject to the usual constraints of economic health, environmental care, and societal acceptance. Insofar as this may be accomplished in a way that will foster improved international relations, such relations will be taken into consideration.

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Some Perspectives on the Energy Crisis: Demand

In about 1967, U.S. demand for energy began to increase markedly. Some perceptive observers began to warn that domestic production of energy was likely to level off soon. In fact, within 3 years domestic natural gas and oil production peaked, while demand grew unchecked. The situation that developed in the past 6 years is atypical (*1*). From 1947 to 1972, the nation's energy consumption grew at an average annual rate of 3.2 percent per year. Over the past decade, this rate has been 4.3 percent, and more recent trends have varied between 4.5 and 5.0 percent.

For most of this century the majority of our inanimate energy needs has been supplied by fossil fuels—from 1947 to 1972, fossil fuels accounted for some 95 percent of our requirements, with hydroelectricity and miscellaneous sources making up the remainder (*2*). The mix of fuels has not remained constant, however. In the early postwar years, coal represented 48 percent of the gross fuel inputs, but it accounts for only 17 percent now. As a result, coal production has decreased somewhat from its peak in World War II and has remained reasonably steady at just under 600 million tons per year for the last decade (*3*).

Natural gas, on the other hand, has grown rapidly in popularity. During the period from 1947 to 1972, its contribution to the total fuel mix went from 13 percent to 33 percent. For the past few years, production has not increased significantly, and an informal rationing system exists such that many potential customers cannot obtain natural gas. Annual consumption reached 22.4×10^{12} cubic feet in 1972 (1 cubic foot = 28.32 cubic decimeters). Historically, oil, including petroleum condensates, has grown at about the same rate as total energy demand. It is essentially the sole source of energy for the transportation sector, having displaced coal used by railroad locomotives some time ago. Approximately 10 percent of current oil consumption goes into such nonenergy uses as the manufacture of petrochemicals, lubricating oils, and asphalt.

Somewhat unexpectedly, oil consumption grew by 6 to 7 percent annually in the past 3 years. Most of the increased growth can be traced to newly established air quality standards, the inability of natural gas to satisfy additional demand, and the short supply of low-sulfur coal. Simultaneously, domestic production of oil leveled off. The only course available was to increase imports. The expense of importing natural gas over long distances, plus the time lag in constructing pipelines from Alaska, Canada, or liquefied natural gas tankers and handling facilities, placed the burden of imports on oil and its products. Oil has become the "swing" fuel, filling in for natural gas and coal in markets where the traditional role of oil had been secondary. By 1972, oil accounted for 45.6 percent of the total fuel mix, and consumption averaged 16.5×10^6 barrels per day (1 barrel = 1.59×10^2 liters).

As of 1947, the United States was a net exporter of oil and petroleum products, but by 1971 it was importing approximately 4×10^6 barrels of oil per day, most of it coming from Venezuela and Canada. Import restrictions were relaxed in 1972, and the oil import figure rose to 5×10^6 barrels per day. The quota system was abandoned last April and replaced by a fee, or tariff, system; oil imports spurted once more, to exceed 6×10^6 barrels per day by midyear. The situation since the October 1973 embargo is unclear, but it is estimated that roughly 2×10^6 to 2.5×10^6 barrels per day should have been affected by the embargo. This estimate is based on the conventional wisdom that imports from the Western Hemisphere are limited in availability, they can supply only between 3×10^6 and 4×10^6 barrels per day, the remainder must be obtained from the Eastern Hemisphere, and a large fraction of this remainder would have come from the oil-producing Arab states. It is worth observing that, were we to continue the trends of the early 1970's, we would be importing half of our oil requirements by 1980 and most of it would have to come from the Middle East.

