pressure and permit twice that price as the going rate." (It is not our intention to comment editorially on the subject of excess profits, but merely to recognize that controversy surrounds the topic. For example, Alaska's Governor William Egan has charged that the oil industry has amassed great wealth around the world because of "a license to steal other people's resources," promising that this would not happen in Alaska with regard to the anticipated pipeline. The Governor's concern is not so much with cost to the ultimate consumer, but rather that the state gets a substantial share of the profits from the pipeline.)

But the joker in the deck, insofar as economics is concerned, is the industry's contention that the FPC either does not know or underestimates the cost of providing natural gas. This may be true – but because all such figures emanate from the oil industry, no outsider, even Government, has facts which can dispute the industry-provided figures. As a result, all present indications point toward a substantial increase, sanctioned by Government, in the price of this vital fuel.

Relief from Alaska?

Gas under the roof of the world. A recent Government report, "Potential Supplies of Natural Gas in the United States," estimated that there is about 325 trillion cubic feet of natural gas deposits in Alaska (as compared with an estimated 850 trillion ft^3 in the entire contiguous 48 states).

Currently, there are three principal study groups—including major U.S. and Canadian gas companies—conducting comprehensive analyses of feasible overland pipeline routes (Fig. 4) from Prudhoe Bay (North Slope) to various regions of the "lower 48." Each group tends to feel that the economics of such a complex gas pipeline project for transmitting the Alaskan fuel can compete favorably with other forms of energy found in the contiguous United States.

Further, the leaseholders of the major Prudhoe Bay discoveries have stated that nearly all gas deposits found to date are associated with the vast oil reserves of the region. In other words, the known gas deposits exist either as gas dissolved in the oil or in the form of "cap gas" overlying the oil. Thus, in neither case is it feasible to extract the gas without tapping the oil.

The same geological formation, however, that created the Prudhoe Bay oil and gas areas extends into northern Canada (Fig. 4). Because of this, extensive new pipeline construction is being proposed to transmit gas from Canada's Northwest Territories to ready markets in the United States. Estimates indicate that this billion-dollar effort could provide U.S. consumers with an additional supply of 1.5 billion ft^3/day.

At this time, the major study groups are also making analyses of overland gas pipelines from the Northwest Territories to the lower 48 states. Militating against the overall scheme, however, are controversial ecological and environmental considerations; factors such as soil stability, permafrost regression, and wildlife habitats in Alaska must be seriously contemplated.

Liquid natural gas. Liquefied natural gas (LNG) in small, but ever-increasing percentages, is being supplied by importation to the U.S. in special cryogenic tanker ships from Libya, Algeria, Venezuela, and other overseas gas-producing regions. The gas is liquefied by cooling it to 147°K. In its liquid state, the gas occupies less than 0.2 percent of its gaseous volume. Very large investments are presently being made in the construction of storage facilities to make LNG available at least in coastal cities of the U.S. (However, the LNG land-based storage facility program, especially in densely populated areas, suffered a severe setback last February when 40 workmen, who were cleaning an empty tank, were killed in an explosion and subsequent fire of undetermined origin.) Several of the unique tanker ships are now in service and more are under construction for service by 1975. And, in 1985, a fleet of 80 such vessels should be available for LNG transport. In all probability, however, LNG will continue to be used for power peaking only.

Coal gasification. Figure 5 is a simple flow diagram of the basic coal-gasification process. Although the illustration is straightforward, the technique encompasses a complex chemical transition of solid coal into a form of natural gas. Essentially, boiler-produced steam is reacted with the carbon in coal to form a hydrogen-enriched gas similar to methane (CH_4). But in the reaction, ammonia (NH_3), carbon dioxide (CO_2), and hydrogen sulfide (H_2S) are also produced. In the following sequential steps, the gaseous products are treated, cleansed, and purified to remove the NH_3, CO_2, and NH_3, and leave a "methanate" consisting of CH_4, hydrogen (H_2), and carbon monoxide (CO). The methanate, however – although combustible—is low in calorific content by comparison with "natural" natural gas.

