

Annex 555

“Restoring the Quality of our Environment: Report of the Environmental Pollution
Panel for the President’s Science Advisory Committee”, *The White House*,
November 1965

RESTORING THE QUALITY OF OUR ENVIRONMENT



*Report of The
Environmental Pollution Panel
President's Science Advisory Committee*

THE WHITE HOUSE

NOVEMBER 1965

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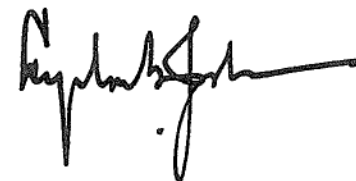
November 5, 1965

Ours is a nation of affluence. But the technology that has permitted our affluence spews out vast quantities of wastes and spent products that pollute our air, poison our waters, and even impair our ability to feed ourselves. At the same time, we have crowded together into dense metropolitan areas where concentration of wastes intensifies the problem.

Pollution now is one of the most pervasive problems of our society. With our numbers increasing, and with our increasing urbanization and industrialization, the flow of pollutants to our air, soils and waters is increasing. This increase is so rapid that our present efforts in managing pollution are barely enough to stay even, surely not enough to make the improvements that are needed.

Looking ahead to the increasing challenges of pollution as our population grows and our lives become more urbanized and industrialized, we will need increased basic research in a variety of specific areas, including soil pollution and the effects of air pollutants on man. We must give highest priority of all to increasing the numbers and quality of the scientists and engineers working on problems related to the control and management of pollution.

I am asking the appropriate Departments and Agencies to consider the recommendations and report to me on the ways in which we can move to cope with the problems cited in the Report. Because of its general interest, I am releasing the report for publication.



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Contents

	<i>Page</i>
Acknowledgements	ix
Introduction	1
The Effects of Pollution	3
Health Effects	3
Excessive air pollution for short periods	3
Prolonged exposure to ordinary urban air pollution	3
Water-borne pollutants and health	4
Pesticides and human health	4
Effects on Other Living Organisms	5
Why do we care?	5
Kinds of effects on organisms other than man	5
Impairment of Water and Soil Resources	7
Excess fertility in waters	7
Soil pollution	7
Polluting Effects of Detergents	8
Deterioration of Materials and Urban Environments	9
Climatic Effects of Pollution	9
The Sources of Pollution	10
Municipal and industrial sewage	10
Animal wastes	10
Urban solid wastes	11
Mining wastes	11
Consumer goods wastes	11
Unintentional Releases	12
In Which Directions Should We Go?	13
Recommendations	16
A. Principles	16
B. Actions	17
C. Coordination and Systems Studies	23
D. Baseline Measurement Programs	25
E. Development and Demonstration	26
F. Research	29
G. Manpower	33
H. Incompleteness of Recommendations	38
Appendixes:	
X1. Challenging Tasks for the Men and Women Who Can Improve the Quality of Our Environment	39
X2. Organizational Questions	48
X3. A "General" Index of Chemical Pollution	57
X4. Standards Development	59
X5. Metropolitan Problems	62
X6. Air Problems	66
X7. Water Quality	70

Subpanel Reports	
	Page
Y1. Soil Contamination.....	74
Y2. Health Effects of Environmental Pollution.....	91
Y3. Benchmark Surveillance.....	102
Y4. Atmospheric Carbon Dioxide.....	111
Y5. Solid Wastes.....	134
Y6. Combined Sewers.....	157
Y7. Effects of Chlorinating Wastes.....	168
Y8. Agricultural Wastes.....	170
Y9. Aquatic Blooms.....	173
Y10. Effects of Pollutants on Living Organisms Other Than Man.....	192
Y11. Improved Pest Control Practices.....	227
Index.....	293

Acknowledgements

The study was conducted under the general supervision of Colin M. MacLeod, Deputy Director, Office of Science and Technology.

The Panel drew on scientists and engineers from within the Federal Government, from state governments, universities and industry to form subpanels of experts, each of which explored a different problem. These busy men put in, on the average, several weeks of their time talking to scientists, studying and evaluating information published and unpublished, and writing reports. The reports are included as the "Y" Appendixes.

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Introduction

Environmental pollution is the unfavorable alteration of our surroundings, wholly or largely as a by-product of man's actions, through direct or indirect effects of changes in energy patterns, radiation levels, chemical and physical constitution and abundances of organisms. These changes may affect man directly, or through his supplies of water and of agricultural and other biological products, his physical objects or possessions, or his opportunities for recreation and appreciation of nature.

The production of pollutants and an increasing need for pollution management are an inevitable concomitant of a technological society with a high standard of living. Pollution problems will increase in importance as our technology and standard of living continue to grow.

Our ancestors settled in a fair and unspoiled land, easily capable of absorbing the wastes of its animal and human populations. Nourished by the resources of this continent, the human inhabitants have multiplied greatly and have grouped themselves to form gigantic urban concentrations, in and around which are vast and productive industrial and agricultural establishments, disposed with little regard for state or municipal boundaries.

Huge quantities of diverse and novel materials are dispersed, from city and farm alike, into our air, into our waters and onto our lands. These pollutants are either unwanted by-products of our activities or spent substances which have served intended purposes. By remaining in the environment they impair our economy and the quality of our life. They can be carried long distances by air or water or on articles of commerce, threatening the health, longevity, livelihood, recreation, cleanliness and happiness of citizens who have no direct stake in their production, but cannot escape their influence.

Pollutants have altered on a global scale the carbon dioxide content of the air and the lead concentrations in ocean waters and human populations. Pollutants have reduced the productivity of some of our finest agricultural soils, and have impaired the quality and the safety of crops raised on others. Pollutants have produced massive mortalities of fishes in rivers, lakes and estuaries and have damaged or destroyed

commercial shellfish and shrimp fisheries. Pollutants have reduced valuable populations of pollinating and predatory insects, and have appeared in alarming amounts in migratory birds. Pollutants threaten the estuarine breeding grounds of valuable ocean fish; even Antarctic penguins and Arctic snowy owls carry pesticides in their bodies.

The land, water, air and living things of the United States are a heritage of the whole nation. They need to be protected for the benefit of all Americans, both now and in the future. The continued strength and welfare of our nation depend on the quantity and quality of our resources and on the quality of the environment in which our people live.

The pervasive nature of pollution, its disregard of political boundaries including state lines, the national character of the technical, economic and political problems involved, and the recognized Federal responsibilities for administering vast public lands which can be changed by pollution, for carrying out large enterprises which can produce pollutants, for preserving and improving the nation's natural resources, all make it mandatory that the Federal Government assume leadership and exert its influence in pollution abatement on a national scale.

We attempt here to describe the problem, to distinguish between what is known and what is not, and to recommend steps necessary to assure the lessening of pollution already about us and to prevent unacceptable environmental deterioration in the future.

an adequate number to start with. They should be selected by use of modern probability methods.

The waters of a single drainage area may vary from small trickles to great lakes. In sampling these waters, however, we can take advantage of the way in which the waters flow from smaller streams into larger ones, and from larger ones into rivers and lakes.

The lands of a drainage area may vary even more widely: highly cultivated farm lands may grade through rangelands to rocky mountains and deserts. All are part of the general environment; the pollution of all must be considered in the overall result. We can take advantage of what we know about the likelihood of pollution of different kinds of land in planning the details of the sampling, but we must give all lands their appropriate chance to contribute to the final result.

APPENDIX Y4

Atmospheric Carbon Dioxide

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Contents

	<i>Page</i>
Section I. Carbon Dioxide From Fossil Fuels—The Invisible Pollutant	112
Introduction	112
The Recent Increase in Atmospheric Carbon Dioxide	114
Partition of Carbon Dioxide Among the Atmosphere, the Ocean, and the Biosphere	117
Probable Future Content of Carbon Dioxide in the Atmosphere	119
Possible Effects of Increased Atmospheric Carbon Dioxide on Climate	121
Other Possible Effects of an Increase in Atmospheric Carbon Dioxide	123
Melting of the Antarctic Ice Cap	123
Rise of Sea Level	123
Warming of Sea Water	123
Increased Acidity of Fresh Waters	124
Increase in Photosynthesis	124
Other Possible Sources of Carbon Dioxide	124
Oceanic Warming	124
Burning of Limestone	125
Decrease in the Carbon Content of Soils	125
Change in the Amount of Organic Matter in the Ocean	125
Changes in the Carbon Dioxide Content of Deep Ocean Water	125
Changes in the Volume of Sea water	125
Carbon Dioxide From Volcanoes	126
Changes Due to Solution and Precipitation of Carbonates	126
Conclusions and Findings	126
Section II. Detailed Computations	128
References	131

Section I. CARBON DIOXIDE FROM FOSSIL FUELS—THE INVISIBLE POLLUTANT

INTRODUCTION

Only about one two-thousandth of the atmosphere and one ten-thousandth of the ocean are carbon dioxide. Yet to living creatures, these small fractions are of vital importance. Carbon is the basic building block of organic compounds, and land plants obtain all of their carbon from atmospheric carbon dioxide. Marine plants obtain carbon from the dissolved carbon dioxide in sea water, which depends for its concentration on an equilibrium with the carbon dioxide of the atmosphere. Marine and terrestrial animals, including man, procure, either directly or indirectly, the substance of their bodies and the energy for living from the carbon compounds made by plants.

All fuels used by man consist of carbon compounds produced by ancient or modern plants. The energy they contain was originally solar energy, transmuted through the biochemical process called photosynthesis. The carbon in every barrel of oil and every lump of coal, as well as in every block of limestone, was once present in the atmosphere as carbon dioxide.

Over the past several billion years, very large quantities of carbon dioxide have entered the atmosphere from volcanoes. The total amount was at least forty thousand times the quantity of carbon dioxide now present in the air. Most of it became combined with calcium or magnesium, freed by the weathering of silicate rocks, and was precipitated on the sea floor as limestone or dolomite. About one-fourth of the total quantity, at least ten thousand times the present atmospheric carbon dioxide, was reduced by plants to organic carbon compounds and became buried as organic matter in the sediments. A small fraction of this organic matter was transformed into the concentrated deposits we call coal, petroleum, oil shales, tar sands, or natural gas. These are the fossil fuels that power the world-wide industrial civilization of our time.