Thus far I have mentioned only the primary fuels used to provide energy. Electricity is a secondary form of energy whose popularity has grown steadily. Its annual average growth rate has been around 7 percent for a number of decades, thereby outstripping the growth in total energy demand. Its relative importance in the energy market may be inferred from the fact that within the past 25 years electricity has grown from 13 percent of total fuel consumed annually to 25 percent. Electricity can be generated from practically any energy source, ranging from solar to trash. The electric utility industry is now poised to embark on the nuclear age. Some 5 percent of the total electricity produced in this country is already obtained from nuclear fuels, and in another 10 years this figure is expected to reach 25 percent. It is predicted that, by the end of the century, half of the total installed generating capacity will employ nuclear energy and will produce over half the nation's total electric power.

In fact, part of our present difficulties can be traced to the slowdown in nuclear power production. Estimates made in the mid-1960's of the rate at which reactors could be constructed and placed into operation were proved overly optimistic. As a result, the electric utility industry was caught short of required capacity, and temporary difficulties were experienced in some localities until gas turbine peaking units were constructed hurriedly and brought in to fill the gap. Unfortunately these units are relatively inefficient and must compete with other markets for precious fuel supplies.

In summary, the present situation evolved from a steadily increasing gap between domestic demand for energy and the amount supplied by domestic sources. Over the past 15 years, production has grown at an annual average rate of only 3 percent, but this rate has been relatively static in the past 3 years. In terms of marginal requirements, the United States was rapidly approaching the situation of the industrialized nations of Western Europe and Japan, whose economies had become heavily dependent on imported oil from the Middle East and Africa.

Energy Resources

Not so long ago, this nation was a net exporter of energy. Any prospects for returning to that position fully or partially hinge on our domestic fuel resources and our capabilities for developing them. Here there are some difficulties in making firm estimates. It is necessary to distinguish between reserves and resources. Reserves are effectively ready inventory—they represent amounts that can be economically recovered with existing technology, and one usually prefixes these quantities with "proved." Invariably, proved reserves are accompanied by submarginal deposits that are not economically attractive to recover. A shift in technology or market prices could promote these quantities to the category of reserves. Thus, for example, cumulative production of oil in the United States has reached approximately 100×10^9 barrels. Roughly 400×10^9 barrels, however, have been left behind. A technique that could increase recovery by 1 percent over the present average of 30 to 31 percent, at an acceptable cost, would add 4×10^9 barrels to our proved reserves (*4*). The extent of our resources is estimated on the basis of geological information and deduction, with varying degrees of precision. Quantities of coal are better known than those of oil or gas; domestic deposits of oil shale can be estimated with greater certainty than those of tar sands.

With these qualifications, one may state that the estimated proved reserves of mineral fuels in this country are approximately 5 Q (quantity of heat; $1\ Q = 1.06 \times 10^{21}$ joules) in terms of heat equivalent. Oil, natural gas, and uranium (based on present converter technology) represent nearly equal parts of this amount, each accounting for 4 to 5 percent of the reserves. Coal accounts for the rest, or somewhat more than 85 percent. Gross U.S. energy consumption in 1972 was 72 mQ ($1\ mQ = 10^{18}$ joules), and one might argue, for the sake of illustration, that it will approach 100 mQ by the end of the decade. At that rate, proved reserves would last 50 years without any new finds or promotion of resources to the reserve category. The deduction is faulty only in that the fuels of preference, natural gas and oil, would be drawn down in less than 10 years.

Including estimates of undiscovered deposits, our recoverable resource base is usually given as 33.7 Q of coal, 1.5 Q of natural gas, 1.6 Q of oil, 7 Q of uranium (which, with the introduction of a breeder economy, becomes 700 Q), and about 7 Q or somewhat less of thorium. Including all grades of oil shale results in an estimated resource base of 6 Q. Domestic tar sand deposits, estimated with far less precision, currently constitute no more than 1 to 2 percent of our oil shale resources. Potential geothermal and direct and indirect solar energy sources are not included in the above enumeration, nor is fusion.

