If we assume the current continuing downtrend in both drilling rate and finding rate, it is expected that domestic crude oil production 10 years hence will provide less than one half of the U.S. demand if demand continues to increase linearly. If it is assumed that the drilling rate will grow linearly for the next 10 years and equal the maximum achieved in 1956, that the finding rate will increase to correspond to the higher finding rates of the past, and that economic and political conditions will be favorable, it is expected that the U.S. domestic production could provide approximately 75 percent of the demand if that demand continues to increase linearly. Any technological breakthrough in exploration, drilling, production, or oil recovery; the discovery of a giant field; or substantial improvement in the economic incentives will reduce the gap between domestic crude oil production and demand.

There is a need, therefore, for urgency and commitment by government and industry to cooperate to solve this problem. It is essential to have a stable, satisfactory economic and governmental regulatory climate. Positive incentives are needed to expand exploration activities and to apply improved oil recovery techniques. More specifically, risk capital is needed to expand activities. This requires a fair return on total investment as well as anticipation of attractive earnings on current and future investments. Price incentives may provide part of the stimulus for such capital.

Complementing and supplementing these incentives, the government should provide a consistent and stable policy directed to encourage accelerated development of oil reserves and increased productivity. Of particular importance are policy issues relating to leasing, including government lands; to environmental conservation and ecological impairment; to production and product regulation; to import quotas; to price regulation, including petroleum, materials, and labor; and to taxation. The seriousness of the energy crisis necessitates practical "trade-offs" which must be instituted to stimulate activity and which can be modified as the solution to the problem evolves.

References and Notes

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7. The proposal to explore the continental shelves through establishment of a National Petroleum Resource Assessment Commission resulted from a meeting of a Geological Committee on Petroleum Resources in December 1973 at the California Institute of Technology, Pasadena, under the leadership of Harrison H. Schmitt, chairman. The committee members included Robert R. Berg, James Boyd, Daniel A. Busch, Mason L. Hill, Michael T. Halbouty, Barclay Kamb, Thane H. McCullough, Grover E. Murray, Richard P. Shelton, Caswell Silver, and Leon P. Silver.

Problems of Expanding Coal Production

John Walsh

Coal is dirty fuel, dangerous to mine underground, expensive to transport, and awkward to handle. It retains, in other words, the disadvantages that caused it to lose markets to oil and natural gas after World War II. In addition, a rapid increase in surface mining operations in recent years has inflicted environmental damage which has incited a campaign for effective controls that could limit expansion of strip mining. Now, of course, waning domestic supplies of oil and natural gas and rising international fuel costs have made coal relatively attractive again.

If the United States is to gain energy self-sufficiency—however defined—by the end of the decade, a prodigious increase in the production and consumption of coal will be necessary. The country has huge reserves of good quality coal. Conservative estimates put at 150 billion tons the coal recoverable by current mining methods. Project Independence, the federal government's plan for becoming "reasonably self-sufficient" by 1980, calls for an increase in coal production from 602 million tons in 1973 to 962 million tons per year in 1980. However, expanding the supply and use of coal, particularly in the short run, requires the successful clearing of a formidable array of environmental, technical, social, and economic hurdles.

These problems have been exacerbated by a lag in research in the coal industry. Attainable technologies, for conversion of coal to synthetic fuels, for example, have not been brought to maturity because of indifferent research and development programs. A defeatist attitude has contributed to the lag. Coal was dethroned by oil and natural gas after World War II, and the conventional wisdom was that nuclear energy was the long-term energy source. It is still hard to convince coal industry veterans that coal is the fuel of the future rather than the fuel of the past.