Throughout most of the half-million years of man's existence on earth, his fuels consisted of wood and other remains of plants which had grown only a few years before they were burned. The effect of this burning on the content of atmospheric carbon dioxide was negligible, because it only slightly speeded up the natural decay processes that continually recycle carbon from the biosphere to the atmosphere. During the last few centuries, however, man has begun to burn the fossil fuels that were

locked in the sedimentary rocks over five hundred million years, and this combustion is measurably increasing the atmospheric carbon dioxide.

In the geologic past, the quantity of carbon dioxide in the atmosphere was determined by the equilibrium between rates of weathering and photosynthesis, and the rate of injection of volcanic carbon dioxide. On an earthwide average, both weathering and photosynthesis must speed up when the carbon dioxide content of the air is increased, and slow down when it is diminished; consequently, over geologic time the carbon dioxide in the air must have risen when volcanic activity was high, and must have gone down when volcanoes were quiescent. On a human scale, the times involved are very long. The known amounts of limestone and organic carbon in the sediments indicate that the atmospheric carbon dioxide has been changed forty thousand times during the past four billion years, consequently the residence time of carbon in the atmosphere, relative to sedimentary rocks, must be of the order of a hundred thousand years.

The present rate of production of carbon dioxide from fossil fuel combustion is about a hundred times the average rate of release of calcium and magnesium from the weathering of silicate rocks. As long as this ratio holds, precipitation of metallic carbonates will be unable to maintain an unchanging content of carbon dioxide in the atmosphere. Within a few short centuries, we are returning to the air a significant part of the carbon that was slowly extracted by plants and buried in the sediments during half a billion years.

Not all of this added carbon dioxide will remain in the air. Part of it will become dissolved in the ocean, and part will be taken up by the biosphere, chiefly in trees and other terrestrial plants, and in the dead plant litter called humus. The part that remains in the atmosphere may have a significant effect on climate: carbon dioxide is nearly transparent to visible light, but it is a strong absorber and back radiator of infrared radiation, particularly in the wave lengths from 12 to 18 microns; consequently, an increase of atmospheric carbon dioxide could act, much like the glass in a greenhouse, to raise the temperature of the lower air. [Water vapor also absorbs infrared radiation, both in the range of the CO₂ band centered at 15 microns, and at wave lengths near 6.3 microns. With the average concentration of water vapor in the lower air at mid latitudes, the effect of carbon dioxide absorption is reduced to about half that which would exist in an absolutely dry atmosphere. (Möller, 1963.) Ozone, which is an important constituent of the upper air, also absorbs some infrared at wave lengths around 9.6 microns, but its principal effect on air temperature is due to its absorption of ultraviolet and visible sunlight.]

The possibility of climatic change resulting from changes in the quantity of atmospheric carbon dioxide was proposed independently by the

American geologist, T. C. Chamberlain (1899) and the Swedish chemist, S. Arrhenius (1903), at the beginning of this century. Since their time, many scientists have dealt with one or another aspect of this question, but until very recently there was little quantitative information about what has actually happened. Even today, we cannot make a useful prediction concerning the magnitude or nature of the possible climatic effects. But we are able to say a good deal more than formerly about the change in the quantity of atmospheric carbon dioxide, and about the partition of carbon dioxide from fossil fuel combustion among the atmosphere, the ocean, and the biosphere.

THE RECENT INCREASE IN ATMOSPHERIC CARBON DIOXIDE

During the five years from 1958 through 1962, 5.3×10^{16} grams of carbon dioxide were produced by the combustion of coal, lignite, petroleum and other liquid hydrocarbons, and natural gas (see Tables 1 and 2).

TABLE 1.—Carbon Dioxide Produced by Fossil Fuel Combustion, 1950–62
[10¹⁶ grams]

Year	Coal ¹	Lignite ²	Liquid Hydrocarbons ³	Natural Gas ⁴	Total	As % of Atmospheric CO ₂ in 1950
1950.....	0.37	0.09	0.17	0.04	0.67	0.29
1951.....	.38	.09	.20	.05	.72	.31
1952.....	.38	.09	.21	.05	.73	.31
1953.....	.38	.09	.22	.05	.74	.32
1954.....	.38	.09	.23	.06	.76	.32
1955.....	.41	.10	.25	.06	.82	.35
1956.....	.44	.11	.27	.07	.89	.38
1957.....	.45	.13	.29	.07	.94	.40
1958.....	.46	.14	.29	.08	.97	.41
1959.....	.48	.14	.32	.09	1.03	.44
1960.....	.50	.14	.34	.10	1.08	.46
1961.....	.48	.15	.36	.10	1.09	.46
1962.....	.50	.15	.39	.11	1.15	.49
Total.....	5.61	1.51	3.54	.93	11.59	4.93

¹ Assumed carbon content, coal=75 percent.
² Assumed carbon content, lignite=45 percent.
³ Assumed carbon content, liquid hydrocarbons=86 percent.
⁴ Assumed carbon content, natural gas=70 percent. (Corresponding to a mixture by volume of 80 percent CH₄, 15 percent C₂H₆ and 5 percent N₂.)
Source: Computed from Table 2.

TABLE 2.—World Production of Fossil Fuels—1950–62
[Millions of Metric Tons]

Year	Coal	Lignite	Liquid Hydrocarbons ¹	Natural Gas ²	Total
1950.....	1,340	530	540	155	2,565
1951.....	1,375	550	620	180	2,725
1952.....	1,375	550	655	200	2,780
1953.....	1,380	555	690	210	2,835
1954.....	1,375	550	725	220	2,870
1955.....	1,500	630	790	240	3,160
1956.....	1,595	665	860	260	3,380
1957.....	1,625	765	905	285	3,580
1958.....	1,665	825	930	305	3,725
1959.....	1,730	845	995	345	3,915
1960.....	1,810	875	1,075	375	4,135
1961.....	1,760	900	1,140	405	4,205
1962.....	1,805	905	1,235	440	4,385
Total.....	20,335	9,145	11,160	3,620	44,260

¹ Includes Petroleum and Natural Gasoline.
² Assumed density of 8×10^{-4} gm cm⁻³ (1000m³=0.8 ton).
Source: World Energy Supplies. Statistical Papers, Series J, United Nations, New York.

This is 2.25 percent of the 2.35×10^{18} grams of carbon dioxide present in the atmosphere in 1950 (assuming an atmospheric carbon dioxide concentration of 300 ppm by volume—445 ppm by weight—and a mass of 5.2×10^{21} grams for the entire atmosphere.) On the average during 1958–1962, the CO₂ produced each year by fossil fuel combustion was 0.45 percent of the quantity in the atmosphere.

Beginning in 1958 and extending through 1963, two nearly continuous series of measurements of atmospheric CO₂ content were made. One of these series was taken at the U.S. Weather Bureau station near the top of Mauna Loa Mountain in Hawaii (Pales and Keeling, 1965), the other at the United States scientific station at the South Pole (Brown and Keeling, 1965). The measurements were carried out on an infrared gas spectrometer, with a relative accuracy for a single measurement of about ± 0.1 ppm. The observing stations are located near the centers of vast atmospheric mixing areas, far from uncontrollable sources of contaminants. Because of these nearly ideal locations, together with the high precision of the instruments, and the extreme care with which the samples were taken, these measurements make it possible to estimate the secular trend of atmospheric CO₂ with an accuracy greater by two

orders of magnitude than ever before. Some fifteen thousand measurements were carried out during the five-year period.

The data show, clearly and conclusively, that from 1958 through 1963 the carbon dioxide content of the atmosphere increased by 1.36 percent. The increase from year to year was quite regular, close to the average annual value of 0.23 percent. By comparing the measured increase with the known quantity of carbon dioxide produced by fossil fuel combustion, given in Table 4, we see that almost exactly half of the fossil fuel CO₂ apparently remained in the atmosphere.

Tables 3 and 4 show that between 1860 and 1940 the amount of CO₂ produced by fossil combustion, chiefly coal, was 7.9 percent, and by 1950, 10.3 percent, of the estimated atmospheric CO₂ content in 1950. By 1959, the total CO₂ production was equal to 13.8 percent of the atmospheric CO₂. Unfortunately, the accuracy of measurements of atmospheric CO₂ before 1958 is too low to allow estimates of the secular variation, and it is therefore impossible to compute directly whether the fraction of fossil-fuel CO₂ remaining in the atmosphere throughout the past hundred years has been constant, or slowly or rapidly changing.

TABLE 3.—Carbon Dioxide Produced by Fossil Fuel Combustion, 1860–1959
[10¹⁶ grams]

Decade	Coal ¹	Lignite ²	Liquid Hydrocarbons ³	Natural Gas ⁴	Total	As % of Atmospheric CO ₂ in 1950
1860–69.....	0.46	0.01			0.47	0.20
1870–79.....	0.70	.03			.73	.31
1880–89.....	1.06	.05	0.02		1.13	.48
1890–99.....	1.49	.08	.04	0.01	1.62	.69
1900–09.....	2.33	.15	.10	.02	2.60	1.11
1910–19.....	3.10	.21	.19	.04	3.54	1.53
1920–29.....	3.26	.31	.48	.07	4.12	1.75
1930–39.....	3.16	.35	.74	.12	4.37	1.86
1940–49.....	3.74	.49	1.14	.25	5.62	2.39
1950–59.....	4.11	1.07	2.44	.62	8.24	3.49
Total	23.41	2.75	5.15	1.13	32.44	13.81

¹ Assumed carbon content, coal=75 percent.
² Assumed carbon content, lignite=45 percent.
³ Assumed carbon content, liquid hydrocarbons=86 percent.
⁴ Assumed carbon content, natural gas=70 percent. (Corresponding to a mixture by volume of 80 percent CH₄, 15 percent C₂H₆ and 5 percent N₂).
Source: Computed from Table 4.

