A PROPOSED INDUSTRY INVENTORY OF OUR FUEL RESOURCES

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> *"The human proclivity for capturing an ever larger fraction of the total flux of the energy of the earth, and eventually for tapping the large supplies of stored energy, has had the effect of continuously upsetting the ecological equilibrium in the direction of an increase in the human population."—M. King Hubbert in "Energy Resources," A Report to the National Academy of Sciences—National Research Council.*[1]

INTRODUCTION

The worldwide population and energy explosions are like the hen and the egg. However, today, the question "Which came first?" is academic. Experts tell us that by the year 2000 United States population will be up 40 percent (to about 280 million people), and our energy needs will be up 40 percent per person (to about 315 million Btu).[2]

Recently, the population and energy explosions have been joined by another—worldwide pollution of our environment. A start has been made on pollution but much more must be done, as we shall see.

Industry can, and will, supply the needed energy, but the problem is complex and will require careful planning. Periodic inventories of all energy available at current prices and operating conditions must be made.

In order to keep up with the fast-changing energy industry of the future we must learn to think in terms of the energy available from each fuel—Btus instead of tons, cubic feet or barrels. Such terms as "reserves" must have the same meaning throughout the industry or costly miscalculations can result. Here are three examples of what is already happening.

First, the Atomic Energy Commission (AEC) has announced that by 1980 nuclear power plants will be generating about 25 percent of the nation's electric power—yet the total U.S. reserves of uranium ore available at today's prices and technology are about one-fourth the requirements of the planned reactors.

Second, a large gas company recently said in its annual report, "Mineable reserves of coal in the United States have been estimated at 830 billion tons. If used solely for gasification, this volume of coal would be sufficient to produce gas for 700 years at the present rate of gas consumption."

How much of the coal mentioned in the annual report is commercial—comparable to the proven reserves of oil and natural gas reported by the petroleum industry? Twenty (20) billion tons, or about 2½ percent of the 830 billion tons mentioned in the report.

Third, United States oil shale policy was recently determined, in part, by reports that oil reserves in federally-owned oil shale lands ". . . contains 2 trillion barrels of shale oil, which conservatively is estimated to be worth $2.5 trillion—or enough for $40,000 for each American household. Its market value may be twice that . . ."

How much of the oil can be recovered from oil shale and sold at a profit? Not one drop. As one wit in the Colorado oil shale country commented, "Talking about the trillions of dollars worth of oil in shale is like talking about the billions of dollars worth of granite tombstones in Pikes Peak awaiting development. The trick is to sell them at a profit."

We need a periodic inventory of the amount of energy available from each fuel. This inventory must report the fuel reserves available *at current prices and technology.* Further, these estimates must be available to everyone. Would a public utility company go ahead with plans to build an $80-million nuclear generating plant if it knew that the fuel for the plant had not yet been found?

Would the gas company management feel as confident about manufacturing gas from coal if it knew the "minable reserves" it was counting on includes coal seams 14 inches thick at a depth of 3,000 feet—and that economics were not a factor in estimating the reserves? I doubt it.

It is not enough to know that a certain tonnage of fuel is waiting to be dug out of the ground. What is important is to know how much energy can be produced at a profit under existing operating conditions. M. A. Adelman,[3] Professor of Economics at Massachusetts Institute of Technology, recently said, "Whether fossil fuels (and also uranium) will be found within our borders in sufficient amounts is no more meaningful than whether there is enough gold dissolved in sea water to expand gold liquidity and cure balance-of-payments problems. There is many times as much gold as we could possibly use, but the cost is prohibitive."

KNOWN RECOVERABLE VS. COMMERCIAL RESERVES

Are any estimates made of the energy available from fuels under current economics and operating conditions? Yes. Such estimates are made periodically for crude oil, natural gas, and natural-gas liquids. They are not made for the other fuels—coal, oil shale, or nuclear fuels. However, rough estimates can be made using the data published in the authoritative study, "Energy R&D and National Progress," prepared by the Energy Study Group under the direction of Ali Bulent Cambel.[4]

Column 1 in table 1 lists "Known recoverable reserves" of fossil fuels and "Known deposits of U_3O_8 at \$5-\$10/lb". (Reproduced from tables 3-1 and 3-8, pages 91 and 106 of the R&D Study.) Column 2 is a tabulation showing estimated reserves recoverable under existing economic and operating conditions. The evidence for the estimates in column 2 is given in the following discussion for each fuel. In addition to reporting the conventional units of each fuel, the energy equivalent is given in Q (quintillion Btu $= 10^{18}$ Btu).

