ENERGY R&D AND NATIONAL PROGRESS

Prepared for the Interdepartmental Energy Study
by the Energy Study Group
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Environmental Considerations

Page

1. With the predicted increase in energy demands, certain environmental problems need immediate attention and will
364 require very much more in the future.

2. Additional R&D is needed to devise economic methods for adequate control of particulate and gaseous air pollution from sulfur and carbon dioxides, oxides of nitrogen, and incompletely burned hydrocarbons. The only sure way to prevent
367; 370 increased air pollution by fossil fuels is to decrease emissions.

3. The pollution of water by processes related to coal, oil, and nuclear fuels will increase as energy industries demand more water. The problems of effective control are susceptible
381 to R&D.

4. Concern for public safety has imposed economic penalties on nuclear-power reactors. R&D could resolve the uncertainties and reduce the extra costs of conservative design. Better and more economical methods are needed for the proc-
381; 387 essing, concentrating, and ultimate disposal of nuclear wastes.

5. Qualitatively, there appears little cause for concern regarding possible effects upon the weather by the increased concentration of carbon dioxide in the atmosphere. In the absence of quantitative knowledge, however, research aimed at defining this problem is needed, together with watchful measurement of world temperatures and atmospheric CO_2
369 concentrations.

Economics

1. From economic considerations, a simple criterion for R&D funding decisions is that the benefits (public and private)
57 should exceed the costs (public and private).

2. Analyses of economic cost-benefit problems for energy R&D must involve the whole energy sector, not one particular segment, and analytical techniques are available for the task. A major barrier to such analyses is the scarcity of statistical inputs that show how the various factors are interrelated. Such
62 statistical data should be developed.

54 3. Conservation, per se, is not an economic necessity.

4. Benefits which can be sought through research or development can sometimes be equaled—or offset—by changes of a non-technical nature such as actions of regulatory bodies, taxation, or labor-management agreements. Decisions on whether to undertake research or development need to be made in the
66 light of these external factors.

Page

5. Available economic techniques can be used to optimize current R&D programs and might enable curtailment of present total outlays. The savings thus realizable might be applied to support of programs that need new or additional effort. To exploit these and other opportunities, it is desirable to pursue research in econometrics, programing studies, models, and optimum rates for all phases of R&D programs. 58; 62; 75

Chapter VIII

ENVIRONMENTAL ASPECTS OF ENERGY DEVELOPMENT

This chapter considers what R&D will be required on physical, chemical, or biological agents that may be released to the environment as energy resources are developed in the future. None of the existing or envisioned energy sources imposes prohibitive health or safety hazards, but there are problems of environmental health that should be studied now and that will require even more attention as space, air, water, and energy demands increase with the Nation's population and economic growth.

The Report of the Committee on Environmental Health Problems submitted to the Surgeon General, U.S. Public Health Service, on 1 November 1961 adequately covers general R&D and manpower needs relative to environmental health. Health problems of energy development are not significantly different from those encountered in everyday industrial and community life. Just as thousands of new substances will have to be toxicologically tested as they are brought into use, so will the biological effects of existing energy forms need continued measurement and evaluation; means must be devised to evaluate effects of new ways of utilizing energy, along with development of acceptable control measures where warranted. This concern with the environment fits into four basic levels, in decreasing order of importance and increasing order of breadth:

1. Insuring the elements of simple survival.
2. Prevention of disease and poisoning.
3. Maintaining an environment suited to man's efficient performance.
4. Preservation of comfort and the enjoyment of life.

Where preventive medicine seeks to alter man's resistance to his environment, the objective of environmental health is to change or control the environment to prevent adverse effects on man and his community; the primary problems, therefore, are of an engineering and scientific nature, with some important medical aspects.

Air Pollution

The air-pollution potential of various energy sources is appraised in table 8–1, which shows fossil fuels as the significant sources of air pollution in 1963, 1980, and 2000.

TABLE 8–1.—*Air-pollution potential of various energy sources*

Energy source	Year			Remarks
	1963	1980	2000	
Coal	High	High	High	Processing and combustion of fuel is the principal source of air pollution in 1963 and, it is believed, will be the principal source in 1980 and 2000.
Oil (including shale oil).	do	do	do	
Natural gas	Medium	Medium	Medium	
Hydropower	None	None	None	No air pollution produced.
Fission	Low	Low	Low	Primarily due to possible accident or improper plant operation at reactor or fuel processing plant, assuming no future air-cooled reactors.
Geothermal	None	None	None	Some dust and noncondensible gases may be discharged.
Solar	do	do	do	No air pollution produced.
Tidal	do	do	do	Do.
Wind	do	do	do	Do.
Biochemical	do	do	do	Some gases may be discharged.
Fusion	Low	Low	Low	Primarily due to possible accident at fusion powerplant.