It would appear that the nation's potential mineral fuel supplies are hardly limited. In fact, few other countries find themselves as well endowed. The problem is how to make these resources available to the economy. The fuels of most interest now are oil and natural gas, which together account for better than three-fourths of our raw energy demand. These two fuels are theoretically interchangeable, since, in a pinch, even road vehicles could operate with methane or with methanol derived from methane, the principal constituent of natural gas. Table 1 gives the shortfalls in oil and natural gas supplies estimated by the Federal Energy Office, assuming past trends were allowed to continue without substantial change. Under normal conditions, these deficits would be filled by imports or substitutes. Such estimates should be viewed as illustrative of the challenges posed by trying to find technological alternatives or economic and societal responses that will change the scale of future supply-demand patterns.

Project Independence: Goals

Project Independence will be a novel experiment on the part of the government in trying to meet some extremely difficult goals in a relatively short time. Unlike the Manhattan Project or the Apollo Project, which could be kept within narrowly prescribed boundaries and pursued exclusively with government resources and contractor help, energy cuts across the entire fabric of society. The energy industries, traditionally the preserve of private enterprise, account for a sizable fraction of our gross economic activity. Presumably they would be the principal instrument for expanding domestic energy supplies. The consuming sectors, consisting of private citizens, commerce, and industry, involve the public at large. Ultimately it is their actions which will determine to what extent growth in energy demand can be restrained.

Somehow the government will have to orchestrate these diverse elements and guide them to a common purpose. For purposes of discussion, the goal of Project Independence may be taken as reducing by 1980 the amount of oil and gas imports to a level that would make us relatively impervious to interruptions. Zero net imports may be not only impractical, but unwise. Ideally, the situation would be such that, even were these imports to disappear overnight, the country could recoup and adjust in a relatively short time; at the same time, the chances of such cataclysmic events would be minimized by making certain our sources of foreign supply are not concentrated in any single geographical area or political sphere. As a responsible member of the world community, the United States should also refrain from placing additional burdens on the world market of energy supplies as long as it remains a seller's market.

The Federal Role

There are a number of ways by which the government may intervene in the energy sector of the economy. Possibly the least objectionable is by funding R & D. One may question whether R & D can have a significant impact by 1980, given the time lags inherent in the system. I believe it can, for more than one reason. In the first place, an intensive program of economic, environmental, systems analytic, legal, social, and technical studies should be undertaken to help illuminate the way in which our energy system works, both on the domestic front and in international trade. This should help decision-makers in government appreciate possible cause-effect relationships before setting policy. A glaring example of where improvements are urgently needed is in our information and data base. Left to its own devices, the marketplace makes adjustments and allocations between supplier and consumer in a highly complex and interconnected way. Whenever the government intervenes in this process, the perturbations may be large and totally unexpected. Both the Executive and the Legislative branches should be armed with the best possible information.

Project Independence provides a unique opportunity to couple energy R & D activities with urgent projects. A question often asked in regard to federally funded R & D activities is, "What happens to a given project once it has passed through the demonstration phase and appears to be commercially viable?" As long as the government is spending R & D money for its own ultimate procurement purposes, as is the case in military or most National Aeronautics and Space Administration programs, this question need not arise. But in the case of energy R & D, the results must ultimately be transferred to the commercial sector. The speed with which novel or improved technology can be transferred and affect energy production or consumption depends in

Table. 1. Petroleum and natural gas supply and demand projections. [Source: unpublished studies of the Federal Energy Office]

Fuels by type	1972*	1973†	1974	1975	1976	1977	1978	1979	1980	1985	1990	2000
Petroleum consumption												
10^6 barrels per day	16.5	17.5	17.7	17.8	18.5	19.2	20.0	20.8	21.6	25.6	28.0	35.6
mQ per year	33.0	35.0	35.5	36.0	37.3	38.8	40.3	41.9	43.5	51.8	57.1	71.4
Domestic petroleum supply												
10^6 barrels per day	11.6	10.9	10.6	10.3	10.1	9.9	10.3	10.8	11.4	11.0	10.6	9.8
mQ per year	23.4	22.0	21.3	20.8	20.3	19.9	20.8	21.7	23.0	22.1	21.4	19.7
Natural gas consumption												
10^{12} cubic feet per year	22.4	22.7	23.1	23.7	23.9	24.1	24.4	24.6	24.9	26.4	28.1	33.0
mQ per year	23.1	23.4	23.9	24.4	24.7	24.9	25.2	25.4	25.6	27.3	28.9	34.0
Domestic natural gas supply												
10^{12} cubic feet per year	21.4	22.9	22.2	21.7	21.1	20.7	20.3	19.9	19.4	18.2	18.7	16.6
mQ per year	22.1	23.6	22.9	22.4	21.8	21.3	20.9	20.5	20.1	18.7	19.2	17.1
Nominal hydrocarbon deficits												
mQ per year	10.6	12.8	15.2	17.2	19.9	22.5	23.8	25.1	26.0	38.3	45.4	68.6