The total energy available from "known recoverable fossil fuel reserves" plus "known deposits" of uranium at \$5 to \$10 per pound of U_3O_8 is reported by the R&D Study Group (R&D) as 27.5 Q. The amount of this energy available at current prices and technology is about 1.21 Q. (Figs. 1 & 2.)

CRUDE OIL, NATURAL GAS AND NATURAL-GAS LIQUIDS

Petroleum is defined as ". . . gas, liquid, semi-solid, or solid, or in more than one of these states at a single place. Chemically any petroleum is an extremely complex mixture of hydrocarbon compounds, with minor amounts of nitrogen, oxygen, and sulphur as impurities."[5]

TABLE 1. Estimates of fossil[1] and uranium fuel reserves of the United States

	(1)	(2)
Fuel	**Known Recoverable Reserves**[2]	**Reserves Recoverable Under Existing Economic and Operating Conditions**[3]
Fossil:		
Petroleum (crude oil)........bbls..	48×10^9 (0.278 Q)[4]	47×10^9 (.276 Q)
Natural gas..............cu ft...	268×10^{12} (0.278Q)	293×10^{12} (.304Q)
Natural-gas liquids.........bbls..	7×10^9 (0.032 Q)	9×10^9 (.032 Q)
Coal................short tons..	220×10^9 (4.6 Q)[5]	20×10^9 (.42 Q)
Oil in bituminous rocks.....bbls..	1.3×10^9 (0.008 Q)	0 0
Shale oil (from oil shale)....bbls..	50×10^9 (0.29 Q)	0 0
Total energy in fossil fuels........	(5.5 Q)	(1.032 Q)
	Known Deposits	
Uranium: U_3O_8 (at \$5-\$10/lb)........tons..	382,000[6] (22 Q)[7]	148,000 (.17 Q)
Total fossil and uranium fuel......	(27.5 Q)	(1.202 Q)

[1] Prepared by D.C. Duncan and V.E. McKelvey of the U.S. Geol. Survey.

[2] As defined here known recoverable reserves include measured, indicated, and inferred reserves. The estimates shown are proved (measured) reserves and therefore not wholly comparable to the estimates shown for the other commodities.

[3] These estimates are based upon information from Energy R&D and National Progress, 1964, and revised to reflect the latest estimates available.

[4] The numbers in parentheses represent the energy equivalent in Q (quintillion Btu) and the total energies are rounded values.

[5] See Energy R&D. Other estimates of the size of these reserves vary widely.

[6] Reported as 323,000 tons uranium metal in R&D, which is here converted to the equivalent tonnage of U_3O_8 to conform to other estimates.

[7] The numbers in the parentheses represent the total energy contained in U-235 as well as U-238. With light-water reactors, using current technology , only 1 or 2 percent of this energy is recoverable. With advanced technology, most of this energy is expected to be recoverable.

Petroleum reserves, called "proved reserves", are defined as ". . . the estimated quantities of crude oil, natural gas, and natural-gas liquids which geological and engineering data demonstrate with reasonable certainty to be recoverable from known reservoirs under existing economic and operating conditions."[6] These estimates are a compilation of estimates by several hundred industry engineers and geologists organized into committees under the direction of the industry associations—the American Gas Association (A.G.A.) and the American Petroleum Institute (API).

The proved reserves shown in column 2, table 1, for crude oil, natural gas, and natural-gas liquids, are the latest estimates available (31 December 1967). The crude oil reserves in columns 1 and 2 include in addition 16 billion barrels of oil considered ". . . economically recoverable by established secondary-recovery methods as estimated by the Interstate Oil Compact Commission (IOCC) as of 1 January 1962." (R&D, p. 97).

In addition to the estimates reported here, A.G.A., API and Independent Natural Gas Association of America (INGAA) also support an industry study that periodically estimates the undiscovered quantities (potential supply) of natural gas. This study is conducted by industry and government geologists and sponsored by the Colorado School of Mines.

The "proved reserves" estimates are the best energy estimates available. However, they should be augmented by regular estimates of the oil recoverable by secondary-recovery methods as was done in 1962 by the IOCC. In addition, the industry should follow the example of the natural gas industry in making regular estimates of the potential supply of crude oil and natural-gas liquids.

COAL

The R&D Study Group defined known recoverable reserves of coal (col. 1) as "those in thick coalbeds lying at depths of less than 1,000 feet; 50-percent recovery of the coal in place is assumed. The minimum thickness of beds of bituminous and higher rank coal included in the estimate is 3.5 feet, and that of subbituminous and lower rank coal is 10 feet." (R&D, p. 92.) Notice that there is no mention of economics or technology in this definition.