AIR POLLUTION BY FOSSIL FUELS

Fossil fuels release two types of pollutants, gases and particulate matter. The presence of these in the atmosphere causes chemical reactions that produce additional pollutants (hydrocarbon emission is of particular concern here). Three of the gaseous pollutants—carbon monoxide, oxides of nitrogen, and sulfur dioxide—are specifically toxic in excessive quantity. Particulate matter causes dirtying, soiling, and loss of visibility and also carries absorbed and adsorbed gaseous and liquid pollutants into the lungs and onto surfaces of plants, materials, and structures. Some of the specifically toxic and carcinogenic airborne substances, such as lead and benz(*a*)-pyrene, exist in the air as solid particles. Most of these pollutants disperse and settle from the air naturally, or eventually are washed from the atmosphere by rain, but in certain congested industrial areas pollutants sometimes accumulate in sufficient amounts to damage property and affect living conditions.

Pollutant Production

Gaseous. Carbon monoxide and hydrocarbons result from the incomplete combustion of all fossil fuels. Nitrogen dioxide results from atmospheric conversion of the nitric oxide formed when nitrogen is combined with oxygen in the high-temperature zone of furnaces and internal combustion engines. Since nitrogen and oxygen are present regardless of the kind of fuel burned, all high-temperature fuel-burning processes yield nitrogen oxide. Sulfur dioxide also is produced by fuel combustion, and in proportion to the sulfur content of the fuel. Carbon dioxide results from the complete combustion of fossil fuels and may have widespread low-level environmental implications.

Particulate Matter. Fly ash, soot, and other liquid or solid particles are produced in combustion processes by two means: (1) entrainment of ash and unburned or partially burned fuel particles, and (2) formation of organic particles by fractionation, pyrolysis, or synthesis in the furnace. The form of the fuel and its method of burning are influential: natural gas has essentially no ash, oil [1] has very little, and coal has large amounts. Coal burned on grates releases less ash to the flue gases than burning pulverized coal. Burning without formation of organic particles is easier with gas than with oil and easier with oil than with coal.

Technology of Pollutant Control

Fly ash is controlled by settling chambers, cyclone separators, water scrubbers, electrostatic precipitators, or filters. Current practice in steam-generating plants is to use electrostatic precipitators alone or in combination with cyclone separators. The efficiency of particulate removal ranges from 20 to 99 percent (see table 8–2). At present, filters are not extensively used for fly-ash collection, although experimental units have been tried; a decision as to their competitive position, particularly with electrostatic precipitators, must await further study. Glass-fiber bags can be used commercially at temperatures exceeding 500° F with an efficiency of greater than 99 percent. Wet scrubbers are not used, because the acidic nature of the gas stream may pose a water-pollution problem, and the cooling effects on the flue gas reduce effective stack height. Fly ash is being controlled by improved-design boilers; e.g., cyclone-furnace, slag-tap, and wet-bottom boilers. These operate at temperatures above the softening point of the ash, inducing melting and the formation of a slag that represents up to 85 percent of the fuel's ash content.

The gaseous emissions from burning fossil fuel are not commercially treated. In firing gas, oil, and pulverized coal, about 95 to 98 percent of the sulfur in the fuel is converted to sulfur dioxide, and about 1 percent goes to SO_3. When coal is fired in a stoker, some of the sulfur reacts with the retained ash and only 60 to 75 percent is emitted as sulfur oxides.

Some of the methods for sulfur oxides removal are adsorption on charcoal or on recirculated fly ash; oxidation on vanadium catalysts; injection of additives such as limestones, calcium oxide, calcium carbonate, gaseous ammonia, and dolomite before precipitation; and scrubbing of the flue gas with sodium and ammonia bisulfite solutions. A promising process uses a moving bed of alkalized alumina. The alternative to removing of sulfur from flue gases is removing it from the fuel prior to burning.

[1] The air-pollution potential of oil does not differ significantly with respect to the source of the oil; therefore, oil from oil shale is not considered separately.