* Actual. † Estimated.

part on how the R & D activities are organized and on the sense of urgency behind them.

There is undoubtedly no single mechanism that works best under all circumstances. I believe, however, that if our sense of urgency under Project Independence is sufficiently great the government should exercise a firm leadership role in selected areas. As an example, there is probably relatively little argument over the necessity for the government to obtain far more accurate data on our mineral resources and reserves. This implies not only that the government should conduct a more thorough and expanded geological exploration program, but that it should devise an independent means for assessing reserves held in private hands and potential reserves under federal lands, both onshore and offshore. It would also be desirable for the United States to foster similar activities in other countries.

More Oil and Gas

A natural extension of these geological exploration activities would be for the government to engage directly in exploration and production of oil and natural gas. It is often stated that high enough prices plus the removal of some legal barriers would lead to substantial increases in the domestic production of oil and natural gas. It might serve the national interest to have a government corporation in the business in order to gather firsthand information, test new finding and drilling techniques, and learn more about reservoir management. Possibly all this could be accomplished far more efficiently with a partnership between the federal government and private concerns. For the time being, however, the political climate is not all that favorable to following the latter route.

A portion of the extra oil and natural gas required will have to come from squeezing more oil out of existing fields and stimulating the flow of gas from tight formations. It has been estimated recently that 35×10^9 barrels of oil and 500×10^{12} cubic feet of gas could be added to our reserve base by means of enhanced recovery (*5*). The techniques required will vary from one geological formation to the next, and the state-of-the-art is not particularly well documented or proven. Privately financed producers may be reluctant to invest the capital required to "get out the last drop" on time scales dictated by national interests, but not necessarily by their own interests. Some form of federal involvement will probably be required to coordinate and accelerate the spectrum of activities necessary to increase recovery yields in the short term.

Ultimately recoverable oil and natural gas reserves have been considered limited compared to reserves of other mineral fuels, both domestically and worldwide. Oil, for example, is consumed at the rate of about 130 mQ per year by the world's population. A middle-of-the-road estimate gives the world's ultimately recoverable reserves as 12 Q (*6*). Given that consumption will continue to grow at about 7.5 percent each year, and that the reserve-to-production ratio will not fall below the range of 10 : 1 to 15 : 1, worldwide production of oil may be expected to taper off sometime between 1990 and 2000. There is probably a comparable amount of natural gas to be found, but its utilization on a worldwide basis is not as easy because of the relatively high cost of long-distance transport. Gas is still being flared off in most Middle East oil fields, and only recently has serious thought been given to converting these supplies to liquefied natural gas or methanol for purposes of transport.

Alternative Fossil Fuels

Under normal conditions, one would expect that, as oil and natural gas prices increased in proportion to their scarcity, the more abundant and less developed fossil fuels would come into the marketplace as substitutes. Thus, in the course of time, coal, oil shale, tar sand, and heavy oil deposits would become commercially attractive. Project Independence is founded on the premise, however, that conditions will not be normal in the foreseeable future. The question facing the United States is the extent to which it should stimulate the advent of a synthetic oil and gas industry based on domestic sources of coal and oil shale, or, in partnership with Canada and Venezuela, on tar sands and heavy oils, respectively.