What portion of the known recoverable reserves are recoverable under present economic conditions? The Energy Study Group reported that this was the chief uncertainty. It reported that an effort was made to acquire an estimate of the coal ". . . analogous to the oil controlled by producers and comprising the amount reported by the American Petroleum Institute (API) as proved reserves. A poll of independent coal producers yielded incomplete results but indicated that 20 billion tons are available at 1960 prices and 35 billion tons would be available at a price 25 cents higher." (R&D, p. 95.)

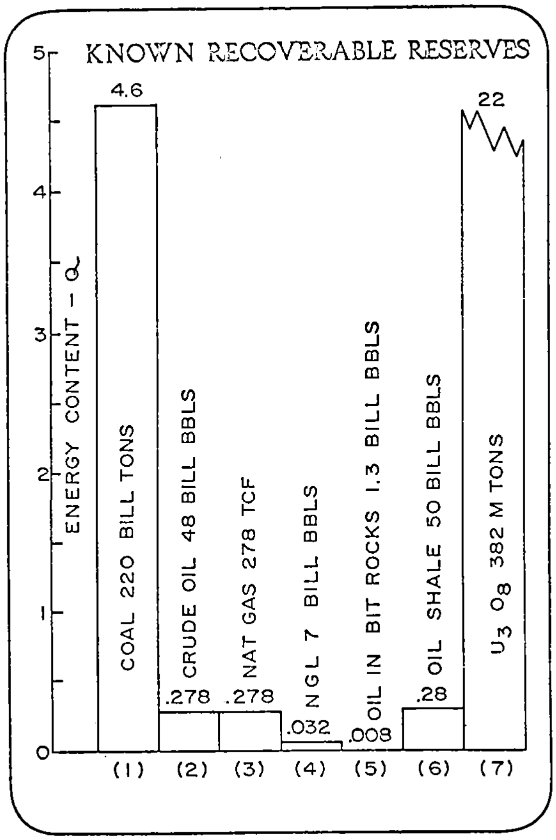

Figure 1.

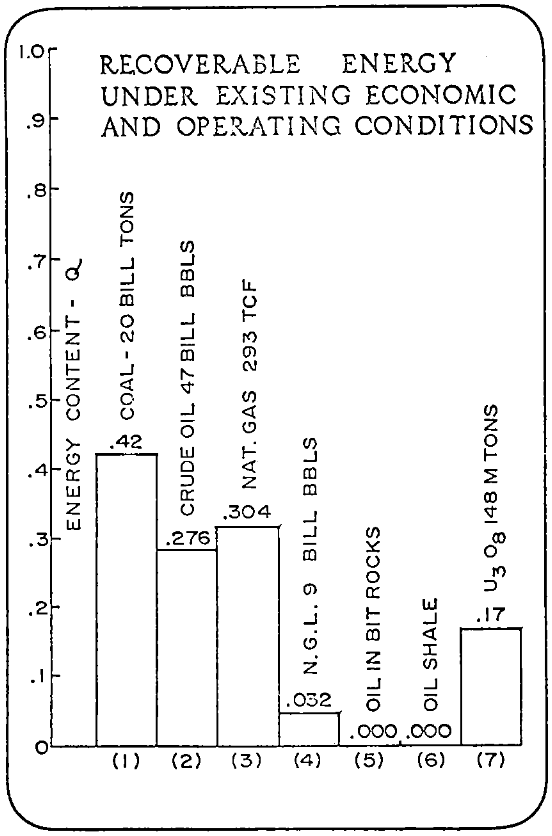

Figure 2.

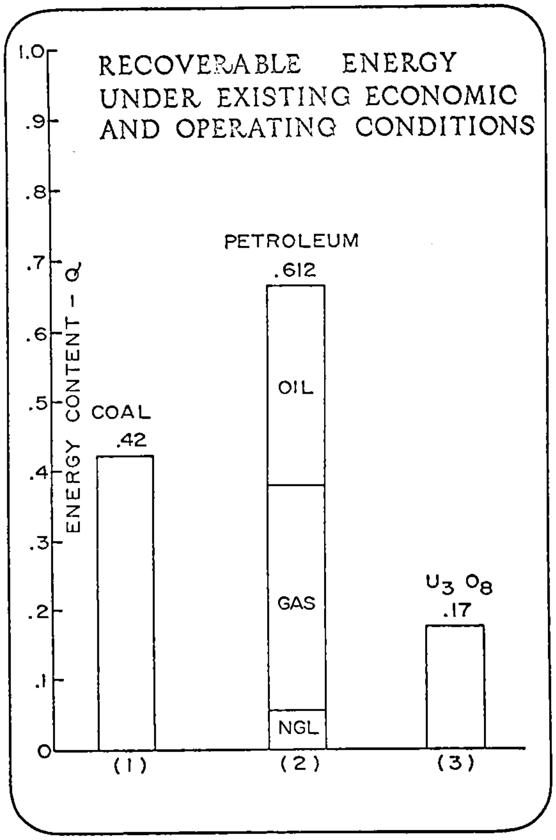

Figure 3.