TABLE 8–2.—*Collection efficiencies for particulate matter from burning fossil fuels*

	Type of collector				
	Mechanical		Electrical precipitator	Electrical precipitators and cyclone collectors in combination	Filter
	Settling chambers	Cyclones			
Collection efficiency..........percent..	20–30	35–75	75–98	85–99+	95–99+

No current technology can economically remove carbon monoxide, hydrocarbons, and oxides of nitrogen from flue gases of stationary combustion sources, although the amount of carbon monoxide and unburned hydrocarbons in flue gases is reduced by the more efficient modern combustion apparatus. Some work is in progress on developing a means to treat the objectionable gases from motor-vehicle exhausts.

Potential Pollutant Production

It is reasonable to expect that by 1980—certainly by 2000—most large industrial cities will have standards to limit the concentration of SO_2, NO_2, CO, hydrocarbons, and particulate matter in the atmosphere. Such regulations may affect the kinds of fuels burned in these cities and may accelerate the use of natural and manufactured gas. If solid and liquid fuels are used in large amounts in congested areas, cleaning of their effluent gases will be required by 1980. These conclusions assume that energy demands will be satisfied without marked changes in the relative contributions of oil, coal, and natural gas, at least through the 1970's. Toward the end of the century, however, the patterns may change as nuclear energy rises, and oil and gas decline, in relative importance.

Carbon Monoxide and Hydrocarbons. The present trend towards larger units aids pollutant control, because these pollutants result from incomplete combustion and because completeness of combustion increases generally with size of combustion apparatus. Except perhaps for the motor vehicle, this trend should continue to the year 2000. Concurrently, combustion should improve in small units and motor vehicles, largely as a result of present and future regulations to control air pollution. Thus, the quantity of CO and hydrocarbons emitted to the atmosphere per million Btu of fuel burned should decrease between 1963 and 1980 and between 1980 and 2000, and this trend probably will counterbalance the trend in the number of million Btu burned; hence, the total quantity of CO and hydrocarbons emitted in 1980 and 2000 will be about the same as in 1963.

Oxides of Nitrogen. The trend to larger combustion units, except for motor vehicles, tends to increase both mean combustion temperature and production of nitrogen oxides. Hence it can be anticipated that multistage combustion, designed to limit maximum flame temperature, will prevail in large units by 1980. However, the rate of increase in fuel consumption in large units is likely to be more rapid than the technological improvement, necessitating development, before the year 2000, of techniques to remove nitrogen oxides from effluent gas streams. Widespread use of devices or techniques to limit production of nitrogen oxide in small units may not be needed between now and 1980, but may be required before 2000.

Sulfur Dioxide. Unless the fuels or the effluent gases are treated, the emission of sulfur dioxide is in direct proportion to the total sulfur content of the raw fuels. Thus, if sulfur content in 1980 and 2000 remained the same as in 1963, the potential sulfur dioxide emission would increase in the ratios predicted for uncontrolled emissions of CO, hydrocarbons, and nitrogen oxide. The assumption on sulfur content, however, is uncertain. Sulfur now is removed almost entirely from natural gas, house-heating oils, and motor fuels before they are burned; partially from coal that is washed; and not at all from unwashed coal and residual fuel oil. No present technology can economically remove sulfur dioxide from powerplant flue gases, although removal may be practical when the need becomes acute. Without control measures, the sulfur-emission potential of burning unwashed coal and untreated residual oil would, by 1980, be almost two and one-half times that in 1963, and from four to six times the 1963 value by 2000. The intolerable pollution problem created by this amount of sulfur will undoubtedly force development and application of improved techniques for sulfur removal. Since this technology will develop slowly, sulfur emissions in 1980 may well be double those for 1963, but the rate of increase should be arrested and probably reversed by 2000, with the reasonable expectation of lower sulfur emissions in that year than in 1963.

Carbon Dioxide. The possible effects upon weather of increased carbon dioxide concentration in the atmosphere by the year 2000 have aroused some concern. The nature of this problem can be estimated by considering CO_2 production on a global basis and viewing the world as a closed ecological system. In 1960, world production of energy from coal and crude oil combined was 110×10^{15} Btu, and the CO_2 liberation was about 10×10^9 tons. The annual respiratory exchange of the 3×10^9 people living on earth during 1960 contributed an estimated 1.0×10^9 tons of CO_2. Without counterbalancing by reductive processes such as photosynthesis, the annual CO_2 contribution to the world's effective atmospheric envelope would be about 1.5 parts per million (ppm) from these two energy sources alone. The present concentration of CO_2 in the earth's atmosphere is 300 ppm by volume. Oxidative energy sources other than fossil fuels and humans will add considerably to CO_2 production in the world. Considering only human and fossil-fuel energy sources, the cause for concern is evident when it is realized that the current doubling time for world population is about 30 years, and about 20 years for world fossil-fuel combustion.