The ultimate, and most difficult, phase of the process is to increase the calorific content of the basically CO gas by further chemical reactions with H_2 to raise the methane content. This is accomplished at

The King is dead . . .

Old King Coal has a dirty old soul . . .
In a hole in the ground lives he
He smells from his smoke.
And he coughs from his coke.
And he pulls for his polluters three
(particulates, fly ash, and SO_2).

Jane Stein,* writing in the February 1973 issue of the *Smithsonian*, puts it this way:

"After decades of declining production and increasing disfavor, coal, our most abundant energy resource [is] staging a comeback. It is one of the ironies—and dilemmas—of our environmentally aware age that we will use more, not less, of this filthiest of fuels. . . . Strip mining, although twice as safe as [pit] mining, has left lunarlike landscapes . . . polluted rivers and water supplies . . . . The blight of coal continues into the burning process, befouling the air with 66 percent of the 14 million tons of SO_2 discharged a year by U.S. smokestacks . . .

"In desperation over coming energy shortages . . . planners are turning again to dirty but ever-abundant coal, found in 38 states with some 1.5 trillion tons of it still [underground]—more than 1000 years' worth at today's recovery and consumption levels . . ."

*Copyright 1973 Smithsonian Institution from Smithsonian Magazine, February 1973.

temperatures of about 1100°K, and very high pressure (more than 65 atmospheres).

The first pilot plant in the U.S., designed to convert coal directly into pipeline-quality "natural" gas, is presently in operation in Chicago. This plant will determine the feasibility of coal gasification over the next several years.

Development of a viable coal-gasification process will release a major new source of gas supply. It is estimated that, by means of economic conversion, about 11 000 trillion ft³ of such gas could become available—enough to supply the gas-energy needs of the U.S., at present consumption rates, for 500 years!

Oil: 43 percent of the pie

As we have noted, the supplies of oil and natural gas are closely interrelated since gas is generally found in connection with petroleum deposits. By referring again to Fig. 1, we see that oil commands the largest slice (43 percent) of the total energy pie. But this past winter also witnessed a dearth of light fuel distillate—which includes oil for domestic heating—and a similar shortage occurred in supplies of jet aircraft (kerosene base) and diesel-engine fuels.

Fortunately, for the areas in which acute shortages were felt, state agencies promptly jumped into the breach to form emergency fuel-distribution pools. Further, a generally milder-than-expected winter in the affected regions helped to mitigate the crisis.

. . . But plenty of gasoline. However, if there was a scarce supply of these products of fractional petroleum distillation, it was certainly not noticeable in the abundance of gasoline available for motor vehicles. The reason for famine pockets in the overall fuel feast is that petroleum refiners are reaping much higher profits from the production of gasoline than they are from fuel oil (which had been subject to Phase 2 price controls).

For example, during the first week of January 1973, U.S. refineries produced 45 million barrels of gasoline versus 21 million barrels of oil for domestic heating—a ratio of more than 2 to 1. Thus it does not require a quantum jump in the power of prediction to conclude that, under Phase 3's loosening of the price-control reins, more fuel oil will be available—at a higher cost. Nevertheless, industry, the utility companies, and commercial enterprises fear the continuation of an uncertain fuel-supply situation in which sporadic short-term shutdowns may be inevitable this year.

The import quotas. One of the primary elements underlying the fuel oil quandary is the fact that the U.S. Government controls the domestic oil supply by restricting the amount of petroleum U.S. companies can import from overseas. These import quotas were introduced back in 1959 for the dual purpose of

- Serving as a national defense measure to ensure an adequate domestic supply and reserve.
- Providing a protective barrier to keep out the cheaper oil from the Mideast and South America.

Ironically, the impact of the quota has been to keep domestic oil prices high and supplies low. In this way, the protectionist safeguard—as well as the national defense consideration—has backfired. Actually, overseas oil is so plentiful and inexpensive that much more of it would be imported, except for our complicated quota restrictions. (In sections of the Mideast, oil is extracted at a cost of 20¢ a barrel—contrasted with $2.00 per barrel in the U.S.)