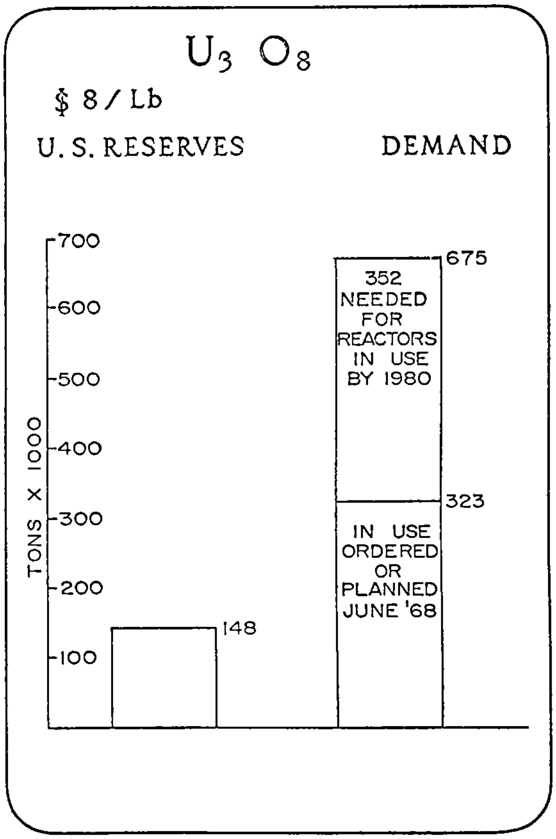

Figure 4.

The Study Group also reported, however, that the 20 billion ton estimates ". . . did not take account of large deposits, both on public domain and privately held, that are not yet controlled by operating companies, but nevertheless could be mined under present conditions." The Study Group went on to say that in their opinion, ". . . the 220 billion tons of reserves can be mined at present costs, but it is likely that much of it can be mined or delivered at lower costs than those prevailing now."

In other words, the 200 billion tons of coal not included in column 2, table 1, are comparable to potential supply of crude oil, natural gas, and natural-gas liquids that is as yet undrilled in known fields, or is undiscovered.

The purpose of this discussion is not to prove that we are about to run out of coal—but to point out the need for accurate estimates of the coal reserves available at current prices in each coal-producing area.

For example, the coal deposits of Pennsylvania and West Virginia have been mentioned as possible sources for coal to be used in manufacturing pipeline gas for eastern markets. How much low-cost coal is available at present prices and operating conditions?

We don't know, but concerning the strip-coal production in this area, Averitt[7] said in 1968, "The fact that strip-coal production in Pennsylvania and West Virginia is falling behind the national trend suggests that much of the readily accessible, low-cost strip coal has been mined out."

Averitt also said, "The future of the strip-mining industry is obviously strongly dependent on an effective nation-wide program of reclamation of stripped-over lands." The additional cost of reclaiming spoil-banks will add to the future cost of strip-mining coal in this area and elsewhere, and must be taken into account in calculating commercial reserves.

OIL IN SHALE AND BITUMINOUS ROCKS

The Study Group says there are 50 billion barrels of "known recoverable reserves" of oil in shale. This includes oil recoverable by destructive distillation of the organic matter from higher grade oil shale in Colorado and Utah, in beds 25 feet or more thick, yielding about 30 gallons of oil per ton of rock, and lying at depths less than 1,000 feet below the surface. The assumed recovery in mining is 50 percent of the shale. (R&D, p. 102.)

Where have the stories of "trillions of barrels of oil from oil shale" come from? R&D describes "known marginal resources" of shale oil of 2 trillion barrels (1,000- to 10,000-foot depth and minimum yield of 10 gallons of oil per ton of rock) and 4 trillion barrels of "undiscovered marginal and submarginal resources" (a speculative estimate of equivalent oil content of selected shale deposits, yielding 10 gallons or more of oil per ton of rock, to depths as great as 20,000 feet). (R&D, p. 103.)

How much of the known recoverable reserves of oil shale are commercial at today's prices and technology? The Study Group said in 1962, ". . . it appears that commercial operation will be feasible in the near future. The known recoverable reserves listed very likely can be produced at or near present prices." Today, 7 years later, no commercial production of shale oil has been achieved. Until this happens, oil shale must be classed as noncommercial.