The problem hinges on the infrared-absorption properties of CO_2, causing outgoing radiant heat from the earth to be trapped near the surface. According to recent calculations, doubling of the CO_2 concentration in the atmosphere would cause a rise of from 2.5° to 6.5° F in the surface temperature. An average temperature shift of this magnitude, in either direction, would have far-reaching meteorological effects. The carbon dioxide theory has provided plausible explanations of the climatic oscillations of geologic time and the coming and going of glacial periods. Unfortunately, satisfactory evidence of CO_2 concentration in the atmosphere during earlier geological epochs has not been discovered; in fact, direct measurements during the past 50 years fail to indicate reliably whether the atmospheric concentration of CO_2 has increased. Plass indicated that a plot of such measurements could be fitted with a linear curve that increased by about 30 ppm during the half century; he stated, however, that the probable error for most of the measurements was so large that this result was not firmly established.

On one side, it must be realized that the current rate of population growth, with its concurrent disturbance of the carbon cycle through combustion of fossil fuels, represents the greatest ecological upheaval in human history. On the other side, it must be noted that worldwide photosynthetic reduction by plants assimilates some 60×10^9 tons of CO_2 per year. Obviously, with an estimable sink this large, and with qualitative considerations of the generation time of various forms of plant life (especially the algae), weathering of rocks, absorption of CO_2 in the oceans, and deposition as carbonates, etc., the onset of a serious imbalance in world ecology, detrimental to man, does not appear to be a problem of alarming magnitude. On a quantitative basis, however, knowledge is lacking. Therefore, research aimed at defining this problem is needed together with watchful measurement of world temperatures and atmospheric CO_2 concentrations, using instruments and techniques with the required sensitivity and reliability.

Particulate Matter. The technology for removing particulate matter from effluent gas streams is well developed, and undoubtedly will be further successful because of the close cooperation and active participation of various Federal agencies and scientific disciplines. From such studies will come more effective long-term monitoring procedures and criteria for future waste treatment.

Physical dispersion of radioactive effluents in estuarine and coastal waters has been studied by the Chesapeake Bay Institute (CBI) of Johns Hopkins University for AEC. Field measurements of currents, temperature, and salinity in New York Harbor by the U.S. Coast and Geodetic Survey and data analyses by CBI have provided means for evaluating the safety of nuclear-ship operations within the harbor. A major technical breakthrough by CBI—development of a rhodamine B fluorescent technique with a field sensitivity of 0.2 parts per billion—allows direct measurement of the dispersion of a controlled contaminant introduced into natural water bodies, on a significant time and space scale and at reasonable material cost. A series of dye studies in coastal waters off Cape Kennedy, which are part of the aerospace nuclear space program, utilizes this technique.

Studies in the sea-disposal areas of the Atlantic and Pacific coasts have examined the oceanic environment to see if the discharge of solid, packaged, low-activity waste caused any adverse effect. Seasonal surveys have included the collection of plankton, bottom sediments, fish, and sea water to the thousand-fathom depth. The results of alpha, beta, and gamma low-level counting analyses showed that radioactivity in bottom sediment, benthonic organisms, and bottom fish did not exceed that of the natural background.

SUMMARY AND CONCLUSIONS

Over $200 million has been spent in the AEC complex on capital facilities for collection, handling, treatment, and disposal of radioactive waste; for these, annual operating costs are estimated at over $6 million. At present, a greater part of the capital cost is associated with handling and storage of high-activity liquid waste. The economics of ultimate disposal of highly radioactive waste is uncertain, however, because there has been no actual operating experience.

Long-range engineering and economic studies at ORNL are aimed at supplying some indication of the magnitude of waste-management costs in a future nuclear-power economy. The work completed so far estimates total cost in the range 0.026 to 0.03 mill per kwh of electricity, for interim liquid storage, calcination, interim solids storage, shipment (1,000-mile round trip) to an ultimate disposal site, and storage in salt deposits. Detailed cost breakdowns of these estimates, as a function of interim liquid-storage time, are given in table 8–10.