My opinion is that the United States would be well advised to earmark about \$50 billion of private and public monies over the course of the next 10 years or less in the expectation that the equivalent of 2×10^6 barrels of oil per day could be produced from coal and shale by 1980 and 5×10^6 barrels per day by 1985. There already exist commercially viable technologies for producing pipeline-quality gas from noncaking coal and extracting oil from shale. The state-of-the-art should improve rapidly under the impetus of a vigorous program of commercial application. Coal liquefaction is still in developmental stages, but its progress could also benefit from the scale of effort envisioned here. The conversion of coal to clean-burning, low heating value gas suitable for feeding steam-generating boilers would also be included in this program.

What is being alluded to above is more in the nature of a crash program for bringing alternative fossil fuel supplies on line than an orderly R & D program. The potential economic, environmental, and legal barriers are so formidable that only by a concerted effort on the part of the federal government do we stand a chance of realizing the target goals within the relatively short span of 6 to 10 years. Therefore, I should like to see a synthetic fuels administration program organized somewhat along the lines of the synthetic rubber program of World War II. There are, I am sure, less drastic ways for the government to take action. A more prudent course might well be to construct a series of model, commercial-size plants like those described by Ray (*7*).

More Coal

An integral part of any strategy for implementing Project Independence must be a plan for bringing the coal industry out of its doldrums and increasing coal's share of the total fuel mix. The reasons for coal's present state of stagnation are well known and need not be reviewed. If the trends of past years are to be reversed, coal must be assured a long-term market and the industry must be helped to increase its production rate. The place to use coal directly, of course, is under utility and industrial boilers. It seems unlikely that this market can be expanded significantly in the near future unless environmental restrictions are relaxed. In many parts of the country, ambient air quality standards could be met even without low-sulfur coal, provided that high stacks were erected. As a precautionary measure, such plants should have low-sulfur fuel available to use whenever unfavorable meteorological conditions warrant it. It is conceivable that within the next 5 to 10 years the art of stack gas cleanup will have improved enough to gain widespread acceptance and plants could operate under the stricter emission standards. A more likely solution, however, is the synthesis of a clean boiler fuel from coal by means of partial hydrogenation, or the use of coal with gasifiers.

Even if additional markets could be guaranteed to furnish the requisite incentives, the coal industry faces formidable problems in any attempt to increase appreciably its production capacity. Incremental production of Eastern coal will have to rely heavily on underground mining. This, in turn, will require considerable investment in the development of new and improved mining techniques in order to reverse the downturn in productivity per miner, while at the same time maintaining rigorous standards for miners' safety and health. If coal production is to double in less than 10 years, Western coal will have to bear the brunt of the expansion. The quickest way to get Western coal out is by surface mining, but it is unlikely that surface mining will be permitted until the public is convinced that land in the arid regions of the West can be restored—which brings me to the often-quoted remark that water availability may place serious limitations on exploiting the coal and shale riches of the West in general.

Some Obstacles

Bringing coal to the market will require additional investments in rail and slurry pipeline transport. This is but part of the total price tag one might ascribe to Project Independence. Regardless of cost and availability of capital, there are many obstacles to overcome if we are to increase our total domestic energy production by such target figures as 4.5 to 5 percent each year. Limitations in skilled manpower and essential materials used in production and construction are but some examples. Streamlining or radically altering the host of federal, state, and local regulations that now impede expansion of production capacity is yet another category of problems requiring attention. Needless to say, a great deal of careful planning and organization will be required if we attempt to do all the things listed on the various menus being prepared for Project Independence.

Restraining Demand

I have said little so far on how to curb demand. For the time being, we are pretty much ordained to live in a world of imposed shortages. This is sometimes confused with conservation. As time passes, we should learn how to distribute the inconveniences of shortages more evenly. The ultimate prospects of Project Independence, however, will depend heavily on the extent to which growth of demand can be limited. The nation's dependence on imports was already uncomfortably high in 1972, accounting for over 15 percent of our total energy requirements, and the corresponding figure today would be even higher if conditions were normal. There is little chance of closing the gap between domestic supply and demand, even with optimistic estimates for increased production, unless growth of demand can be held to an average of less than 3 percent per year for the remainder of the decade.