TABLE 4.—World Production of Fossil Fuels, 1860–1959
[Millions of Metric Tons]

Decade	Coal	Lignite	Liquid Hydrocarbons ¹	Natural Gas ²	Total
1860–69.....	1,660	85	5		1,750
1870–79.....	2,560	180	15		2,755
1880–89.....	3,850	285	55	10	4,200
1890–99.....	5,405	495	140	40	6,080
1900–09.....	8,455	880	310	80	9,725
1910–19.....	11,240	1,270	590	155	13,255
1920–29.....	11,850	1,875	1,510	285	15,520
1930–39.....	11,500	2,135	2,335	485	16,455
1940–49.....	13,570	2,995	3,605	970	21,140
1950–59.....	14,960	6,465	7,710	2,400	31,535
Total.....	85,050	16,665	16,275	4,425	122,415

¹ Includes petroleum and natural gasoline.
² Assumed density of 8 x 10⁻⁴ gm cm⁻³ (1000m³=0.8 ton).

Sources: From 1860 to 1949, United Nations, Department of Economic and Social Affairs: "World Energy Requirements". Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 1, pp. 3–33, 1956. For 1950–59, United Nations, World Energy Supplies. Statistical papers, Series J, United Nations, New York.

There are measurements of a somewhat different kind, which can give us useful information however. These are determinations of the so-called "Suess Effect."

PARTITION OF CARBON DIOXIDE AMONG THE ATMOSPHERE, THE OCEAN, AND THE BIOSPHERE

Because the fossil fuels have been buried for millions of years, they contain no Carbon 14. (This radioactive isotope is produced in the atmosphere by cosmic ray bombardment of nitrogen, and it has a half-life of only about six thousand years.) Consequently, the addition to the atmosphere of CO₂ from fossil fuel combustion, and its subsequent partition among the atmosphere, the ocean, and the biosphere will cause the ratio between radioactive and nonradioactive carbon to decrease. This manifests itself as a measurable reduction in the amount of radioactive carbon, for example, in tree rings grown in recent years compared with rings that grew during the 19th Century. This reduction, due to fossil fuel combustion, is called the "Suess Effect," after Professor Hans Suess, who first observed it (see Revelle and Suess, 1956).

The measurement of the "Suess Effect" is beset with many difficulties, the chief among them being that the Carbon 14 content of the atmosphere—more precisely the ratio of C^{14} to $C^{12} + C^{13}$ —varies by 1 or 2 percent from century to century apparently depending on the long-term variations in sunspot intensity. Tree ring measurements show that this ratio went up during the 15th and 17th Centuries, and down during the 16th and 18th, in each case by about 2 percent (Suess, 1956). Prior to the atomic weapons tests of the mid-Fifties, the ratio was lower by between 1 and 2 percent than in the middle of the 19th Century. This change during the past hundred years was apparently largely due to the "Suess Effect."

Taking the "Suess Effect" as between 1 and 2 percent over the period from 1860 to 1950, during which time the total carbon dioxide produced from fossil fuels was 10% of the atmospheric CO_2 , and assuming that presently occurring changes in the magnitude of the "Suess Effect" are in the same proportion to CO_2 from fossil fuel combustion as in the past, we can compute both the relative sizes of the oceanic and biosphere reservoirs that are taking up part of the added CO_2 , and the partition of CO_2 between these reservoirs. The amount taken up in the biosphere will be different if there are two or more sources of additional carbon dioxide, than if fossil fuels are the only source, but the amount absorbed by the ocean will not vary. Implied in the calculation is the further assumption that any CO_2 from other sources will have about the same ratio of C^{14} to total carbon as the atmosphere. Details are given in Section II.

The calculation shows that if the oceanic layer mixing with the atmosphere is several hundred meters thick, the amount of exchangeable carbon in the biosphere is less than or about equal to that in the atmosphere. These are both "reasonable" values. On the other hand, if another significant source of CO_2 is assumed for the last few decades, the amount of CO_2 added to the biosphere becomes so large that it should have been observed. In fact, no increase in the biosphere has been noted. Perhaps the most striking result is that the ocean takes up a relatively small fraction of the total added CO_2 , probably about 15%. In the past, the usual scientific belief has been that by far the larger part of any added CO_2 would be absorbed in the ocean. This is undoubtedly true if we consider a sufficiently long time period, of the order of thousands or even, perhaps, hundreds of years, because the ocean as a whole contains nearly sixty times as much carbon dioxide as the atmosphere. But over shorter times, only the uppermost layers of the ocean take part in exchanges with the air. Moreover, most of the oceanic carbon dioxide is present as carbonate and bicarbonate, balanced against metallic cations,

and a marked increase in oceanic CO_2 therefore requires an increase in cation concentration, which can be brought about only by rock weathering or solution of calcium-rich sediments. These are slow processes.

PROBABLE FUTURE CONTENT OF CARBON DIOXIDE IN THE ATMOSPHERE

We can conclude with fair assurance that at the present time, fossil fuels are the only source of CO_2 being added to the ocean-atmosphere-biosphere system. If this held true throughout the last hundred years, the quantity of CO_2 in the air at the beginning of the present decade was about 7% higher than in the middle of the last century (see Table 3).

Throughout these hundred years, the rate of fossil fuel combustion, and thus of CO_2 production, continually increased, on the average about 3.2 percent per year. The amount produced in 1962 was almost 25 times the annual production in the mid-1860's. The rate of increase may be accelerating. During the eight years from 1954 to 1962, the average rate of increase was 5%.

We can ask several questions about the future CO_2 content of the atmosphere. Two of these questions are:

- (1) What will the total quantity of CO_2 injected into the atmosphere (but only partly retained there) be at different future times?
- (2) What would be the total amount of CO_2 injected into the air if all recoverable reserves of fossil fuels were consumed? At present rates of expansion in fossil fuel consumption this condition could be approached within the next 150 years.

The second question is relatively easy to answer, provided we consider only the estimated recoverable reserves of fossil fuels. The data are shown in Table 5. We may conclude that the total CO_2 addition from fossil fuel combustion will be a little over 3 times the atmospheric content, and that, if present partitions between reservoirs are maintained, the CO_2 in the atmosphere could increase by nearly 170 percent.

The answer to the first question depends upon the rate of increase of fossil fuel combustion. Table 6 shows that if this combustion remains constant at the 1959 level, the total CO_2 injected into the atmosphere by the year 2000 will be about 28 percent of the atmospheric content in 1950. If the average rate of increase of combustion continues at 3.2 percent per year, the quantity injected into the atmosphere by the year 2000 will be about 42 percent; if the 5% rate of increase during the last 8 years persists, the quantity injected will be close to 60 percent. Assuming further that the proportion remaining in the atmosphere continues to be half the total quantity injected, the increase in atmospheric CO_2 in the year 2000 could be somewhere between 14 percent and 30 percent.

Based on projected world energy requirements, the United Nations Department of Economic and Social Affairs (1956) has estimated an amount of fossil fuel combustion by the year 2000 that with our assumed partitions would give about a 25 percent increase in atmospheric CO₂, compared to the amount present during the 19th Century. For convenience, we shall adopt this figure in the following estimate of the effects on atmospheric radiation and temperature.

TABLE 5.—*Estimated Remaining Recoverable Reserves of Fossil Fuels*

	10 ⁹ Metric Tons	Carbon Dioxide Equivalent, 10 ¹⁸ gms	As % of Atmospheric CO ₂ in 1950
Coal and Lignite ¹	2, 320	5. 88	252
Petroleum and Natural Gas Liquids ²	212	. 67	29
Natural Gas ³	166	. 43	18
Tar Sands ²	75	. 24	10
Oil Shales ²	198	. 63	27
Total.....	2, 971	7. 85	336

¹ Assumed to be 20 percent lignite containing 45 percent carbon, and 80 percent bituminous coal containing 75 percent carbon.

² Assumed carbon content of petroleum, natural gas liquids, and hydrocarbons recoverable from tar sands and oil shales=86 percent.

³ Assumed composition of natural gas by volume: CH₄=80 percent, C₂H₆=15 percent, N₂=5 percent.

Source: Computed from data given by M. King Hubbert, "Energy Resources, A Report to the Committee on Natural Resources of the National Academy of Sciences—National Research Council," NAS Publication 1000-D, 1962, pp. 1-141.

TABLE 6.—*Estimates of Carbon Dioxide From Fossil Fuel Combustion in Future Decades, Assuming Different Rates of Increase of Fuel Use*

Year	As percent of Atmospheric CO ₂ in 1950		
Growth rate, percent/year.....	0	3. 2	5. 0
1959.....	13. 80	13. 80	13. 80
1969.....	17. 30	18. 00	18. 47
1979.....	20. 79	23. 79	26. 15
1989.....	24. 28	31. 94	37. 90
1999.....	27. 77	41. 96	58. 75
2009.....	31. 26	57. 04	93. 14

POSSIBLE EFFECTS OF INCREASED ATMOSPHERIC CARBON DIOXIDE ON CLIMATE

One of the most recent discussions of these effects is given by Möller (1963). He considers the radiation balance at the earth's surface with an average initial temperature of 15°C (59°F), a relative humidity of 75 percent, and 50% cloudiness. We may compute from his data that with a 25 percent increase in atmospheric CO₂, the average temperature near the earth's surface could increase between 0.6°C and 4°C (1.1°F to 7°F), depending on the behavior of the atmospheric water vapor content. The small increase would correspond to a constant absolute humidity, that is, a constant weight of water in the atmosphere. The larger increase would correspond to a constant relative humidity, that is, as the temperature rose, the water vapor content would also rise to maintain a constant percentage of the saturation value. A doubling of CO₂ in the air, which would happen if a little more than half the reserves of fossil fuels were consumed, would have about three times the effect of a twenty-five percent increase.

As Möller himself emphasized, he was unable to take into account the vertical transfer of latent heat by evaporation at the surface and condensation aloft, or of sensible heat by convection and advection. For this reason he was unable to consider the interactions between different atmospheric layers in a vertical column. In consequence, Möller's computations probably over-estimate the effects on atmospheric temperature of a CO₂ increase. A more comprehensive model is being developed by the U.S. Weather Bureau. This includes processes of convection and of latent heat transfer through the evaporation and condensation of water vapor. Meaningful computations should be possible with this model in the very near future. But climatic changes depend on changes in the general circulation in the atmosphere, and these will be related to the spatial distribution and time variation of carbon dioxide and water vapor. The ratio of CO₂ to water vapor is higher in the polar regions than in low latitudes, higher in winter than in summer, and much higher in the stratosphere than near the ground. For example, the volume of carbon dioxide in the atmosphere at high latitudes is about half the volume of water vapor, while near the equator it is less than a tenth of the water vapor volume. As a result, the radiation balance of the earth will be affected differently at different seasons, latitudes, and heights by changes in the atmospheric CO₂ content. Without a comprehensive model incorporating both the fluid dynamics and the radiation transfer processes of the atmosphere it is not possible to predict how these effects will perturb the general circulation. Such a model may be available within the next two years.