TABLE 8–10.—*Management costs in mills per kilowatt-hour of electricity for Purex*[1] *and Thorex wastes*

Management operation	Interim liquid storage time (years)				
	0	1	3	10	30
	Mills per kilowatt-hour				
Interim liquid storage	0	0.0027	0.0040	0.0064	0.0095
Pot calcination	.0161	.0124	.0091	.0087	.0087
Interim solid storage	.0046	.0046	.0044	.0039	0
Shipment	.0035	.0035	.0028	.0025	.0025
Disposal in salt	.0061	.0057	.0060	.0073	.0073
Total	.0303	.0289	.0263	.0288	.0280

[1] Fuel exposures taken as 10 Mwd per kg U and 20 Mwd per kg Th.

Economic analysis and data from laboratory and engineering-scale operations foster a firm belief that waste-management operations should not be a major obstacle to development of economical nuclear power.

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Appendix A

PRESIDENTIAL DIRECTIVE

THE WHITE HOUSE

WASHINGTON

February 15, 1963

MEMORANDUM FOR

The Secretary of the Interior
The Secretary of Commerce
Chairman, Atomic Energy Commission
Chairman, Council of Economic Advisers
Chairman, Federal Power Commission
Director, Bureau of the Budget
Director, National Science Foundation
Director, Office of Science and Technology
Director, Office of Emergency Planning

SUBJECT: Interdepartmental Energy Study

1. Following receipt of the Atomic Energy Commission report, dated November 20, 1962, on the subject of Civilian Nuclear Power, I asked the Director of the Bureau of the Budget for his recommendations as to the most effective way to deal with the question, which the Commission considered inappropriate to cover in its report, of the possible effects of major research efforts on the economics of non-nuclear energy sources, or on improved transmission methods for either nuclear or non-nuclear produced energy. In addition, I requested recommendations for dealing with the broader economic questions which are implicit in the Commission's report, such as the size and characteristics of future demands for energy, possible price trends for fuels, and available alternative technical approaches to the problem of supplying the long-term energy requirements of the nation.

2. The significance of energy resources to our society has again been underscored by recent studies of the National Academy of Sciences and the Federal Council on Science and Technology, and by the Report of the National Fuels and Energy Study Group to the Senate Interior and Insular Affairs Committee. These studies also stress the need for balanced, comprehensive development of energy sources, improved generation and trans-

mission facilities, and greater efficiency in the utilization of energy. The report by the Atomic Energy Commission focused attention on the role of civilian nuclear power in our total supply of energy over the future decades. Each of these reports, in whole or in part, discusses the impact of research and development on the cost and availability of energy to the nation. A study of electric power requirements has also been undertaken by the Federal Power Commission.

3. The amount and allocation of Federal research and development in the energy field will affect the efficiency of various components of our energy system, and, consequently, the rate and pattern of our national economic growth.

4. Acting upon the recommendations of the Director of the Bureau of the Budget, I direct that a comprehensive study be undertaken of the development and utilization of our total energy resources to aid in determining the most effective allocation of our research and development resources. I would expect the Department of the Interior and the Federal Power Commission to provide significant assistance in the conduct of the study.

5. The study is to be undertaken under the direction of a committee comprised of the above listed officers, with the Director of the Office of Science and Technology as Chairman and the Chairman of the Council of Economic Advisers as Vice Chairman. Where appropriate, departments and agencies not represented on the committee should participate in the development of the study and be consulted regarding it.

6. An interim report should be submitted by September 1, 1963.

(S) John F. Kennedy

Appendix B

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American Gas Association
American Petroleum Institute
Independent Petroleum Association of America
National Coal Association
Nation Coal Policy Conference, Inc.

Appendix E

INDUSTRY ADVISORY COMMITTEES

Coal Conversion to Liquid and Gaseous Fuels

Coal Extraction Techniques

Coal Transportation

Education

Energy Economics

Fission Reactors

Fuel Cells

Fusion

Gas Transportation

Magnetohydrodynamic Power Generation

Oil and Gas Utilization

Oil Exploration and Extraction

Oil Shale

Oil Transportation

Physics and Basic Science

Pollution Problems

Solar Energy

Thermal Power Generation

Thermionic Power Generation

Thermoelectric Power Generation

Transmission and Storage of Electricity

Water Desalination

744-041 O—65——30

Appendix F

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Agruss, B.	Solar Energy	General Motors Corporation.
Allen, George	Oil Shale	Union Oil Company of California.
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Calhoun, John C., Jr.	Water Desalination	U.S. Department of the Interior, Office of the Secretary.
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Guthrie, Boyd	Oil Shale	Socony Mobil Oil Company.
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Kilgore, Lee A	Thermal Power Generation.	Westinghouse Electric Corporation.
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Weast, Robert	Gas Transportation	Con-Gas Service Corporation.
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Winger, J. A.	Oil Transportation	Texaco, Inc.
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Appendix G