Voluntary conservation measures on the part of the public can go only so far in bringing down demand. A major burden will fall on the shoulders of industry, which, when its share of electricity consumption is included, uses nearly 40 percent of the total energy used in this country. There are many technological opportunities for industry to devise more efficient ways of using energy throughout their manufacturing cycle (*8*). In the course of time, the transportation sector, which currently accounts for 25 percent of our energy consumption, should introduce significant energy savings with more efficient power plants and smaller weight vehicles. Continuing emphasis on improving efficiencies in the end uses of energy is warranted because this promises to accomplish the goals of conserving energy with the least inconvenience to the individual consumer.

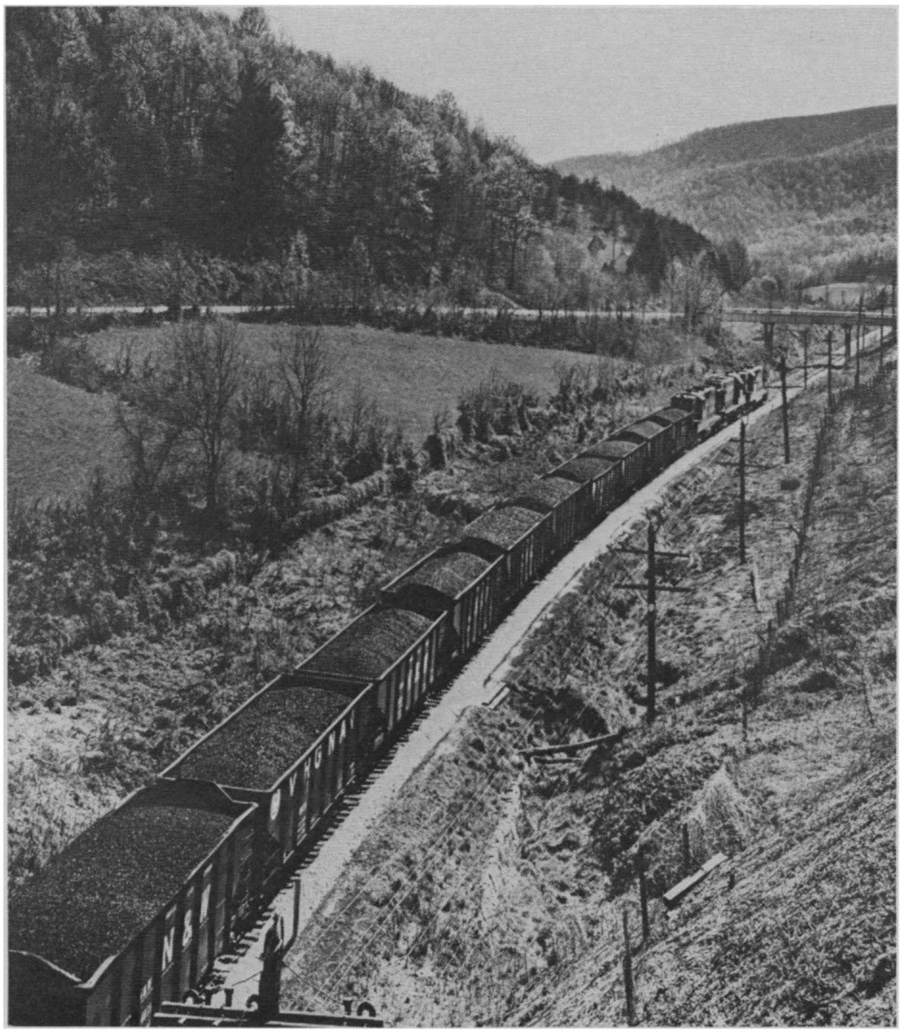
Future Prospects

The problems of meeting energy demand with adequate supplies, subject to constraints already mentioned, promise to be with us for some time to come. On a more extended time scale, we envision a repetition of past history, which has already witnessed a number of substitutions in energy forms and modalities. When proper account is taken of society's dependence on energy, it is somewhat surprising to find that per capita consumption in this country has hardly doubled over the past century (*9*). Just as in the past we found substitutes for wood and other derivatives of solar energy, so we will have to substitute coal and other forms of fossil fuels for oil and natural gas. Ultimately, we will have to depend on even more abundant resources, such as those available through the efficient utilization of nuclear fuels, or on truly renewable resources, such as solar energy. Geothermal energy is also a future prospect and, like hydroelectricity, is more than likely to make a contribution on a selected regional basis.

These options are discussed in some detail elsewhere in this issue, and it is only necessary here to make some general comments with regard to ordering priorities within an integrated energy R & D program. There may be little quarrel with the general notion that urgent issues should receive the highest priority and greatest attention. Some disagreement is sure to arise, however, over the extent to which the government should intervene in these issues. I would assign the highest priorities to energy conservation and expanded fossil fuel production and would encourage considerable government participation in both. Since the federal energy R & D budget has always emphasized nuclear energy, I turn to it first.

The Nuclear Option