For the coal industry and for the electric power industry that uses about two-thirds of the coal consumed domestically, the major immediate issue is air pollution. One of the chief accomplishments of the environmental movement, which crested in the 1960's, was fostering the passage of the Clear Air Act of 1970. Provisions of the act scheduled to go into effect next year set standards for sulfur emissions which, in effect, would rule out the use of a major portion of the coal from the fields that now supply power plants in the East. The chances that the Clean Air Act would be fully enforced on schedule virtually vanished in the winter energy shortage. Several states have already relaxed their own air

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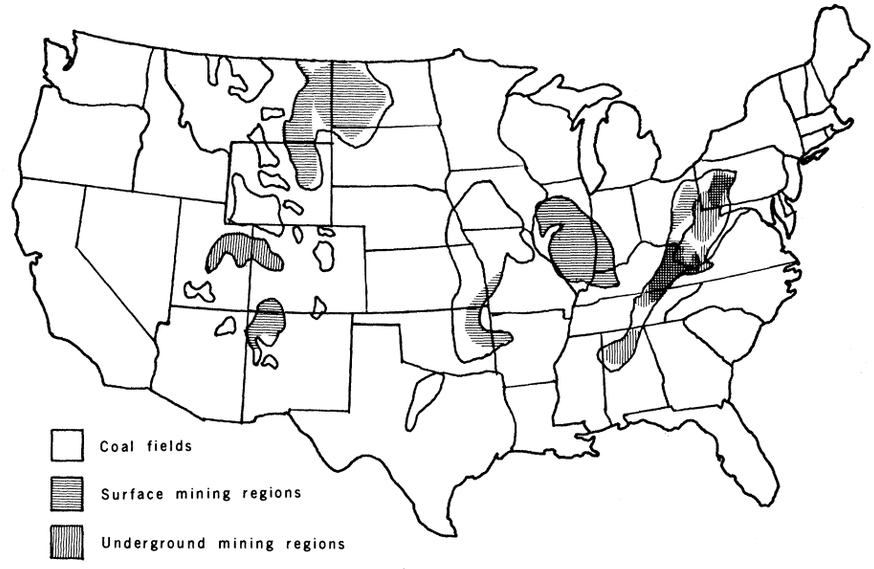
quality standards and federal energy administrator William E. Simon has called for the setting aside of some secondary air quality standards for a 5-year period. The real question now for the government seems to be how drastically and for how long to postpone effective air pollution controls.

The coal and power industries have been pushing hard for policies they say are necessary to permit the rapid expansion of coal production in the years immediately ahead. Coal industry spokesmen like Carl E. Bagge, president of the National Coal Association, recently have been most active in opposing tighter regulation of environmental damage as proposed in strip-mine legislation (H.R. 11500) now under discussion in Congress. But the industry also continues to exert strong pressure on government policy-makers to postpone air pollution controls.

The coal industry feels insecure about the firmness of the nation's new commitment to coal and argues that the industry needs solid guarantees from government before it can attract the investment capital that will be needed. What it asks is that coal be given status as a kind of most-favored fuel. The industry's two basic demands are (i) that relaxation of air quality controls be set for long enough to persuade Eastern power companies to convert to coal and for mining companies to invest the large sums required to expand supplies, and (ii) that strip-mine regulations not prevent large-scale surface mining in the Western coalfields.



Major coal reserves and mining areas in the United States.

Clean Air Act Levels

The practical possibilities of meeting Clean Air Act standards by preventing sulfur emissions that exceed the standards of the act are largely discounted by the power industry, at least for most of the rest of the 1970's. Industry generally takes a more pessimistic view of sulfur-removal technology than do other knowledgeable sources (a full discussion of sulfur removal follows in an article on page 346) but there seems to be genuine uncertainty about when fully reliable, commercially feasible equipment will be available for installation. Industry sources are also skeptical about the likelihood of achieving significant new energy sources by 1980 through conversion of coal to synthetic fuels. Development of synthetic fuels through coal gasification and by synthesizing liquid fuels from coal is a major element in Project Independence. Industry attitudes appear to be influenced by fears that contemplated use of Western coal for large-scale coal conversion operations may be undercut by restrictions on strip mining and by problems of securing the large supplies of water required in the conversion processes (*Science*, 2 November 1973).