DISTRIBUTION OF CONTRIBUTORS

	Technical papers	Reviews	Advisory commit-tees	Staff and special contributors	Total	Percent of total
Industry	5	85	130	8	228	46
Government	71	39	48	6	164	33
University	2	20	37	11	76	15
Other	2	15	10	1	28	6
Totals	80	159	225	31	496	100

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ENERGY R&D AND NATIONAL PROGRESS:

FINDINGS AND CONCLUSIONS

An Interdepartmental Study • September 1966

PRINCIPAL GOVERNMENT R&D ISSUES AND RECOMMENDATIONS

Nuclear Power

The major energy issue is the size and direction of the atomic power program, both in magnitude of Government involvement and in overall national significance. The most economical program should be pursued which will insure flexibility and reap the benefits of lower energy costs. Past Government encouragement and participation was necessary to develop light-water reactors. Now, private industry is investing additional R&D in further improvements which will undoubtedly lower energy costs.

In the long run R&D should be directed towards improving reactor fuel utilization (e.g., higher conversion ratios and power densities), or providing additional supplies of low-cost fissile fuel. Even with the expected advent of breeder reactors (with conversion ratios greater than one) which would produce more fissile material than that consumed, the continued growth of nuclear power will probably be faster than the production rate of bred fissile material; therefore some fissile material will have to be supplied from natural resources. Ultimately, breeding will provide most of the fissile material for system requirements.

While private industry will probably concentrate on improving existing commercial reactors, the Government should play a key role in developing more advanced reactors with better fuel utilization. Present development schedules should be maintained so as to accomplish development and final commercial application within the normally expected 15-year time period. Concurrently, the Government should encourage development of more than one breeder or near-breeder concept as a hedge against possible failure of any one approach.

Crude Oil and Natural Gas Substitutes

Domestic reserves of gas and petroleum are relatively small enough to warrant governmental interest in the timely availability of additional resources and economical substitutes. Imports from other countries with large reserves and lower production costs, or substitutes in the form of fuel cells

or storage batteries, will tend to offset the impact of declining domestic reserves; but it is still desirable to retain the flexibility which domestic liquid and gaseous fuels provide.

The vast supply of shale oil represents one domestic substitute for petroleum. Both private and Government R&D have decreased processing costs. The Government should encourage R&D in extraction techniques, basic geology, and processing and utilization. Advanced mining systems deserve emphasis—particularly *in situ* and other extraction methods which might reduce both costs and damage to environment.

Government support of research in the conversion of coal to petroleum products is desirable as a feasible future substitute. Also, R&D should be encouraged to lower production and other costs of coal processing in general.

Environmental Pollution Abatement

An important energy issue lies in the extent to which the increasing atmospheric pollution from fossil fuel combustion may require imposition of further regulations on the use of these fuels. Although such a development does not appear imminent, present understanding of environmental pollution problems is rudimentary. Consideration is being given to the research recommendations contained in the report of the Environmental Pollution Panel of the President's Science Advisory Committee (October 1965), and many of these are being implemented. It is entirely possible that our overall R&D program may have to be substantially altered to control pollution.

The trend of pollution regulatory policy will stimulate substantial private research and development directed at cleansing conventional pollution sources, but unfortunately practical and economical results through this approach may not reduce pollution quickly enough. Therefore, the Government should accept its share of responsibility for increasing R&D aimed at reducing damage from ongoing activities as well as developing substitute energy sources and processes that do not pose environmental problems.

The long-run pollution problems—such as heating of streams by power-plants, acid mine drainage, and radioactive and other contamination of water and air—require continuing Government research and surveillance. Existing programs in these areas should be strongly supported.

The aesthetic "pollution" caused by open wire electric transmission in many localities is a special area for Government concern. Except for encouragement via regulation or direct Government purchase, there appears to be sparse private incentive for R&D in overhead direct current or advanced underground high-voltage transmission. Support for R&D in this technology may have to come from the Government.

Effective coordination of energy research and development programs, within the larger framework of national energy policy, will require continued attention. The committee has considered various suggestions for new coordinating mechanisms, but makes no specific recommendations at this time in the belief that questions related to research and development can either be handled by existing mechanisms, such as the Federal Council for Science and Technology, or should be looked at in a broader national context than energy alone.

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