Models of atmospheric thermal equilibrium in which vertical convection is allowed to maintain the observed vertical temperature gradient have recently been constructed by S. Manabe of the U.S. Weather Bureau (Manabe and Strickler, 1964; Manabe, 1965). These show that the effect of infra red absorption from the present atmospheric carbon dioxide at mid latitudes is to maintain a ground temperature about 10°C (18°F) higher than would prevail if no CO_2 were present. An increase in the CO_2 content without a change in absolute humidity would, according to these models, produce a somewhat smaller surface temperature rise than that estimated by Möller. But a considerable change would occur in the stratosphere, where the CO_2 concentration by volume is perhaps 50 times that of water vapor. A 25% rise in carbon dioxide would cause stratospheric temperatures to fall by perhaps 2°C (3.6°F) at an altitude of 30 kilometers (about 100,000 feet) and by 4°C (7°F) at 40 kilometers (about 130,000 feet).

One might suppose that the increase in atmospheric CO_2 over the past 100 years should have already brought about significant climatic changes, and indeed some scientists have suggested this is so. The English meteorologist, G. S. Callendar (1938, 1940, 1949), writing in the late 1930's and the 1940's on the basis of the crude data then available, believed that the increase in atmospheric CO_2 from 1850 to 1940 was at least 10%. He thought this increase could account quantitatively for the observed warming of northern Europe and northern North America that began in the 1880's. From Table 2 and our estimate of the CO_2 partition between the atmospheric, the ocean, and the biosphere, we see that the actual CO_2 increase in the atmosphere prior to 1940 was only 4%, at least from fossil fuel combustion. This was probably insufficient to produce the observed temperature changes. [But it should be noted that up to 2.5% of the atmospheric carbon dioxide (after partition with the ocean and the biosphere) could also have been added by the oxidation of soil humus in newly cultivated lands.]

As Mitchell (1961, 1963) has shown, atmospheric warming between 1885 and 1940 was a world-wide phenomenon. Area-weighted averages for surface temperature over the entire earth show a rise in mean annual air temperature of about 0.5°C (0.9°F). World mean winter temperatures rose by 0.9°C (1.6°F). Warming occurred in both hemispheres and at all latitudes, but the largest annual rise (0.9°C or 1.6°F) was observed between 40° and 70° N latitudes. In these latitudes, the average winter temperatures rose by 1.6°C (2.8°F).

The pronounced warming of the surface air did not continue much beyond 1940. Between 1940 and 1960 additional warming occurred in northern Europe and North America, but for the world as a whole and also for the northern hemisphere, there was a slight lowering of about 0.1°C (0.2°F) in mean annual air temperature (Mitchell, 1963). Yet dur-

ing this period more than 40% of the total CO_2 increase from fossil fuel combustion occurred. We must conclude that climatic "noise" from other processes has at least partially masked any effects on climate due to past increases in atmospheric CO_2 content.

OTHER POSSIBLE EFFECTS OF AN INCREASE IN ATMOSPHERIC CARBON DIOXIDE

Melting of the Antarctic ice cap.—It has sometimes been suggested that atmospheric warming due to an increase in the CO_2 content of the atmosphere may result in a catastrophically rapid melting of the Antarctic ice cap, with an accompanying rise in sea level. From our knowledge of events at the end of the Wisconsin period, 10 to 11 thousand years ago, we know that melting of continental ice caps can occur very rapidly on a geologic time scale. But such melting must occur relatively slowly on a human scale.

The Antarctic ice cap covers 14 million square kilometers and is about 3 kilometers thick. It contains roughly 4×10^{16} tons of ice, hence 4×10^{24} gram calories of heat energy would be required to melt it. At the present time, the poleward heat flow across 70° latitude is 10^{22} gram calories per year, and this heat is being radiated to space over Antarctica without much measurable effect on the ice cap. Suppose that the poleward heat flux were increased by 10% through an intensification of the meridional atmospheric circulation, and that all of this increase in the flow of energy were utilized to melt the ice. Some 4,000 years would be required.

We can arrive at a smaller melting time by supposing a change in the earth-wide radiation balance, part of which would be used to melt the ice. A 2% change could occur by the year 2000, when the atmospheric CO_2 content will have increased perhaps by 25%. Since the average radiation at the earth's surface is about 2×10^5 gram calories per square centimeter per year, a 2% change would amount to 2×10^{22} calories per year. If half this energy were concentrated in Antarctica and used to melt the ice, the process would take 400 years.

Rise of sea level.—The melting of the Antarctic ice cap would raise sea level by 400 feet. If 1,000 years were required to melt the ice cap, the sea level would rise about 4 feet every 10 years, 40 feet per century. This is a hundred times greater than present worldwide rates of sea level change.

Warming of sea water.—If the average air temperature rises, the temperature of the surface ocean waters in temperate and tropical regions could be expected to rise by an equal amount. (Water temperatures in the polar regions are roughly stabilized by the melting and freezing of ice.) An oceanic warming of 1° to 2°C (about 2°F) oc-

current in the North Atlantic from 1880 to 1940. It had a pronounced effect on the distribution of some fisheries, notably the cod fishery, which has greatly increased around Greenland and other far northern waters during the last few decades. The amelioration of oceanic climate also resulted in a marked retreat of sea ice around the edges of the Arctic Ocean.

Increased acidity of fresh waters.—Over the range of concentrations found in most soil and ground waters, and in lakes and rivers, the hydrogen ion concentration varies nearly linearly with the concentration of free CO_2 . Thus the expected 25% increase in atmospheric CO_2 concentration by the end of this century should result in a 25% increase in the hydrogen ion concentration of natural waters or about a 0.1 drop in pH. This will have no significant effect on most plants.

Increase in photosynthesis.—In areas where water and plant nutrients are abundant, and where there is sufficient sunlight, carbon dioxide may be the limiting factor in plant growth. The expected 25% increase by the year 2000 should significantly raise the level of photosynthesis in such areas. Although very few data are available, it is commonly believed that in regions of high plant productivity on land, such as the tropical rain forests, phosphates, nitrates and other plant nutrients limit production rather than atmospheric CO_2 . This is probably also true of the oceans.

Biological processes are speeded up by a rise in temperature, and in regions where other conditions are favorable higher temperatures due to increased CO_2 might result in higher plant production.

OTHER POSSIBLE SOURCES OF CARBON DIOXIDE

We are fairly certain that fossil fuel combustion has been the only source of CO_2 coming into the atmosphere during the last few years, when accurate measurements of atmospheric carbon dioxide content have been available. Carbon dioxide may have been produced by other sources during earlier times but it is not now possible to make a quantitative estimate. However we can examine the order of magnitude of some of the possible inputs from other sources, on the basis of our knowledge of the processes that might be involved.

Oceanic warming.—The average temperature of the ocean cannot have increased by more than 0.15°C during the past century, since any greater warming would have caused a larger rise in sea level than the observed value of about 10 centimeters. A more probable upper limit is $.05^\circ\text{C}$, because most of the sea level rise can be accounted for by glacial melting. An average $.05^\circ\text{C}$ rise would correspond to 0.5° in the top 400 meters. This would cause a nearly 3% rise in the CO_2 partial pressure.

After equilibration with the atmosphere, the partial pressure in both the air and the uppermost ocean layer would be higher by about 2.5%.

Burning of limestone.—Annual world production of carbon dioxide from the use of limestone for cement, fluxing stone, and in other ways, is about 1% of the total from fossil fuel combustion, or 4×10^{-5} of the atmospheric CO_2 content per year.

Decrease in the carbon content of soils.—Since the middle of the Nineteenth Century, the world's cultivated farmland has been enlarged by about 50%. This is an increase of close to a billion acres or 1.6 million square miles, corresponding to 2.7% of the land area of the earth, and perhaps to 5% of forests and grass lands. Most soil humus is believed to be concentrated in forests and grassy areas. Assume that the total humus is equal to twice the amount of carbon in the atmosphere and that half the carbon in the humus of the newly cultivated lands has been oxidized to carbon dioxide. The total injected into the atmosphere from this source becomes less than 5% of the atmospheric CO_2 .

Change in the amount of organic matter in the ocean.—About 7% of the marine carbon reservoir consists of organic material. Since a 1% change in the carbon dioxide content of the ocean changes the CO_2 pressure by 12.5%, a decrease by 1% in the marine organic carbon (which would increase the total oceanic carbon dioxide by .07%) would raise the carbon dioxide pressure of the ocean and the atmosphere by about 1%. An increase in the temperature of water near the surface, during the past one hundred years, could have speeded up the rate of oxidation of organic matter relative to its rate of production by photosynthesis. Measurements of the content of organic matter in the ocean are neither accurate enough nor sufficiently extended over time to allow a direct estimate of this possibility. A change of several percent could have occurred without detection.

Changes in the carbon dioxide content of deep ocean water.—The deep ocean waters contain about 10% more carbon dioxide than they would if they were at equilibrium with the present atmospheric content. This is a result of the sinking of dead organic remains from the surface waters and their subsequent oxidation in the depths. The combination of biological and gravitational processes can be thought of as a pump that maintains a relatively low carbon dioxide content in the surface waters and in the atmosphere. If the pump ceased to act, the atmospheric carbon dioxide would eventually be increased five fold. Variations in the effectiveness of the pump could have occurred without detection during the past 100 years, and could have caused notable changes in the atmospheric carbon dioxide content.

Changes in the volume of sea water.—During the Ice Age the volume of sea water varied by about 5%. Changes of this magnitude would change the carbon dioxide content of the atmosphere by 10 to 15%.

But during the last several thousand years, variations in oceanic volume have been small. During the past hundred years, world average sea level has varied by less than 10 centimeters. This very small volume change would have no appreciable effect on the atmospheric carbon dioxide.