But, in a reversal of a 13-year policy, the U.S. Government—because of the fuel oil crisis—was forced to relax the quotas over a four-month period last winter and increase the overseas importation of home-heating oil by one million barrels a day. One of the paradoxes of the Government's theory that more investment should be applied to the domestic exploration and production of petroleum is that many major U.S. companies have gone overseas to build their refineries—notably in the Caribbean, Venezuela, and the Middle East—for two salient reasons:

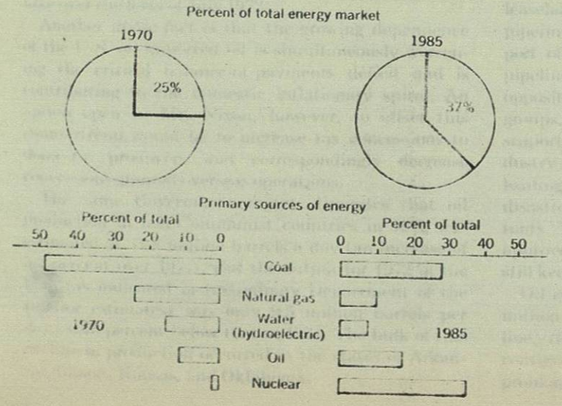
1. There is a larger supply of crude oil *outside* of the U.S.

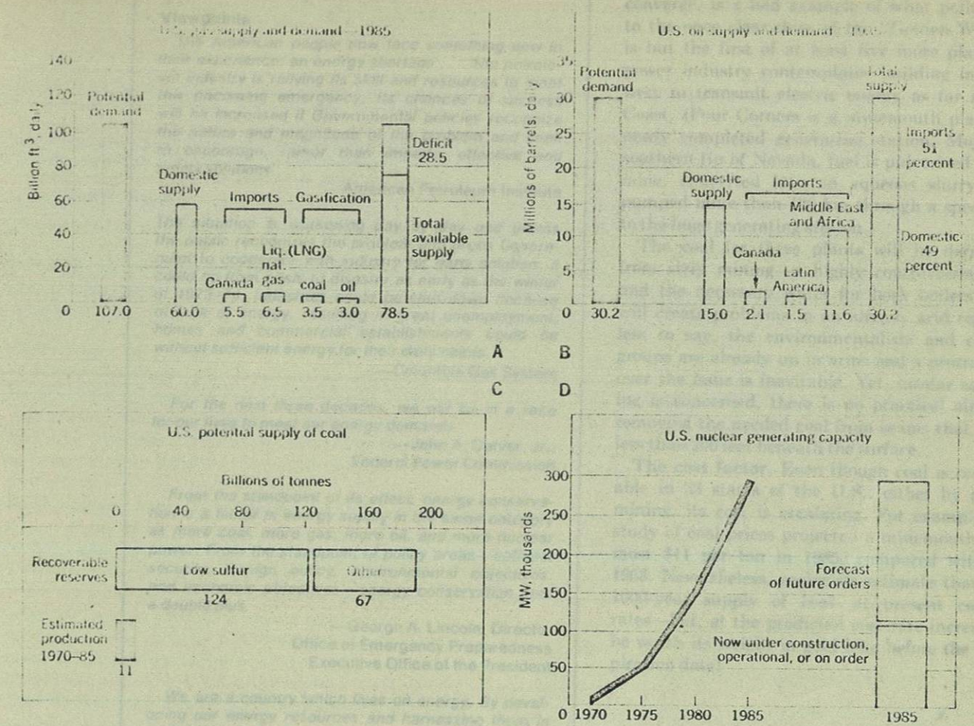
2. Taxes on a U.S. oil company's overseas profits are *lower* than taxes on its domestic enterprises.

Too little too late? In 1970, a Nixon-appointed task force estimated that import quotas forced the price of domestic oil up by $5 billion a year (representing an extra fuel bill of $24 annually for every U.S. citizen).