Problems of the environment and of the state of the art are by no means the only ones that affect the expansion of coal production. Human factors will also exert strong influence. Higher coal production in the next few years will require increased output from existing underground mines and the opening of new mines. A major increase in the work force will occur at a time when the labor relations in the coal industry have entered a period of uncertainty. Productivity has declined in recent years. Industry attributes this in part to the requirements of the Coal Mine Health and Safety Act of 1969, but probably more significant is that coal mining, as much as any occupation in the United States, is being affected by deep currents of social change. These changes are symbolized as well as anything by the attempts to reconstruct the United Mine Workers of America (UMW) by a reform union administration which now faces its first contract negotiations with the bituminous coal industry. Many observers feel that the ingredients are present for a period of unrest in the coalfields unmatched since the turbulent years after World War II.

What all of this means is that devising a strategy for coal as a component of a national energy policy will not be easy. In the past, major coal industry decisions have been based on judgments of profitability. How and to what extent the federal government is to influence such decisions in the future has not been made clear. A key question which must be answered, for example, if Project Independence is to achieve a significant degree of reality, is, What will the government do to induce the coal industry to create a capacity for producing synthetic liquid fuels which are intensely vulnerable to price competition from oil?

A policy of increasing coal production entails hard decisions on what kind of coal to mine, where to mine it, and how to mine it. American coal varies greatly in accessibility, in heat values, and in geochemistry. The coalfields of the United States can be grouped roughly into three regions with different kinds of coal, different mining problems, and different options for coal use. The oldest major mining region, which stretches along the line of the Appalachians from Pennsylvania to Alabama, has large deposits of good quality bituminous coal, including valuable metallurgical or coking coal marketed widely here and abroad. Appalachian coal generally has a high heat value, but only about 20 percent of available deposits is thought to meet the maximum 0.7 percent sulfur content which the Clean Air Act sets as a primary standard. Underground mines are characteristic of Appalachia, although there has also been extensive strip mining including destructive

"contour stripping" on the region's steep hillsides.

The "midcontinent" region is comprised primarily of areas in western Kentucky, Indiana, Illinois, and Ohio. Surface mining is dominant here. Midwestern bituminous coal has a large market as a fuel for big power plants, but has a high sulfur content which has begun to limit its markets in areas where air pollution regulations are stiff.

The largest reserves of Western coal are subbituminous and lignite varieties found in the tier of Rocky Mountain states, although mining operations seem to be increasing in the Southwest. Western coal has a relatively low heat value compared to coal found east of the Mississippi, but it is low in sulfur. High transportation costs seem to make it unlikely that great quantities of Western coal will be shipped out of the region. Already, however, power companies are generating electricity from big plants literally in the coalfields, and Western coal is regarded as logical raw material for a coal conversion industry. Opening of a real coal rush in the West has been delayed, however, at least until the debate on strip-mine reclamation is settled and until investment prospects on synthetic fuels are clearer. Government policy on leasing federal lands for mining will also be particularly significant in the West, where much coal land is federally owned.

In recent years, about two-thirds of the nation's coal has been mined in the Appalachian region, including Ohio, but production has been increasing more rapidly in the Midwest, which has accounted for about a quarter of production, and the West, which produces most of the rest.

Industry decisions are likely to continue to be influenced by a strain of caution and pessimism which is the legacy of the coal industry's experience since World War II. This period for coal was one of slump and partial recovery. Coal production last year was almost exactly what it was in 1947. Employment in bituminous coal mining, however, fell from about 400,000 to perhaps 150,000 last year. The loss of markets for coal occurred rapidly starting in the late 1940's, when oil and natural gas became widely available as a result of expanded production during the war and the coming of the big pipelines. Coal rapidly lost the markets for domestic heating and railroad fuel. The late 1940's were years of serious labor trouble in the industry. So severe did the disruptions become that the government at some points took over the mines. The dominant figure in this era was John L. Lewis, who had guided the UMW through the violent organizing campaigns of the 1930's and exercised virtually unquestioned authority over the union.