Carbon dioxide from volcanoes.—Over geologic time, volcanic gases have been the principal sources of new carbon dioxide injected into the atmosphere. On the average the influx of volcanic CO_2 must have balanced the extraction from the atmosphere by rock weathering. The present rate of influx of volcanic CO_2 is close to a hundred fold less than that from fossil fuel combustion. No data exist on the worldwide level of volcanic activity over geologic time. It is conceivable that the level has fluctuated by two orders of magnitude, and that the fluctuations persisted for millenia, or even for millions of years.

Changes due to solution and precipitation of carbonates.—Calcium and magnesium carbonate precipitation on the sea floor lower the total CO_2 content of ocean water, but increase the carbon dioxide pressure and the free CO_2 content. Conversely, chemical weathering of limestone and dolomite on land lower the atmospheric CO_2 and the free CO_2 content of the sea, but increase the total oceanic CO_2 . The rates of these processes are about one order of magnitude lower than the present rate of production of carbon dioxide by fossil fuel combustion.

We conclude that the only sources of carbon dioxide comparable in magnitude to fossil fuel combustion during the last 100 years could have been a decrease in soil humus due to the increase in the area of cultivated lands, a decrease in the content of "dissolved" organic matter in the ocean, or a lowering of the carbon dioxide content of deep ocean waters. Marked changes in the oceanic regime would have been necessary for the latter two processes to have significant effects. As we have shown, none of the three processes are likely to be significant at the present time. Nor are any oceanographic data available which suggest that the required changes in the ocean occurred during the last hundred years.

CONCLUSIONS AND FINDINGS

Through his worldwide industrial civilization, Man is unwittingly conducting a vast geophysical experiment. Within a few generations he is burning the fossil fuels that slowly accumulated in the earth over the past 500 million years. The CO_2 produced by this combustion is being injected into the atmosphere; about half of it remains there. The estimated recoverable reserves of fossil fuels are sufficient to produce nearly a 200% increase in the carbon dioxide content of the atmosphere.

By the year 2000 the increase in atmospheric CO_2 will be close to 25%. This may be sufficient to produce measurable and perhaps marked

changes in climate, and will almost certainly cause significant changes in the temperature and other properties of the stratosphere. At present it is impossible to predict these effects quantitatively, but recent advances in mathematical modelling of the atmosphere, using large computers, may allow useful predictions within the next 2 or 3 years.

Such predictions will need to be checked by careful measurements: a series of precise measurements of the CO_2 content in the atmosphere should continue to be made by the U.S. Weather Bureau and its collaborators, at least for the next several decades; studies of the oceanic and biological processes by which CO_2 is removed from and added to the atmosphere should be broadened and intensified; temperatures at different heights in the stratosphere should be monitored on a worldwide basis.

The climatic changes that may be produced by the increased CO_2 content could be deleterious from the point of view of human beings. The possibilities of deliberately bringing about countervailing climatic changes therefore need to be thoroughly explored. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric CO_2 could be produced by raising the albedo, or reflectivity, of the earth. Such a change in albedo could be brought about, for example by spreading very small reflecting particles over large oceanic areas. The particles should be sufficiently buoyant so that they will remain close to the sea surface and they should have a high reflectivity, so that even a partial covering of the surface would be adequate to produce a marked change in the amount of reflected sunlight. Rough estimates indicate that enough particles partially to cover a square mile could be produced for perhaps one hundred dollars. Thus a 1% change in reflectivity might be brought about for about 500 million dollars a year, particularly if the reflecting particles were spread in low latitudes, where the incoming radiation is concentrated. Considering the extraordinary economic and human importance of climate, costs of this magnitude do not seem excessive. An early development of the needed technology might have other uses, for example in inhibiting the formation of hurricanes in tropical oceanic areas.

According to Manabe and Strickler (1964) the absorption and re-radiation of infrared by high cirrus clouds (above five miles) tends to heat the atmosphere near the earth's surface. Under some circumstances, injection of condensation or freezing nuclei will cause cirrus clouds to form at high altitudes. This potential method of bringing about climatic changes needs to be investigated as a possible tool for modifying atmospheric circulation in ways which might counteract the effects of increasing atmospheric carbon dioxide.

Section II. DETAILED COMPUTATIONS

Calculation of the Relative Sizes of the Ocean and Biosphere Reservoirs and the Probability of Other Sources of Carbon Dioxide at the Present Time

A portion of the carbon dioxide coming into the atmosphere will be transferred to the ocean, and another part will enter the biosphere. We can test the possibility of carbon dioxide sources other than fossil fuel combustion by examining the relative sizes of the required ocean and biosphere reservoirs.

Let

$A = \text{CO}_2$ in atmosphere.

$B = \text{equivalent CO}_2$ in the part of the biosphere that exchanges with the atmosphere.

$M = \text{CO}_2$ in the oceanic reservoir that exchanges with the atmosphere.

$\Delta A, \Delta B, \Delta M = \text{changes in CO}_2$ content of these reservoirs.

$s = \frac{-\Delta C^{14}\text{O}_2}{C^{14}\text{O}_2}$ in the reservoir system, $A + B + M$.

$a = \frac{\Delta A}{A} = \text{fractional change of atmospheric CO}_2$ content.

$fA = \text{CO}_2$ produced by fossil fuel combustion.

$bA = \text{CO}_2$ produced by other processes.

Then, at equilibrium,

$$\Delta A + \Delta B + \Delta M = (f + b)A$$

$$\Delta A = aA$$

$\Delta M = oM$, where $o = \frac{a}{12.5}$, owing to the buffer mechanism of sea water (Bolin and Eriksson, 1958).

And assuming that CO_2 produced by other processes has approximately the same C^{14} content as the atmospheric CO_2 , and knowing that fossil fuel CO_2 contains no C^{14} .

$$A + B + M = \frac{f}{s}A$$

Solving for ΔB , M , and ΔM , we find

$$\Delta B = A \left(o + f + b + \frac{of}{s} - a \right) \quad (1)$$

$$M = A \left(\frac{f}{s} - 1 - c \right) \quad (2)$$

$$\Delta M = oA \left(\frac{f}{s} - 1 - c \right) \quad (3)$$

Where

$$c = \frac{B}{A}$$

We know from measurements of tree rings grown during the middle of the Nineteenth Century, compared with those grown during the last few years, that for the period 1850–1950

$$0.02 \geq s \geq 0.01 \text{ (the "Suess Effect")}$$

During this same period, $f = 0.1$, hence

$$\frac{f}{5} \geq s \geq \frac{f}{10}$$

The series of atmospheric CO_2 measurements at Mauna Loa and Antarctica from 1958–1963 show that during these years

$$a = \frac{f}{2}$$

Substituting in equations (1), (2) and (3) we find, for different values of b and $\frac{B}{A}$, the values shown in Table 7 for $\frac{M}{A}$, $\frac{\Delta M}{f}$ and $\frac{\Delta B}{f}$.

From this table we see that with a "Suess Effect" of 2% (the most probable value), with fossil fuel combustion as the sole source of additional CO_2 , and with "effective" biosphere sizes of 2.5 to 0.5 times the atmospheric CO_2 , the oceanic reservoir is 2.6% to 6.0% of the volume of the oceans, equivalent to a layer of water 100 to 240 meters thick just below the surface. The size of the oceanic reservoir varies inversely with the size of the biosphere. For a "Suess Effect" of 1% (probably too low), and the same range of biosphere sizes, the assumed layer of complete mixing contains 11% to 14% of the ocean volume, and has an effective thickness of 440 to 560 meters.

TABLE 7.—Possible Sizes of Oceanic and Biosphere Reservoirs and Partition of Added CO₂ Among Reservoirs

$$b=0; s=0.2f; a=0.5f$$

$$(f=0.1)$$

$\frac{B}{A}$	$\frac{M}{A}$	$\frac{\Delta B}{f}$	$\frac{\Delta M}{f}$	$\frac{\Delta B}{B}$	$\frac{\Delta M}{M}$
0.5	3.5	0.36	0.14	0.072	0.004
1.0	3.0	.38	.12	.038	.004
1.5	2.5	.40	.10	.027	.004
2.0	2.0	.42	.08	.021	.004
2.5	1.5	.44	.06	.018	.004

$$b=0; s=0.1f; a=0.5f$$

0.5	8.5	.16	.34	.032	.004
1.0	8.0	.18	.32	.018	.004
1.5	7.5	.20	.30	.013	.004
2.0	7.0	.22	.28	.011	.004
2.5	6.5	.24	.26	.010	.004

$$b=.5f; s=0.2f; a=0.5f$$

0.5	3.5	.86	.14	.172	.004
1.0	3.0	.88	.12	.088	.004
1.5	2.5	.90	.10	.060	.004
2.0	2.0	.92	.08	.046	.004
2.5	1.5	.94	.06	.038	.004

A layer of water a few hundred meters thick would be acceptable to oceanographers as defining mixing over several decades. Hence, if the "Suess Effect" is close to 2%, the size of the biosphere reservoir is probably about equal to, or less than, that of the atmospheric reservoir. This coincides with other estimates that the effective size of the biosphere on land, including both living organisms and humus, ranges from 1/2 to one times the atmospheric carbon content. Possibly the organic content of the oceanic mixing layer should be included in the biosphere reservoir, but this is only a few tenths of the atmospheric CO₂.

In terms of the amounts of carbon they contain, the biosphere reservoir is much smaller than the oceanic reservoir. However, over short times in the ocean, only the relatively small "free" CO₂ content (dissolved and hydrated carbon dioxide) needs to be taken into account. Most of the oceanic carbon dioxide is present as carbonate and bicarbonate, and because of the peculiar buffer mechanism of sea water they do not have a very large quantitative effect on the partition between the sea and the air.

The Table shows if sources other than fossil fuel combustion had contributed much carbon dioxide to the air within the last few decades,

the biosphere would have increased in size by what is probably an observable amount. Such an increase has not been noted. We can conclude that, at least during the recent past, fossil fuel combustion has been the only significant source of CO₂ added to the ocean-atmosphere-biosphere system. The available data do not rule out the possibility that in earlier decades carbon dioxide may have come from oxidation of marine or terrestrial humus, as well as from fossil fuels, but if so, more than half of the amount produced was re-absorbed in the biosphere and the ocean.