Unfortunately, under rapidly changing economic conditions—notably the devaluation of the dollar, sharply increased royalty payments demanded by overseas sources, and much higher transportation costs—imported oil is hardly the bargain it used to be. In fact, an article in *The New York Times* of March 5, 1973, alleged that an unpublished U.S. Government study indicates that U.S. refineries now pay more for some overseas crude than for domestically produced oil. This information has apparently been confirmed by oil industry sources. The primary reason for this surprising cost reversal is that demand (on a worldwide basis) was more than supply in 1972. As a

[6] Energy usage by electric utilities in the U.S. Left-hand portion of graph shows the percentages of various energy sources as of 1970; right-hand graph indicates the projected percentages of these same sources in 1985.





[7] A—Projected natural gas supply and demand (in terms of billions of cubic feet daily) from all sources—and artificial processes—by 1985. B—A similar projection with respect to the oil situation 12 years hence. C—Horizontal bar chart of estimated coal reserves. D—Projection of nuclear generating capacity between 1970 and 1985.

present cost example, Libyan crude oil transported to the port of Baton Rouge, La., commanded a price of $4.36 per barrel as of March 1, compared with a top price of $4.07 a barrel for domestic offshore oil. Further, the Libyan price represented a 90¢ per barrel hike over the level of July 1972.

Another ironic fact is that the growing dependence of the U.S. on imported oil is simultaneously worsening the critical balance-of-payments deficit and is contributing to the domestic inflationary spiral. An option open to Mr. Nixon, however, to offset this countertrend would be to increase tax concessions to domestic producers and correspondingly decrease concessions granted overseas operations.

The same Government report stipulates that oil production in non-Communist countries in 1972 was estimated at 41.8 million barrels a day (an increase of [illegible] percent over 1971). But the output for 1972 in the U.S. (as indicated in preliminary Department of the Interior estimates) was only 9.5 million barrels per day—0.75 percent below that of 1971. The bulk of this decline in production occurred in the states of Arkansas, Illinois, Kansas, and Oklahoma.

The U. S. already imports more than 25 percent of its oil and, according to virtually every survey, future energy requirements will, by 1985, double that percentage (Fig 6). Clearly some sort of Federal action must be taken. [*Editor's note:* At press time, President Nixon had announced that he had acted to terminate the oil import quotas.]

The trans-Alaskan pipeline. Since the discovery of large oil deposits in the Prudhoe Bay region of Alaska's North Slope several years ago, the major oil leaseholders have been trying to build a 1300-km-long pipeline to transport the crude from its source to the port of Valdez on the Gulf of Alaska. The proposed pipeline, however, triggered a widespread storm of opposition from conservationists and environmental groups, and the seafood interests at Valdez—a major seaport for the Alaskan fishing fleet and canning industry—who fear that oil spills from supertankers loading at the terminal end of the pipeline would be disastrous to the existence of the town and its inhabitants. Thus, although the pipeline scheme has been approved by the Interior Department, litigation is still keeping the construction project in limbo.

Oil company experts estimate that a peak of 2 to 3 million barrels per day could flow through the pipeline, thereby easing the petroleum situation in the contiguous 48 states. But some authorities on fuel problems question, aside from environmental consid-

Viewpoints

The American people now face something new in their experience: an energy shortage . . . The petroleum industry is rallying its skill and resources to meet this oncoming emergency. Its chances of success will be increased if Governmental policies recognize the nature and magnitude of the problem and seek to encourage, rather than impede, effective and timely solutions

—American Petroleum Institute

The situation is worsening day by day and unless the public recognizes the problem and urges Government to cooperate with industry for early solution, it could go from crisis to disaster as early as the winter of 1973-74. Industries could be shut down because of lack of energy, resulting in great unemployment; homes and commercial establishments could be without sufficient energy for their daily needs.

—Columbia Gas System

For the next three decades, we will be in a race for our lives to meet our energy demands.

—John A. Carver, Jr.,
Federal Power Commission

From the standpoint of its effect, energy conservation is a factor in energy supply in the same category as more coal, more gas, more oil, and more nuclear power. From the standpoint of policy areas—national security, foreign policy, environmental objectives, and economic objectives—energy conservation gets a double plus.