Project Independence goals call for installed nuclear capacity of 125,000 megawatts of electricity by 1980, corresponding to 7.5 mQ of energy per year. This figure is perhaps 25 percent larger than current AEC projections. Presumably we would have to compress the planning-completion cycle of power reactors from the present span of more than 10 years to less than 6 years. This might be accomplished by cooperation between industry and the AEC to standardize both reactor systems and licensing procedures. A move in this direction should also help arrest the rapid escalation of reactor construction costs.



Ribbons of coal bend their way from mountains to sea on the Norfolk and Western mainline. [Courtesy Norfolk and Western Railway]

In fact, one might take the attitude that the nuclear industry has achieved full maturity, with large amounts of private capital committed to it. The government could relax somewhat its concern with advocacy and pay more attention to regulation. It should concentrate more on planning, uranium and thorium ore exploration, siting, safety research, and waste disposal. It should also decide where the focus of isotope separative work will be in the future—in government or private industry—and monitor carefully all aspects of the total fuel cycle.

The bulk of the federal R & D funds allotted for civilian nuclear energy are spent on one version of a fast breeder, the LMFBR (liquid metal fast breeder reactor). There is no question that at some point in the future the nuclear industry will require a breeder in order to remain viable. One can only debate how soon this may be and, consequently, just how urgent the breeder is. Opinions will vary as a function of how much one believes that there is considerably more uranium to be discovered than the amount given in official estimates and as a function of how much faith one places in the success of advanced converters. A recent review (*10*) leads one to conclude that much would be gained from a major redirection of the original LMFBR program and little would be lost by any delays suffered as a result. It also seems undesirable to concentrate funds on LMFBR to the near exclusion of alternate breeder concepts, particularly since the rest of the world is putting all its bets on the liquid metal concept.

It is conceivable that the future needs of the nuclear industry will be served by fusion, but that remains to be proved. Although research on fusion has made very significant advances within the past few years, it has yet to demonstrate scientific and engineering feasibility. If it appears that the federal share of R & D funds going into relatively long-range programs such as the breeder or fusion is disproportionately high, this in itself does not necessarily constitute grounds for criticism. The government must assume special responsibility for projects that are too risky to attract sufficient private investment or that warrant, in the public interest, faster development than would be forthcoming through the natural forces of the marketplace. Nevertheless, it is perfectly valid to ask whether other promising sources of energy are being neglected because of our preoccupation with nuclear power.