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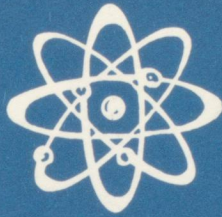
Annex 556

G. Seaborg, “The Role of Energy”, *United States Atomic Energy Commission*,
13 January 1966

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Remarks by
Dr. Glenn T. Seaborg, Chairman
U. S. Atomic Energy Commission
at
The Second Nobel Conference
Gustavus Adolphus College
St. Peter, Minnesota
January 13, 1966

THE ROLE OF ENERGY

It is a privilege and a pleasure for me to be here at your Second Nobel Conference and to take part in discussions of some of man's endeavors that are of vital concern to us today. Because the subject of energy, which I have been asked to cover, is a vast one, I will only be able to touch on some aspects of it. But I will try to highlight those aspects with which we will be most involved in the future - those areas of energy development and use which will, to a great extent, determine our future.

The role of energy in the history of mankind is a fascinating subject, and it is difficult to resist the temptation to trace this relationship in detail. I will try to resist this temptation today. Nevertheless, it is worthwhile to reflect somewhat on the history of energy and to recall some of its landmarks, if for no other reason than to remind ourselves of the dynamics of energy growth and application, and therefore to better prepare ourselves to understand and deal with energy in the future.

Man has been called "the animal who thinks, who reasons," "the tool-making animal," "the information-transmitting creature" and so on. But to a great extent he is a creature who has progressed only in proportion to his ability to extract and convert to useful, productive purposes the energy in his environment; his entire success may be outlined in

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terms of his achievement in energy extraction, conversion and application. And I should remind you that, at this point, I am referring to all energy - including agriculture and the use of animals for food and muscle power.

History reveals that the ascendancy of states and civilizations was greatly affected by their control of energy, whether it was their predominance in the use of animals - the horse or elephant, for example - or the ways in which they used energy to extract and convert mineral resources to tools and weapons. However, if we look back at man's use of energy, we realize that, relatively speaking, it is only in the last few moments of his existence here on earth that he has become an energy-consumer and manipulator to any large degree. Man's energy use has grown in the most remarkably exponential manner. For example: for the first million years of our existence, we consumed and converted energy on the animal level and only with the crudest of tools to give us any energy advantage over animal life. The discovery and control of fire gave us a small amount of light and heat and helped lift us from the Stone Age, but nothing more for thousands of years. With the advent of agriculture and animal husbandry, we raised ourselves a few more rungs on the energy ladder. Simple machines raised us further, but we were still using only food energy, converted by human and animal muscle, as our primary power. Taking another step forward, we harnessed wind and water - at times powerful, but sometimes undependable, sources of energy.

In all this time, from the very beginning of our history - the evolution of the human race - to the beginning of the 18th Century, the manner in which man extracted and converted energy did not change significantly. Men were able to make some use of the energy of wind and water - the windmill and the waterwheel were prime examples of this - but heat and light resulted from the burning of plant and fossil fuels, and kinetic energy was produced for the most part by the same processes of converting the energy of the food chain to muscle power - no matter whether that power came from a man or a team of oxen. Regardless of how we may revel in the glories of the past - the great pyramids, the temples of Ancient Greece, the early empires of the East and West - we must remember that all these were made by the muscle of man and beast - often working side by side and, for the most part, both harnessed to a life of slavery and incessant toil.

Then within the span of only a hundred years - the 18th Century - a new advance was conceived and took hold, one

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which added a new link in the energy conversion chain and began to release mankind from a life of endless drudgery. The idea, at first embodied in the steam engine, was that of converting the heat energy of burning fuel to mechanical energy to be used directly by a machine.

I think that too few of us today realize the significance of this discovery. The evolution of the steam engine was far more than the beginning of the Industrial Revolution. It was, in effect, a turning point in a million years of human history, and it happened, relatively speaking, overnight.

Up to this point, man had essentially only one way to amplify all the intelligence and creative energy he had been accumulating and passing on through the ages. That was directly through his own physical labor. The advent of the steam engine - a power machine which could be made portable and was independent of wind and water power - began to release man from living on the subsistence level, allowed him to turn in greater numbers to the use of the intellect and to extend the benefits he was beginning to enjoy to ever-increasing numbers of his fellowmen. It affected every facet of human life - the production and distribution of food, the building of shelters, methods of transportation and communication, the growth of cities, and the rise and fall of nations. In the century following the invention of the steam engine, man used more energy than he had in all previous recorded history, including his food consumption. And at this point in history an upward spiral began in man's creative evolution - his conscious modification of his environment - as well as in his use of energy.

The exponential growth of energy use continued with the invention of the internal combustion engine, which added a new demand for oil to our growing demand for coal. Prior to the use of coal and oil, almost all of man's heat energy had come from his food and the burning of wood. Now as we leaped forward in progress, we were moving backward in time to ancient energy sources - to the fossil fuels created under the earth millions of years ago.

It is interesting to note two factors in relation to man's energy consumption. The first is that we seem always to have discovered a fuel well before we had any great demand for it or technology for using it. Coal, for example, was only a minor substitute fuel for heating homes in England before it was found extremely useful for smelting ore and

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later for powering steam engines, and oil was used as a lamp fuel for centuries before its need as an engine fuel was developed. Secondly, in the course of our energy progress, man's use of various fuels has been evolutionary, with the applications of different fuels and the technologies for using them overlapping in time. The same or similar relationships, incidentally, seem to be present in the introduction of civilian nuclear power. Such relationships, in spite of the incredible changes in our over-all energy picture, were brought to mind most vividly in a recent article which pointed out, quite casually, that a man who had chopped wood as a youth to heat his family's home, and who was now the president of a major electric utility, was about to use nuclear power to supply heat, light and other labor-saving energy to all the homes of his vast community. Here, in the lifetime of one person, is represented a picture of the shift of uses of all major energy resources applied by man since the beginning of time. I have been reminded that many of us still chop and burn some wood today - though I hope more out of pleasure than necessity. And most of us are still using, to varying degrees, and for different uses, all of the major fuels used throughout our energy history - wood, coal, gas and oil.

It is interesting to note that as one energy source replaces another, the replaced material is needed and used for other applications. Wood today represents less than 1% of our total fuel in the U.S., but the demand for it for other uses is great and continues to grow. Though the time is still somewhat in the future, there will come a day when uranium and thorium will have replaced coal to a large extent as an energy source, and when coal will be far more valuable - probably vital - as a source of hydrocarbons and other complex and wondrous organic molecules for the chemical industry. There is even some current thinking about the future use of hydrocarbons as the basis for making synthetic food. This is only speculative, however, and the shift in our possible uses of resources is a vast subject which I cannot explore to any extent today.

Following the development of the steam engine, probably no other development has had as widespread an effect on man as that of electricity. There are many significant factors concerning the introduction and development of electricity which affected man's total energy picture. Electricity provided a rapid means of transporting energy over great distances. It made possible the conversion of heat and mechanical power into a form which could be "shipped" great

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distances through a wire and then converted back into heat and mechanical power and into light. It was able to supply men with power in smaller and more easily controlled quantities. But perhaps most significantly, it was responsible for a revolution in human communication - a revolution which is still continuing. It is almost overwhelming to contemplate the rapid extension of knowledge and ideas since electricity made possible the introduction of the telegraph, telephone, radio, television and the electronics of the computer and data-processing technology.

History may some day show that the discovery and use of electricity, the ingenious ways in which man learned to apply it, were responsible for the most significant advances of the human race. In addition to the control it has given us over larger amounts of energy, its refinement in systems which give us control over the most minute quantities of energy make possible a new relationship between men, and between man and nature, providing us with a better understanding and control of nature. We are just beginning to delve into vast new possibilities in the field of electronics - particularly in relation to computers, automatic data processing equipment, control and communications systems, and the new discipline of bionics. Advances in these areas will have much to do with how we live in the future. They will also be largely responsible for our exploration outward into the cosmos and inward to the mysteries of matter and life. In this latter regard, we are using energy to help us discover what energy is - and also what we, its users, are.

In discussing the role of energy it is important to note that, in terms of end uses, a major energy requirement is for heat - space heat and industrial process heat. About 40% of our total energy input goes for such uses. In these applications natural gas plays a leading role, supplying about 40% of our space heating and about 35% of our industrial process heat. Natural gas and natural gas liquid together supply a larger percentage of our industrial process heat than does coal, and the use of gas for all heating seems to be growing.

We have come a long way in our development of hydro-energy since the days of the waterwheel. However, as large and efficient as our modern hydroelectric systems are, the use of this form of energy accounts for less than 5% of our total energy in the U.S., and its share is declining. This does not hold true in other parts of the world though, where

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the existence of less fossil fuel gives hydropower a relatively more important role.

Our most recent advance in the history of energy, control of nuclear fission, has had a profound effect on mankind, partly because of the way it was introduced but perhaps more so because with its introduction came the realization that man had reached a new and crucial point in his ability to create and use power. With the first release of nuclear energy, twenty-odd years ago, we knew that it was only a matter of time before man would be able to amass and activate enough power to destroy himself completely or to raise himself to new high standards of living. I think we have now reached that time in human history.

Today our destiny depends not only on our control of destructive energy - nuclear weapons - a problem of which we are fully aware and for which we are earnestly seeking solutions, but also on how well we can put all energy to peaceful and productive uses. Assuming we will go the peaceful route - we must if we are to survive - there is still a major problem to be faced. And it is a problem ultimately involved in world peace as the control of nuclear weapons.

Looking at the energy statistics of today - or perhaps just looking at the conditions of peoples of the world - that problem is starkly revealed. Throughout my remarks to this point I have been talking about energy and "man" but, in reality, when I have been referring to man's ever growing use of energy and the benefits it has brought him, I have been referring to only a portion - the smaller portion - of those people who inhabit this earth. While some of us have experienced the dramatic growth of energy and its associated blessings, by far the larger percentage of the world's peoples are still living at the energy level of primitive man.