—George A. Lincoln, Director
Office of Emergency Preparedness
Executive Office of the President

We are a country which lives on energy. By developing our energy resources and harnessing them in machines, we have achieved a standard of living that is far beyond the dreams of most of mankind for most of history. Overwhelming evidence points to the fact that a close correlation exists between living standards and energy use. Not surprisingly, nations with the highest living standards also rank at the top in per capita energy use.

—Edison Electric Institute

Crude oil reserves in the lower 48 states are now at the lowest point in 20 years, while natural gas reserves are at the lowest since 1957.

—Mobil Oil Company

erations, whether the trade-off of the large investment in building the pipeline versus the limited number of years of peak production is worthwhile.

Coal: up from the ashes

Paradoxically, coal, the most polluting of the fossil fuels, is also the most plentiful source of energy and it presents the U.S. with its major hope of meeting the fuel/energy crisis. It is still used to fire boilers for the generation of 55 percent of all steam-electric power in the country—although it accounts for only 20 percent of the total energy pie in Fig. 1. The controversial "Four Corners" plant (see p. 20), situated where the states of Utah, Colorado, Arizona, and New Mexico converge, is a bad example of what pollution can do to the once clear skies of the "Golden West." And it is but the first of at least five more plants that the power industry contemplates building in the Southwest to transmit electric energy as far as the West Coast. (Four Corners is a minemouth plant, but at a newly completed generating station, Mojave, at the southern tip of Nevada, fuel is pulverized at a distant mine, converted into an aqueous slurry, and then pumped more than 430 km through a special pipeline to the huge generating station.)

The coal for these plants will be derived mainly from strip mining—a highly controversial method—and the necessary water for both boilers and slurry will create problems in an already arid region. Needless to say, the environmentalists and conservation groups are already up in arms and a protracted battle over the issue is inevitable. Yet, insofar as strip mining is concerned, there is no practical alternative to removing the needed coal from seams that are usually less than 200 feet beneath the surface.

The cost factor. Even though coal is readily available in 38 states of the U.S., either by pit or strip mining, its cost is escalating. For example, a recent study of coal prices projected a minemouth cost of almost $11 per ton in 1985, compared with $3.92 in 1968. Nevertheless, geologists estimate that there is a 1000-year supply of coal—at present consumption rates—but, at the predicted cost-rate increase, it may be worth its weight in gold long before the supply expiration date!

Nuclear: increasing—but too slowly

The energy crisis in the U.S. is getting more acute because we are not able to maintain our nuclear generating plant construction program according to plan. For example, at the beginning of 1972, nuclear generation was behind schedule by 15 000 MW; by January 1, 1973, the deficiency had doubled to about 30 000 MW. Present indications are that the deficit will become increasingly severe with the passage of years. Thus our already strained fossil-fuel reserves are dealt another setback, because each 10 000-MW annual deficiency in nuclear generation requires that 100 million more barrels of oil must be consumed as a substitute. At present, the annual shortage in the U.S. is some 300 million barrels—or about 820 000 barrels per day.

But, over the long haul, we may be in even more serious nuclear trouble because present state-of-the-art generation by nuclear fission is only a temporary answer. Although the U.S. *now* has a surplus of uranium ores, there may be a shortage by 1990—unless a major push is made in developing an operational fast-breeder reactor (FBR), or there is a dramatic breakthrough in power generation by nuclear fusion. Hopefully, both the AEC and the Federal government are now committed to an all-out effort to achieve these objectives.

Figure 7 consists of bar graphs that indicate and project (1) gas supply and demand, (2) oil supply and

Editor's note: This is the introductory article of a series in which qualified authors will present their diverse viewpoints on the fuel and energy crises. This first article presents an overview of the general situation, including some options representing possible solutions to the problems. Subsequent articles will elaborate upon the views of those active in the power industry, fuel production, government, and environmental protection. It seems inevitable that the series will generate controversy, which, hopefully, may encourage dialogue leading to a positive energy policy and program.

demand, (3) potential supply of coal, and (4) nuclear generating capacity in the U.S. between the years 1970 and 1985.