Concerning oil in bituminous rocks or tar sands, the Study Group said, "None of the tar-sand deposits in this country or Canada are being mined commercially now and hence it is perhaps premature to class them as reserves minable under present economic and technological conditions."

At present, there is one large-scale operation attempting commercial production in Canada. There are no commercial operations in the United States and no reports of any being attempted in the near future. Therefore, the minable reserves of oil in bituminous rocks are considered noncommercial under present economic and technologic conditions.

URANIUM

The R&D Study Group's provisional estimate of "known deposits" of uranium metal available at $5 to $10 per pound of U_3O_8 is 323,000 tons. This is equivalent to 382,000 tons of U_3O_8. The "theoretical maximum energy value" for this amount of fuel is given as 22 Q (R&D, p. 106).

How much energy is available from 382,000 tons of U_3O_8 using present technology? R&D said, "The numbers in the parentheses represent the total energy contained in U-235 as well as U-238. With light-water reactors, using current technology, only 1 or 2 percent of this energy is recoverable." Two (2) percent of 22 Q is .44 Q—the energy available using present technology.

What are the most recent estimates of uranium reserves? Butler,[8] in 1967, estimated that U_3O_8 mined and in reserves at the end of 1970 would be 243,000 tons. He arrived at this figure by projecting the 1962-66 discovery rate and adding 40,000 tons assuming that the price would be raised to $10 per pound from the present $8.

In October 1968, AEC Chairman Glenn T. Seaborg said that at the current official price of $8 a pound for U_3O_8, economically recoverable uranium reserves total only 148,000 tons. He said that if the price was raised to $10 a pound the total economic reserves would only total about 200,000 tons.[9]

Using the most recent estimate, the present U.S. uranium reserves available at present prices and technology are 148,000 tons with an energy value of .17 Q.

SUMMARY—FUEL RESERVES

The striking contrast between "known recoverable reserves" and "recoverable energy under existing economic and operating conditions" is shown in figures 1 and 2.

In order to report the energy reserves of the United States in equivalent units one final correction is necessary. "Coal", which includes anthracite, bituminous, subbituminous, and lignite coals, should be compared with "Petroleum", which includes crude oil, natural gas, and natural-gas liquids. When this is done (fig. 3), it is interesting to see that under existing economic and operating conditions there is .612 Q of recoverable energy in petroleum, .42 Q of energy in coal, and .17 Q of energy in uranium.

In 1965, T. A. Hendricks[10] of the U.S. Geological Survey said, "Because man cannot see oil and gas resources, it is not surprising that he has been ultra-conservative in estimating yet-undiscovered quantities. Repeatedly, expert estimates of total undiscovered quantities have been exceeded within a decade or so by quantities actually discovered."

Conversely, because man can see coal and oil shale —can measure it, and estimate the tonnage available— it is not surprising that he has been over-optimistic in estimating the value of these reserves.

In the past, a few government experts have made the published estimates of coal reserves. Perhaps in the future they will be joined by industry experts in each producing area and together they will make periodic estimates of the commercial quantities of coal available for market.

In the uranium industry, past estimates have been made by government experts, and there appears to have been confusion over the reserves available for industry. As with the coal and petroleum industries, uranium reserves should be estimated by teams of industry and government experts working together, and the estimates published so that industry can make long-range plans based upon realistic price and reserves estimates.

FOSSIL FUEL AND THE ATMOSPHERE

What does our use of fossil fuel have to do with the oxygen, carbon dioxide, and pollution in our environment?

All play a part in nature's great carbon dioxide-oxygen cycle. Fossil fuel and the "excess" oxygen in our atmosphere were both created from sunlight, carbon dioxide and water by photosynthesis—the process by which plants create the starches and sugars, of which they are made, and release oxygen to the atmosphere.[1] Plants may be eaten by animals, but eventually, when plants or animals die and decompose, or are burned, the remains recombine with oxygen to form the original carbon dioxide and water. When plant and animal remains are buried, or sink to the ocean bottom where there is no oxygen, they become fossil fuel—and some oxygen remains in the atmosphere.

Throughout geologic time somewhere between 50 and 90 percent of the world's oxygen has originated in the oceans from microscopic organisms called phytoplankton.[11&12] The carbon dioxide and pollution in the atmosphere and the oceans have a bearing on how much oxygen the phytoplankton are able to produce.

The fact that most of the world's oxygen was formed in the oceans has a bearing on where fossil fuel is to be found. And, the survival of mankind depends on the phytoplankton's continuing ability to generate oxygen.