By the early 1950's unemployment was making deep inroads in the miners' ranks and Lewis abruptly changed tactics to accord with a fundamental change of policy. He decided to embrace mechanization of the mines, which meant a smaller but better-paid, unionized, work force with relatively secure employment. In a few years, typical mining methods changed from the traditional system in which miners blasted coal from the coalface and then loaded it by hand into carriers to a highly mechanized "continuous mining" operation. Productivity climbed, but demand for coal kept falling until it reached a low point of about 400 million tons in 1958. The industry pacesetters in this period were the so-called "captive" mines owned by major steel companies, utilities, and railroads which used the coal from their mines exclusively for their own use. These corporations had the resources to carry out mechanization and offer relative security to miners, while employment of miners continued to drop in the industry as a whole.

Coal production turned up in the early 1960's, if sluggishly, reaching 512 million tons in 1965 and 602 million tons in 1970. What mainly revived demand was the new, coal-using technology in big power plants.

Coal Industry Changes

The shape of the coal industry altered drastically in the 1960's. Surface mining produced a rapidly increasing proportion of coal output (coal production now is divided almost evenly between deep mines and surface mines) and a new pattern of ownership developed. Coal companies were taken over in growing numbers by conglomerates. Often, these were "integrated energy companies," in many cases oil industry "majors."* These corporations were aware that domestic fossil fuel supplies were dwindling and were astute and rich enough to hedge their bets. The big companies, especially, have been attracted by the prospect of converting low-sulfur Western coal to synthetic fuels and are said to control reserves of 25 billion tons of low-sulfur, strippable coal.

These takeovers by "outsiders" are deplored by some critics as creating the conditions for energy monopolies. (On 1 April the Supreme Court let stand a Federal Trade Commission decision that Kennecott Copper should divest itself of Peabody Coal on the grounds that the acquisition in 1972 violated antitrust laws.) It is usually conceded, however, that the new owners, particularly the oil companies, have both the inclination and the resources to bolster the coal research effort. The general industry explanation for its poor research record in the past is that profits on coal have been too low to finance a major research effort. Certainly, the industry was not attuned to seeking salvation in the laboratory, and this listlessness appears to have been reflected in government-sponsored research on coal as well. Relatively small sums have been available over the years for coal research administered by the Interior Department's Bureau of Mines and the record has not been brilliant. In the late 1950's the survival instinct did make the coal industry bestir itself and seek a fresh start on government-financed coal research. The result was establishment of the Office of Coal Research (OCR) which is part of the Interior Department, but separate from the Bureau of Mines. Starting with initial funding of $1 million in fiscal year 1961, OCR's budget rose relatively slowly during the halcyon days of research in the 1960's (the figure was $6.8 million in 1966) but entered its own period of exponential growth with the energy shortage. The budget for fiscal year 1973 was $43.5 million; in the current year it is $123 million, and the estimated budget for next year is $283 million.

Bureau of Mines research has characteristically been in-house research while most OCR research has been contract research with industry. Contributions by industry to cooperative research projects with OCR next year will amount to an estimated $100 million.

One of the explanations for the lackluster record of coal R & D is that moving from the laboratory and pilot plant stages to commercial application

* Some of the bigger acquisitions were Consolidation Coal (which produced 60 million tons of coal in 1973) by Continental Oil; Peabody Coal (69.5 million tons) by Kennecott Copper; Island Creek (24.5 million tons) by Occidental Petroleum; and Ayrshire Collieries (16.6 million tons) by American Metal Climax.

of a process is a difficult and expensive proposition. Federal research funding has until recently been inadequate to finance crucial pilot plants and demonstration plants. Coal gasification, for example, is the synthetic fuel process thought to be nearest to commercial application in the period between now and 1980. The basic technology was developed by the Germans to meet the necessities of World War II. (Coal gasification technology is discussed in the article on page 340.) Industry sources predict economic production of synthetic gas by 1978, although the prediction seems to be based on the assumption that surface mining in Western coalfields will be expanded to provide coal for gasification.