I was vividly reminded of this fact again on a trip around the world last fall following my attendance at a conference in Tokyo of the International Atomic Energy Agency. In several of the countries I visited, I found a majority of the population still living under almost primitive conditions while a small percentage, living on a level commensurate with the more industrially developed nations and using some of the latest science and technology, struggle to raise the living standards of the entire country.

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While the energy consumption of a country is not the only measure of its well-being, it does represent a very important factor. Most of you may be aware of the fact that the United States, with only 6% of the world's population, uses about 35% of the world's energy output. The specific figures showing the general disparity between the energy consumption of developed nations and the developing ones are similarly striking. This does not mean that a greater increase and a sharing of energy resources alone is the key to world development and a higher standard of living throughout the world. Much capital equipment is needed by a developing nation before it can productively use any large amounts of energy. Education and training are essential in order for it to be able to use the equipment and energy. And, of course, in most areas of the world, the very basic energy of food is still not being produced in quantities sufficient to keep the population alive and healthy.

But though most of this must be accomplished before a nation can make maximum use of energy resources, before its economy can reach the so-called "take-off" point, these prerequisites alone require the expenditure of much energy, and that energy must be expended and the equipment and the training to use it must somehow be made available. Before the developing nations can pull themselves up by their bootstraps, someone must supply the boots. In this respect, the developed nations of the world must realize that they are their brother's keeper. If they fail to act as needed, the disparity between the have and the have-not nations will grow at an even greater rate, eventually reaching a point where the situation becomes insoluble by peaceful means. (And considering the destructive power at man's disposal today, the use of other than peaceful means is unthinkable.)

The total energy challenge facing us is compounded by the fact that, when we talk about energy requirements, we are talking about dynamic, ever-growing needs. This is apparent not only because of the growth of world population, which by the end of this century - only 34 years away - will almost double, but also because no developed economy stands still. In the United States, total energy requirements have been increasing at a rate of about 3-1/2% a year and our demand for electricity has been doubling every ten years.

A major challenge facing the world, then, is: Can we muster and put to work enough energy not only to keep our developed and developing nations supplied and growing but also to lift our underdeveloped areas into the mainstream

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of the 20th century - above the mere subsistence level and hopefully to the point where they can begin to enjoy the benefits shared by the rest of mankind?

From the standpoint of the production of energy alone, I think that this can be accomplished and I would like to devote the remainder of my talk to discussing some ways in which this aspect of the problem can be solved. Of course, all that I am going to say is based on the assumption - the necessity - that the major powers of the world solve their political differences peacefully.

First of all, let us tackle a big, over-all question: Do we have enough energy resources here on earth to support our growing population at a high-energy level - a level which will see almost everyone well-fed, well-clothed and well-housed? Projecting the total energy on earth and reaching the earth, and assuming reasonable control of the growth of world population can be obtained, I believe we can be optimistic about this - but only if we take full advantage of all the energy resources at our command and develop the best technologies for using them.

While our fossil fuels are not inexhaustible and we are consuming them at a great rate, new reserves are being discovered which convince most people we are in no danger of running out of such fuel in the near future. But in this era of rapid change, the near future has a way of quickly becoming the present, and therefore it will not be long before we will be depending on the atom - on nuclear fission - to supplement our fossil fuels, and eventually to take over their work in certain areas. In the light of this, technologies are being developed to more efficiently and economically unlock the tremendous nuclear energy in the world's extensive uranium and thorium resources.

I will go into some detail on these technologies later, but just let me bring to light here a few facts which may give you some food for thought. Most of you are aware of the tremendous energy which can be released by nuclear fission from uranium and thorium as compared with the burning of fossil fuels. A cubic inch of uranium metal has the energy-potential of about 20,000 cubic feet of coal, 30,000 cubic feet of oil, or 25 million cubic feet of natural gas. Bearing this in mind, consider that the world's reserves of uranium and thorium number in the millions of tons, and that the breeder reactor technology now under development will allow us to extract two thirds of the nuclear fission energy

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in this quantity of fuel. Such a supply of energy, even at rates of consumption much greater than those of today, could keep us going for centuries to come. From the standpoint of the atom's contribution to our total energy picture, I think you will agree that our future looks bright.

There are, of course, many people who look to the darker side of the picture and point out the total destructive potential of all the nuclear weapons in existence today. Certainly the existence of such destructive power is reason for grave international concern and for the most intensive efforts toward arms control and disarmament. We are making these efforts and we are making some progress in them, even if it is primarily in agreement that some systems of arms control and disarmament must be put into effect. We simply must see more substantial progress made in this area in the future.

But idealistic as it may seem in the light of the current world situation, let me go so far as to reverse the situation. Think for a moment what the world might accomplish if all this potentially destructive energy were turned over to peaceful, productive uses, and the nations of the world agreed to devote it to such. And I might add that such a conversion of nuclear fuel from military to peaceful uses is entirely feasible from a technical point of view.

It is mainly through energy that man is able to amplify his intelligence and creativity - his wisdom or folly. In view of this, what tremendous opportunities are possible, therefore, for the human race if it could somehow make patience, reason and understanding prevail.

Hopeful that such will eventually be the case, let me turn in the concluding minutes of this talk to some of the specific energy challenges we face.

A first and foremost energy problem in the world today is the production of enough food to feed the growing population. While agriculture is decidedly not my field - I do not even have a green thumb - I have heard few experts in this area who do not believe that it is possible, with considerable effort, to substantially raise world food production and keep it growing in line with a reasonably controlled rate of growth of world population. To do this, there are many associated energy requirements. They involve such things as the increased production of chemical fertilizers, the development of more arable land, better control of land

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and water resources, the development of new and improved crops - of more yield and more resistant to weather and disease - and better methods of planting, harvesting, processing and distributing food. In addition to these efforts to produce more food on land, we will probably see in the future a greater effort to harvest the enormous food resources of the sea and, as I indicated before, the possibility of someday producing synthetic food. All these efforts will require the consumption of increasing amounts of energy.

Returning to those forms of energy with which I am more familiar - those we use to give us process heat and power - we must consider some of the ways in which we are going to meet the growing demand ahead.

Conservative estimates predict that world-wide fossil fuel consumption in the year 2000 will be over five times our consumption today, and this is based on an average consumption far below the present high-energy level of the U.S. Similar estimates tell us that the total energy the world will consume between now and the end of the century - again I remind you that this is a mere 34 years away - total world energy consumption will be over three times all the energy consumed from the beginning of human history to the present day. In the light of this, and if we hope to raise living standards all over the world, I do not think we have arrived any too soon at our knowledge of nuclear energy.

In the past two decades I believe we have made remarkable progress in learning about the many aspects of this versatile new source of energy - nuclear fission - and in developing a range of technologies to put it to use.

While I do not have time to go into detail on the many applications of radioisotopes, I should point out that these compact sources of energy, capable of supplying both radiation and heat, and so ideally suited to work in combination with electronics, have become valuable assets to medicine, agriculture and industry, as well as scientific research. Radioisotopes, which are to a great extent the by-products of what is unfortunately called "atomic waste," have begun to play an important role in our space program, in the supplying of auxiliary electrical power, and also on earth for supplying power for many types of remote unmanned information gathering and transmitting stations and devices.

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However, nuclear energy will probably make its greatest contribution to mankind in its role as a supplier of large amounts of electrical power. The nuclear power reactor is now beginning to take its place alongside the conventional power station as a major producer of electricity in the United States. While nuclear plants are currently producing only a small percentage of America's total electrical energy, they have recently become economically competitive with conventional plants in many areas of the country, and this fact, plus their proven reliability and safety, accounts for a growing interest in nuclear power.

Today we have 12 central station nuclear plants in operation in the U.S. producing enough electricity to supply the needs of more than a million families. Another dozen or so new plants are under construction or firmly planned - two of them to be adjacent to and supplementing the power of nuclear plants in operation for several years. It is also encouraging to note that there is hardly an electrical utility company in the country that is not seriously considering the possibility of using nuclear power to meet its growing demands.

But in nuclear power technology, as in the development of all technologies, there is no standing still. The nuclear power reactors in use today are primarily pressurized water and boiling water reactors of the type which "burn" only 1% or less of their atomic fuel. While these systems are efficient and apparently economic by today's nuclear standards, we must look ahead and consider the total nuclear energy picture, planning and working toward the maximum efficient use of our nuclear energy resources. Our ability today to gather information and make projections of future demands gives us great advantages in planning, and, we hope, will keep us from squandering many irreplaceable natural resources as we have unknowingly done in the past.

At present, the hope for our making maximum use of our uranium and thorium fuel reserves seems to be in the development of what we call advanced converter and breeder reactors. These reactors, in conjunction with fuel reprocessing systems, will allow us to use not a small percentage of our nuclear fuel, but essentially all of it. The reference I made earlier regarding the large amount of energy we could get from our nuclear fuels was based on the use of such reactor technologies. They are able to accomplish this because as they "burn" the fraction of the fissionable isotope uranium-235 in their initial fuel, they also transmute

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the abundant non-fissionable isotopes uranium-238 or thorium-232 in that fuel to fissionable plutonium-239 and uranium-233 respectively. Both these new fissionable isotopes, therefore, can be burned in place, as is done in some types of reactors, or they can be separated and reprocessed into new fuel elements for use in the same or other reactors. The difference between the advanced converters and the breeder reactors is essentially that, while the converter creates substantial quantities of new fissionable fuel by the method I have just described, the breeder actually produces more fissionable fuel than it consumes. Therefore, a nuclear fuel economy based on the use of these breeder reactors - producing power and their own fuel - offers us a way of stretching the world's supplies of uranium and thorium - supplies which are vast but which could still be used up too rapidly if we did not develop these new technologies. It is toward such a nuclear energy economy that the government, through the Atomic Energy Commission and in partnership with our growing nuclear industry, is working.

In addition to the role of nuclear power in conserving and making maximum use of our total energy resources, we see many other benefits. Abundant energy, economically produced, means cheaper energy. And in a world growing in population and needing to make better use of its land, cheaper energy makes more land liveable. It makes possible more heating in cold climates, air conditioning in hot climates (and do not underestimate the future growth of this), water for arid lands (we feel that nuclear desalting plants will someday play an important role in this area), improvements in agricultural production, and better transportation and communication, making the most remote areas of the globe accessible. In addition to this, we must remember that more energy - and cheaper energy - will be needed for the very process of extracting and using energy resources and materials from the earth as, of necessity, we have to go to deeper and to lower grade ores for all our vital mineral resources.