Oxygen, Carbon Dioxide and the Atmosphere

The burning of fuel is shown by the schematic equation:

$$\text{Fuel} + O_2 = CO_2 + H_2O + \text{Heat}$$

It takes about 2¼ pounds of oxygen to burn 1 pound of coal—and the results of this chemical reaction are about 3 pounds of carbon dioxide, varying amounts of water, and about 13,000 Btu of heat.

The U.N. publication, "World Energy Supplies,"[13] reported that in 1966 the world consumption of fossil fuel was equivalent to 6.2 billion tons of coal. This means that the world also consumed more than 14 billion tons of oxygen from the atmosphere—and dumped about 19 billion tons of carbon dioxide and 8 billion tons of water vapor into the atmosphere.

Apparently, so much of the world's fossil fuel is scattered through the rocks in noncommercial amounts that we can burn all of the commercial deposits of fossil fuel without burning too much oxygen. Francis S. Johnson,[11] of the Southwest Center for Advanced Studies, has calculated that if ". . . the total reservoir of fossil carbon in forms suitable for exploitation . . . (was) . . . fully expended, the oxygen consumption associated with it would not be enough to seriously deplete the atmospheric oxygen reservoir."

What about the carbon dioxide we are dumping in the atmosphere? There is cause for concern about the effect of carbon dioxide on our climate—but evidence, too, that this may be offset by atmospheric pollution.

Writing in the Government publication "Restoring the Quality of our Environment", Roger Revelle, et al[14] reported evidence that the carbon dioxide in the earth's atmosphere had increased 10 percent since the beginning of this century, and that by the year 2000 it could be 25 percent above the level of the 19th century. The effect of this carbon dioxide would be to trap and hold more of the sun's heat and warm the earth's atmosphere (called the "greenhouse effect") to the point where the Antarctic icecap could be melted in from 400 to 1,000 years. This would raise the sea level somewhere between 4 and 10 feet every 10 years —enough to have a disastrous effect upon the seaside cities in which 80 percent of the world's population live. Melting the whole Antarctic icecap would raise the sea level 400 feet.

Pollution of the Atmosphere and the Oceans

However, Reid A. Bryson and Wayne M. Wendland[15] have recently reported that the pollution in the earth's atmosphere is having a cooling effect on the earth. They said, "Since 1940 the effect of the rapid rise of atmospheric turbidity (dustiness) appears to have exceeded the effect of rising carbon dioxide, resulting in a rapid downward trend of temperature."

If most of the world's oxygen is produced in the oceans by phytoplankton, what is the effect of atmospheric pollution on these organisms? There is some evidence that they may be in trouble.

Francis Johnson[11] says, "The growing spread of pollution has already shown up indirectly in midocean areas. DDT dust has been observed far out at sea." He mentions evidence that some sea-birds are harmfully affected by chlorinated hydrocarbons (insecticides) that got into the birds food chain ". . . from fish, whose food source in turn goes back ultimately to the phytoplankton, which presumably gathered the insecticide from dust settling into the ocean."

Lawrence R. Cory,[16] a biologist at California's St. Mary's College, cites a laboratory study,[17] so far unconfirmed, that only a few parts of DDT per billion in water interferes with the capacity of phytoplankton to absorb carbon dioxide and produce oxygen. The oceans already contain the chemical in this concentration.

Most of the oxygen produced by plants is recombined with carbon to form carbon dioxide when the plant dies. It is only when plant or animal remains are kept from oxygen in a few areas of the world that oxygen is added to the oxygen reservoir of the atmosphere. Francis Johnson says, ". . . the net oxygen production —photosynthesis exceeding respiration and decay—is very small compared to the total production. A few ocean areas with anoxic (no oxygen) bottom conditions and a few marshy areas in which peat is forming are presumably the key areas for maintaining our oxygen replenishment on a long-term basis. These limited areas are at least as susceptible to poisoning as are the open oceans. It is a matter of importance to man's future to recognize and preserve these areas."

Fossil Fuel Beneath the Sea

How much fossil fuel is associated with the present ocean basins? If there is a direct connection between oxygen in the atmosphere and buried organic material (fossil fuel), it might be interesting to speculate on how much fossil fuel is to be found beneath the ocean basins—based upon oxygen production from the ocean basins.

Frederick J. Vine[18] has estimated the ocean basins' age at 200 million years. Discounting oxygen production during the first 75 million years of their growth, and assuming that for the past 125 million years that they have produced an average of 25 percent of the world's oxygen, then 25 percent of the world's fossil fuel should be beneath the present oceans. This seems a conservative estimate since over 50 percent of the world's oxygen is being produced in the ocean basins today.