Other sources of energy

Among the short- and long-term practical source development possibilities[1] are solar energy, geothermal energy, chemical batteries (such as lithium-sulfur), and fuel cells. Their merits have been discussed in some detail in previous *IEEE Spectrum* articles by this writer and other authors. Suffice it to say, these R&D programs generally suffer from either a less than all-out commitment or lack of adequate funding from both Government and private sources—or both.

However, according to Charles A. Zraket, of the Mitre Corporation, the two options for the long term (year 2000 and beyond) that should be pursued much more vigorously include solar energy for large-scale power needs, and the possible use of hot, dry rock from geothermal sources well below the surface of the earth (from 3000 to 5000 meters deep) as a regional supplement for energy. He points out that a solar energy system has already been studied that will produce hydrogen fuel, which can then be used in the "hydrogen economy"—notably for fuel cells.

In the nuclear energy area, he contends that, in addition to the liquid-metal fast-breeder reactor (LMFBR), much more emphasis—for both environmental and economic reasons—should be placed on the high-temperature gas-cooled reactor, the heavy-water reactor, and the molten-salt breeder reactor. Also, more R&D should be given towards fusion reactors, especially laser function.

By the turn of the 21st century, Zraket believes that nuclear energy will be used for the base load in the overall energy system—including both electric power needs and as a source for powering electrified vehicles and mass-transit systems. Finally, he feels that the international implications of the nuclear fuel cycle must be addressed with respect to uranium enrichment and the processing and transportation of fuels and waste.

A guessing game in oil and coal

As long as decisions are being made under the improvised energy policies that were devised before the urgent need for a national "master plan" became apparent, the U.S. can neither address nor accurately assess the dimensions of the fuel/energy crisis. Thus there is an uneasy feeling in some quarters that present policies are contradictory, outdated, and outmoded.

In the realm of "guesstimation," we have seen a plethora of reports (seldom in agreement) from Governmental agencies and private organizations as to whether there is really an energy crisis, a shortage of fuels, and an inevitably upward price surge. (In this context it is interesting to note that last March the Administration reimposed controls on gasoline, restricting this fuel to a 1.5 percent maximum price increase to ensure more production of oil for domestic heating and industrial use.)

Meanwhile, Sen. Henry M. Jackson (D-Wash.), chairman of the Senate Interior Committee, resumed hearings last February 22 on the committee's examination of the present fuel shortages. The hearings were held as part of the U.S. Senate's National Fuels and Energy Policy Study authorized by the 92nd Congress. In Jackson's words: "There has been an apparent breakdown in our national energy system. Serious shortages still persist in many parts of the country. The committee needs to know why it has not been possible to anticipate and meet the demand for various fuels. We are particularly interested in what role Government policies have played in creating the present situation."

On April 10, Sen. Jackson released a staff analysis of Federal energy organization, prepared for the Senate's national fuels and energy policy study. At the time, Sen. Jackson expressed surprise that until very recently almost no formal consideration was given to the manner in which the Federal government is organized to administer energy policy. He alleged that, when the Senate study began, there was not even a good description of the existing Federal energy organization available!

Continuing on this theme, he said, "in the course of its study . . . the staff has identified 64 agencies which administer programs or implement policies that probably were not intended to be energy oriented . . . There is little doubt that this multitude of agencies can be better organized and directed that it has been in the past. It is increasingly clear that, as new, more comprehensive national fuel and energy policies are developed, the implementation of these policies will depend upon a more effective organization . . ."

Based on Sen. Jackson's statements, and other critical analyses, there will inevitably be those who will call for a centralized Federal "Fuel and Energy Agency," perhaps at Cabinet level, and similar in policy-making authority to the EPA. We undoubtedly will hear more of this and other proposals in subsequent articles in this series.

The source of the graphic information shown in Figs. 1 and 3 is the U.S. Department of the Interior, Bureau of Mines; the source of Fig. 2 is the American Association of Petroleum Geologists; and the source of Figs. 6 and 7 is the survey, "Outlook for Energy in the United States to 1985," prepared by the Chase Manhattan Bank.

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