Prospects for production of liquid fuels from coal appear more distant. The consensus seems to be that considerable additional laboratory and pilot plant work will be necessary. The exception appears to be methanol, a clean-burning liquid fuel with about half the heat value of kerosene. Methanol can be produced by an adaptation of the technology for making high-Btu gas. The resulting methanol would be suitable, for example, for use as boiler fuel or perhaps jet fuel.

The crucial questions about synthetic fuels seem to be economic rather than scientific or engineering questions. To get through the demonstration plant stage into commercial production, it may be necessary for the government to pay producers in the synthetic fuel industry the difference between the market price and production costs. Formulation of federal policy on this point is in the very early stages, and there appears to be stiff resistance at top policy levels to a costly, long-term government support program for synthetic fuel producers. The alternative to such a program, however, may be no significant synthetic fuel production.

The main technical problem facing the coal industry is dealing with coal's sulfur content. It is theoretically possible to remove sulfur from coal before, during, or after burning. The present strong consensus is that the best hope for controlling sulfur emissions in this decade lies in the improvement of stack gas scrubbing processes now being developed (see page 346 for a discussion of sulfur-removal technology). One practical difficulty is that the power industry, which is the major user of high-sulfur coal, looks on stack gas scrubbers as expensive and unreliable. A National Academy of Sciences study panel in 1970 reported† that a "commercially proven technology for control of sulfur oxides from combustion processes does not exist." Despite substantial investment in development work since then, informed opinion is that 2 or 3 years more will be required before it will be possible to identify the best operational system. The word in the industry is that none of the available scrubbing equipment works for more than 2 months without a complete teardown, and that the need for self-cleaning hardware will not be met for at least several years.

A Mass of Uncertainties

Energy planners are faced with a mass of uncertainties similar to those that inhibit sulfur removal. If Project Independence is to be more than a slogan, however, effective long-term planning is obviously required. Until now, federal energy officials have dealt mainly with allocation of existing fuel supplies, with conservation programs, and with efforts to increase the output of present energy sources. Particularly for the period between now and 1980, national energy policy means a national fuel policy. And it is widely agreed that coal will play an increasing role in such policy.

The extent of that role will be heavily influenced in the next year by decisions made on pending strip-mine legislation and on implementation of the Clean Air Act and the Coal Mine Health and Safety Act. These decisions will be made under heavy pressure from the coal and power industries for what amounts to an environmental moratorium. The industry attitude is expressed, for example, in the remark of the Coal Association's Bagge that the nation "can say goodbye to the idea of a synthetic fuels industry based on coal" if Congress sharply curtails surface mining.

Labor relations may be the unanticipated catch in expanding coal production. The new leaders of the UMW are fighting a two-front war. They are working to restructure the union on democratic lines. At the same time they are seeking to win a contract for their members in the bituminous coal industry with advances in wages, working conditions, and fringe benefits that would make up ground the leaders felt has been lost in past years. There is no reason, incidentally, to doubt the seriousness of the union's new president, Arnold Miller, in stating the view that coal should be mined safely or not at all. It seems very possible that contract negotiations between the union and the coal companies could produce a major confrontation which would soon involve the government.

Expanding coal production in the 1970's is not, therefore, just a matter of decisions by high-level federal officials about what share of needed energy should be supplied by coal, as compared with oil, natural gas, or nuclear power. Perhaps surprisingly, many informed people express greater doubts about attaining the energy goals of 1980 than reaching the higher levels of 1985, perhaps because prospective investments in R & D are expected to pay off by then. With respect to coal in a national energy policy, then, the questions remain elementary ones: Can we mine it and can we burn it?

† Ad Hoc Panel on Control of Sulfur Dioxide from Stationary Combustion Sources, *Abatement of Sulfur Oxide Emissions from Stationary Sources* (National Academy of Sciences–National Research Council, Washington, D.C., 1970).