The R&D Study Group estimated the world's recoverable reserves of coal at 18 Q and of petroleum (oil, natural gas, and natural-gas liquids) at 3.8 Q. Averitt[19] estimates that substantially all coal reserves have been formed since the beginning of Carboniferous time (350 million years ago). Based upon Levorsen's[5] estimates it is assumed that 90 percent of the R&D petroleum estimate was formed during the same period of time. In other words, a total of 21.4 Q of recoverable reserves of fossil fuel were formed during the past 350 million years. Assuming an average rate of fossil fuel deposition, 9 Q of energy would have been deposited during the past 125 million years.

The R&D estimates are largely based upon the fossil fuel deposited upon the present continents—representing 75 percent of the world's oxygen supply and fossil fuel. The R&D estimates do not take into account the fossil fuel that resulted from the 25 percent of the world's oxygen and plant life formed in the ocean basins.

Therefore, the total recoverable reserves of fossil energy should be 12 Q for the world—9 Q on the continents and 3 Q in the ocean basins. Since practically no coal is to be found on the margins of the present oceans, probably this fossil fuel will be petroleum.

If an additional 3 Q of energy (doubling the R&D estimates of recoverable petroleum reserves) are waiting to be found beneath the present ocean basins, where will it be found? Probably between the continental margins and the abyssal plain. This is where the phytoplankton are to be found that produce the oxygen.

NUCLEAR ENERGY PROBLEMS

As was said earlier, using present technology, only 1 or 2 percent of the energy is recoverable from uranium ore. This is because current reactors must rely upon the only isotope capable of fissioning naturally—uranium-235. U-235 comprises 0.7 percent of whole uranium. The rest of natural uranium is the isotope U-238.

With U-235 as a starter, it is possible to create fissionable isotopes from uranium-238 and also thorium-232 by a process that is known as "breeding".

When the breeding process is developed commercially, not only will it be possible to use U-238 (140 times more abundant than the present fuel, U-235) and thorium (3 times as abundant as U-238), but the development of nearly complete breeding will change the cost of the operation in such a manner as to make it economical to utilize rocks with low uranium or thorium contents. The fuel added in this manner is millions of times greater than that available when only U-235 can be used.[1]

Since the breeder reactor is an impossibility without U-235, it would seem prudent to stockpile enough of this fuel to start the breeding process when the breeder reactors are developed. Instead, present U.S. policy seems bent upon consuming more than all known U.S. reserves available at present prices. Figure 4 illustrates the present supply and demand for nuclear fuel.

The U_3O_8 needed to supply the lifetime needs of reactors in use, ordered or planned as of June 1968 is 323,000 tons. Another 352,000 tons of U_3O_8 will be needed for reactors that will be in use by 1980. United States reserves available at current prices are 148,000 tons of U_3O_8.

With a sufficient supply of U-235 on hand when the breeder reactor is developed we have the possibility of limitless energy. Without U-235 we face nuclear bankruptcy.

Safety

Apparently, there is some question among experts about the safety of the present generation of nuclear reactors. In September, 1968, Edward Teller[20] deplored the proliferation of surface nuclear reactors and urged that they be buried "deep underground". Teller said, "A nuclear reactor 700 feet under Manhattan is safer than a nuclear reactor 70 miles from Manhattan." The nuclear scientist added that only "great care and a little luck" have prevented a major nuclear power station accident.

Radioactive Waste

Concerning nuclear wastes, Dr. Clyde L. Cowan,[21] nuclear physicist at Catholic University of America, said (September, 1968) that one of the biggest problems facing the world today is the way man is increasing the amount of nuclear power he is generating without knowing the world's storage capacity for the deadly waste.

Thermal Pollution

Nuclear plants will be releasing 40 to 80 percent of the heat generated as waste. Wilfrid E. Johnson,[22] Commissioner, U.S. Atomic Energy Commission, said (January, 1968) that it has been estimated that by 1990 more than half of all river runoff in the U.S. would be required for cooling purposes if the heat were rejected to the rivers. Phillip N. Ross,[23] Westinghouse Electric Corporation engineer, told the President's Water Pollution Control Advisory Board, December 1968, that generating plants in the United States would have enough waste heat by the year 2000 to raise the temperature of the entire Mississippi River by 100 degrees.

Nuclear Theft

One other unique problem with nuclear power is the possibility that criminals or terrorists might steal the materials for making an atomic bomb. Theodore Taylor,[24] who headed the Defense Department's atomic bomb design and testing program for 7 years, was recently quoted by the Wall Street Journal as saying the once-secret information needed to build nuclear bombs became available in unclassified literature several years ago. He especially recommends the World Book for its explanation of how a bomb works.