Alternative Sources of Energy

Solar radiation is certainly a prodigious source of energy. Integrated over the continental masses, solar flux amounts to approximately 1000 Q per year, which should be compared with the 225 mQ the world now consumes. Federal support for solar energy research has been relatively meager in the past, but there has been a sharp reversal within the last 3 years, and its budget has grown by leaps and bounds. Whereas our technological society is accustomed to concentrated sources, solar energy is diffuse; it will take some time and considerable advances before we may expect solar energy to have a major impact. On the other hand, some applications are in almost full-scale commercial use. Heating homes by solar energy is feasible in some localities today, and cooling should be practical shortly. Space conditioning of low-slung commercial structures is also possible. Here, again, the government could step outside the narrow confines of R & D and stimulate public adoption of solar space heating and cooling by devising appropriate incentive programs. Some 20 percent of our total fuel requirements go into heating and cooling buildings. If 10 percent of this amount could be supplied by solar energy by 1980 (admittedly an ambitious target), it would represent saving the equivalent of about 1×10^6 barrels of oil per day.

Unless the promise of extracting heat contained in hot dry rocks under the earth's surface turns out to be a reality, geothermal energy is probably destined to remain of regional interest only. Readily developable dry steam fields like the one at The Geysers, California, are unlikely to be found extensively elsewhere. In some places, the Imperial Valley of California for example, salinity continues to be a troublesome obstacle. With additional effort it should be possible to develop these resources in a manner reminiscent of the way hydroelectric sites were developed. The two together, geothermal and hydroelectric, could grow in step with the increasing demand for electricity and continue to supply some 15 percent of the electric power generated for several decades to come.

Electricity

Nuclear energy, solar energy, and geothermal energy are considered primarily as sources for the production of electricity. The demand for electricity is growing so rapidly that the utility industry promises to become the single largest consumer of energy in the near future. The utility industry requires more than three units of primary energy input for every unit of electricity consumed. The inefficiencies inherent in the generation and transportation of electricity are made up for, in part, by its relative efficiency in end use. Nevertheless, electricity comes at a premium—the average customer may pay three to four times as much for electricity as for its nearest competitor, natural gas, on an equivalent energy basis.

Were electricity to be produced from such virtually inexhaustible sources as solar, geothermal, or nuclear fuels with breeder or fusion technology, its relative efficiency of energy conversion would be of little consequence to the total energy budget. There would be other considerations involved, however —primarily those of an environmental nature and, eventually, of an economic nature. Neither the industry nor its technological base is configured well enough at present to support a trend toward increasing dependence on electricity. This fact is recognized by both industrial and government planners, who are initiating programs that would radically change conversion technology, transmission, and distribution, as well as storage. Finding ways to minimize environmental impact is also high on the agenda. Organizational changes may be in the offing if and when the electric sector moves toward power park complexes and a national grid system.

Large concentrations of thermal energy need not be used exclusively to generate electricity; some believe that, in time, hydrogen will be produced from water by thermal catalytic or electrolytic methods at commercially attractive costs. Hydrogen may eventually become an alternative to electricity as a secondary form of energy.

Institutional Arrangements

At present, responsibility for implementing energy policies and R & D programs is still fragmented throughout a number of agencies within the Executive Branch. Congressional oversight of energy matters is divided among many committees. Planning and coordination are made difficult by the necessity for prolonged negotiations between groups with vested interests. From an organizational point of view, greater centralization would be desirable. At the same time, one wishes to be assured that combining energy activities under one roof would not lead to the supression of certain programs because of a loss in bargaining power.

The Administration has proposed creating a Federal Energy Administration and an Energy Research and Development Administration; the former would be an action center, while the latter would concentrate on R & D. Policy coordination between the two would presumably be carried out through the Office of the President. Eventually, these two organizations would be combined under a single, cabinet-level Department of Energy and Natural Resources.

Whatever the outcome of these reorganization plans, both the Executive and Legislative branches face difficult times in trying to organize themselves properly to meet the energy problems of the future. It is relatively easy to specify what should be done, but it is not quite as easy to reach agreement on how it should be done. The magnitude of the problems ahead is such that all attractive choices should be pursued to whatever degree is feasible and wise. Money for R & D does not appear to be the limiting factor at the moment. The requisite management, scientific, and engineering talent may be in shorter supply. Finally, we must find ways to translate with all speed the accomplishments of R & D into practical terms to the benefit of the economy and the public.

References and Notes

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