The Wall Street Journal quoted scientists as saying that it takes only 13 pounds of plutonium to make an atomic bomb as powerful as the one that devastated Nagasaki. This is less than one-tenth of 1 percent of the plutonium that the world's nuclear reactors will soon be producing yearly as one of the by-products of their chain reactions. This plutonium is shipped to reprocessing plants, and experts say the shipments will soon be so numerous it will be extremely difficult to guard all of them adequately. Rep. Chet Holifield of California, vice chairman of the Joint Congressional Committee on Atomic Energy, quoted experts as saying that security measures at the reprocessing point are minimal, and that plutonium is "easily accessible to diversion" during reprocessing.

Export of Nuclear Fuel

In November 1967, the AEC reported[25] that to date it had shipped abroad approximately 20 thousand kg of U-235 representing a value of about $200 million, and that it expected to ship abroad nuclear fuel at the rate of 10 to 15 thousand kg U-235 per year over the next several years, primarily for power reactors. In October 1968, the chairman of the AEC said that American and some foreign nuclear power plants could be producing enough by-product plutonium by 1980 "to make potentially dozens of nuclear weapons per day." Dr. Glenn T. Seaborg[26] said the prospect "should emphasize the importance of the nuclear non-proliferation treaty and the application of international safeguards through the International Atomic Agency."

Since the United States has only about one-fourth of its projected needs of U-235 it seems fair to ask why we are exporting nuclear fuel at all.

In 1957, Schubert and Lapp[27] said, "One cannot escape the conclusion that we are proceeding toward a full-scale nuclear power economy on the basis of high optimism that somehow or other the future problems will be solved." Today, 12 years later, it appears that we are still roaring into production of nuclear power with inadequate fuel supply, and only early pilot-plant knowledge of reactor technology and radioactive waste disposal.

A LOOK INTO THE FUTURE

Looking into the future, it appears that we have plenty of energy available for United States, and world, needs. The problems facing the energy industry, and government, concern the orderly development of the fuels available, and the proper handling of pollution problems.

Industry, in the name of "enlightened self-interest", should team up with government to make periodic inventories of all U.S. energy resources. When this is done, mineral economists and other future-planners will be able to draw up realistic blueprints for the world of tomorrow.

The survival of mankind depends upon the oxygen he breathes. Pollution of the atmosphere and the oceans appears to have a direct bearing upon the rate at which most of the world's oxygen is produced in the oceans. Since the burning of fossil fuel consumes great quantities of oxygen—and adds pollution (including carbon dioxide) to our environment, "enlightened self-interest" again dictates that the energy industry take the lead in research to preserve the world's oxygen supply and prevent the pollution of the atmosphere and the oceans. The importance of these problems was underscored by Francis Johnson[11] before the American Association for the Advancement of Science at its December 1968 meeting, when he said "Because of the importance of these problems to man's future we should be very confident of our full understanding of them . . . Catastrophic problems appear to be in prospect for mankind because of the population explosion and its associated pollution explosion."

The nuclear industry appears to be attempting full-scale production with inadequate fuel supply, and incomplete knowledge of technologic problems, including the disposal of radioactive wastes. In a report, entitled "U.S. Energy Policies, an Agenda for Research", Resources for the Future (RFF)[28] mentioned the possibility of a "bandwagon psychology" developing in some segments of the nuclear industry. RFF quoted an energy expert in the nuclear industry who said, "If I were asked whether I thought that all of the pro-nuclear power decisions have been based on thorough studies illuminated by enlightened self-interest, I could not say yes. I think there may even be something in the idea that one sometimes encounters these days that what we are seeing reflects the general adoption of a fashion . . ."

A unified industry-government approach can identify and solve our fuel problems. We have plenty of fossil fuel to last until nuclear problems are licked.

If we stockpile sufficient U-235 to fire up the breeder reactor program when it is developed commercially, we have the prospect of limitless power to serve mankind. The breeder reactors will be able to use U-238 and thorium. And, low-grade ores such as the Conway granite of New Hampshire (that crops out over a 300-square-mile area) can be used. This granite contains enough thorium per ton to equal the energy in 168 tons of coal.

King Hubbert[1] has pointed out that when limitless power is achieved it will be possible to use this power to synthesize chemical fuel from limestone and water. The chemical fuel will be just as useful for highway and air transport vehicles as our present petroleum products.

When mankind achieves the dream of limitless energy to do his work, will he have achieved Utopia—or limitless population? In 1962, Hubbert[1] said of the world's energy-triggered population explosion, "It represents, in fact, one of the greatest biological upheavals known in geological as well as in human history."

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