Since nuclear fuels are highly compact and easily transportable, they are relatively independent of geography and, therefore, will eventually be able to provide their energy at lower cost than conventional fuels anywhere in the world. This will become an important factor in the closing of the "energy gap" between nations and hopefully in raising the living standards of all people.

Aside from its use on land, nuclear power offers great promise on and under the sea and in space. The success of

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the Nuclear Ship Savannah, now in commercial service after 90,000 miles of trouble-free demonstration cruises to the world's leading ports, has stimulated interest in the building of more long-range nuclear-powered cargo and passenger ships.

The nuclear submarine has proved the superiority of nuclear propulsion under the sea, and this source of power, plus nuclear auxiliary power for supplying electricity for communications and undersea research equipment, will play a major role in our future exploration of "inner space" and the way in which we make use of the vast resources beneath the oceans of the world.

For the future of our exploration of outer space - and it will be in the not-too-distant future considering the fine progress we are making - we will require the use of nuclear rockets for space propulsion. Nuclear powered rockets with their high energy-to-weight ratio will be our best means of carrying large manned and unmanned payloads to and from the planets. Such rockets are being developed now with up to 250,000 pounds of thrust produced by hydrogen heated in a reactor only twice the size of a large garbage can. When we reach the moon and planets, and should we want to stay there for any length of time, I think it will be nuclear energy which will make long stays possible. The assembling and fueling of such nuclear power stations in orbit or on the moon or planets will provide some fascinating challenges.

Returning to our interests here on earth, there is another energy challenge I might call to your attention which merits some serious thought. Realizing the extent of the pollution of our environment these days, President Johnson last year requested a study of this matter by a special panel of his Science Advisory Committee. In the report the panel submitted to the President on November 6, 1965, one of the problems highlighted was stated as follows:

"Carbon dioxide is being added to the earth's atmosphere by the burning of coal, oil and natural gas at the rate of 6 billion tons a year. By the year 2000 there will be about 25 percent more carbon dioxide in our atmosphere than at present. This will modify the heat balance of the atmosphere to such an extent that marked changes in climate, not controllable through local or even national efforts, could occur. Clearly, we need to understand this problem and follow the details of change. Thus, it may be very important

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to find means of preventing or counteracting the changes or to change our source of energy to one that produces less carbon dioxide."

This is one particular pollution problem as highlighted in the report to the President. And the reason I bring this problem to your attention is that I think the growing use of nuclear energy may provide one of a number of solutions to this problem. Since nuclear power does not involve combustion, it can cleanly produce electric power for industry, homes and transportation, and possibly provide space heating for all three, either directly, as is currently being done by the Swedish reactor at Farsta, or through electricity. The possibility of electrically powered automobiles, operating on batteries which could be charged at service stations receiving nuclear-generated electricity, might also help to solve air pollution problems. I believe that these are a few of the important contributions which the atom could make to man.

In all that I have covered concerning nuclear energy to this point, I have been speaking primarily about nuclear fission. We must remember that success in the work we are undertaking in the field of controlled thermonuclear fusion would lead to a vast new source of energy. When we have solved the tremendously perplexing problems involved in controlled fusion, we will be able to use as a most abundant and powerful fuel the heavy hydrogen atom - deuterium - found in common sea water. The harnessing of such energy through controlled fusion will provide the world with a virtually limitless source of energy. Such energy would be helpful in raising the world's living standards and maintaining them indefinitely at a level approaching our own with its high-energy demands.

As most of you know, it is the fusion energy of the Sun that is the basis for so much of the energy here on earth and which is responsible for life itself. Only a tiny fraction - one-two billionth - of the Sun's energy reaches the earth, but that energy is so enormous that every twenty seconds it equals more energy than that in all nuclear weapons currently in existence. The Sun's energy is also responsible for lifting 100,000 cubic miles of water from the earth every year, which returns in the form of rain. While we use a great amount of the Sun's energy indirectly through plant life and hydroelectric power, we are able to harness only a small portion of it directly. No doubt our methods of using solar energy will be improved in the future

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and, in addition to the other energy sources available to us, we will need to make more use of the Sun's great energy.

I have covered many aspects of the role of energy today and have tried to give you a broad picture of their relationship to our progress and their importance to our future. I hope I have given you some idea of the prospects and problems we face in dealing with energy.

As I have indicated, and hopefully impressed you with the facts, the challenges that are posed by energy - our need for it, our ways of using it, and our control of it - are challenges that can be met by men who fully realize, as did Alfred Nobel, not the importance of power alone, but the power of science and technology, of knowledge, and of peace. If the world can be convinced - and I believe it can - that the better, and quicker, path to abundance and the good life is through the sharing of energy resources and the technologies for using them, I think many of you can look forward to reviewing the role of energy in the year 2000 and once again marvelling at the progress we have made. I hope I will be around at that time if for no other reason than to say, "I told you so."

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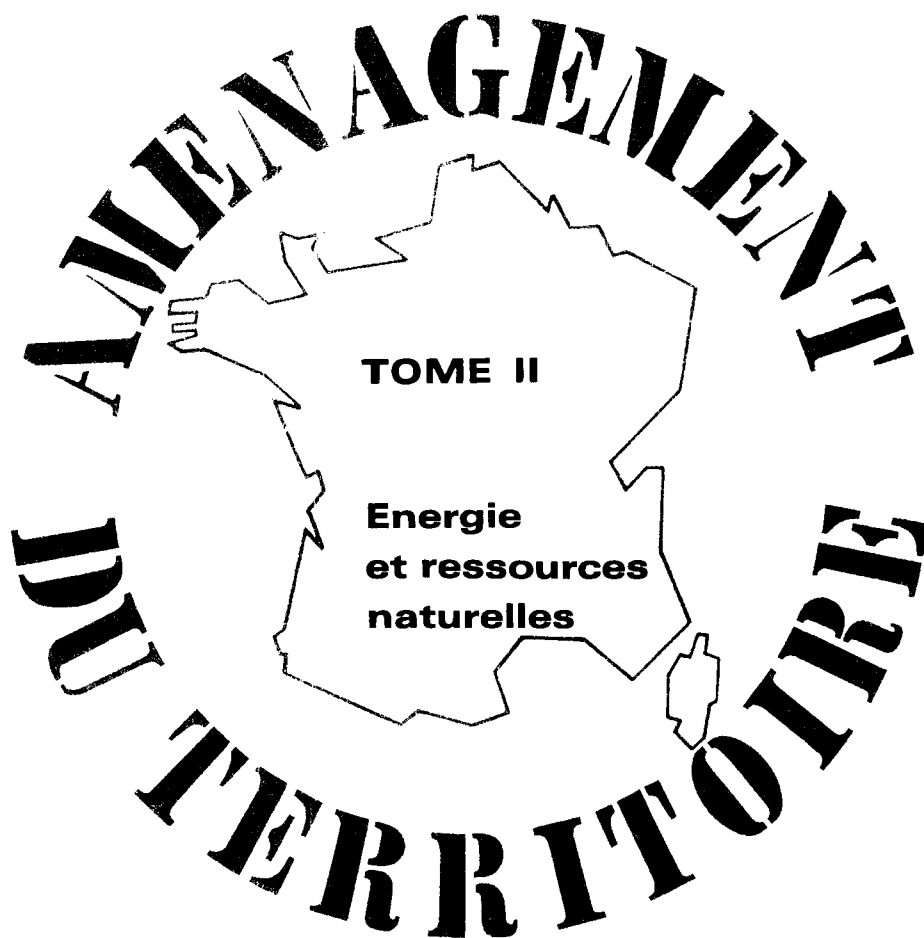
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Annex 557

“1er Colloque International sur l’Aménagement du Territoire et les Techniques
Avancées”, *Collège des techniques avancées et de l’aménagement du
territoire*, March 1968, pages 50-55, 17-36

Collège des techniques avancées
et de l'aménagement du territoire

^{1er}
**COLLOQUE INTERNATIONAL
SUR L'AMENAGEMENT
DU TERRITOIRE ET
LES TECHNIQUES AVANCEES**



mars 1968

LES PROBLEMES DE LA POLLUTION

Un autre point qui a été tout à l'heure mentionné par M. le Président, mérite d'être à nouveau indiqué, c'est l'aspect pollution. Je pense que cette considération jouera d'une façon très considérable à l'avenir, à côté des considérations strictement économiques et en faveur d'un développement croissant du nucléaire.

M. TUBIANA (F.). - Je suis d'accord avec M. Vendryes pour penser que les problèmes de pollution vont jouer un rôle fondamental dans le développement de l'utilisation de l'énergie, mais, en tout cas tant que l'on restera à la fission, les problèmes de déchets atomiques se poseront également de façon critique pour l'énergie nucléaire.

M. VENDRYES (F.). - Un mot à la suite de la remarque de M. Tubiana.

Je suis d'accord avec lui, à savoir que le problème des déchets peut devenir un problème tout à fait majeur vers la fin du siècle, compte tenu des productions et des consommations en question. C'est un problème inéluctable, que nous aurons à résoudre de toute manière. M. Tubiana a fait au passage une remarque en disant "au moins dans le cas de la fission" ; je voudrais souligner que dans le cas de la fusion également il y aura déchets. De toute manière c'est un problème très important auquel nous allons être confrontés.

Dans le rapport on mentionne cette solution futuriste d'expédier les déchets par des fusées sur une trajectoire de non retour. Je ne sais pas si on en arrivera à ces solutions extrêmes ; je pense qu'il existe d'autres solutions terrestres, mais incontestablement c'est un problème majeur lié au développement de l'énergie nucléaire.

M. BALACEANU (F.). - On a posé la question des combustibles solides par rapport aux liquides. Il faut bien voir que le combustible liquide a avant tout un avantage d'utilisation, qui a fait le succès actuel du pétrole. Il est certain que les schistes bitumineux et les gisements de charbon restent plus importants comme réserves géologiques que les hydrocarbures eux-mêmes, mais on a l'impression que la technique évolue d'une façon continue en utilisant d'abord les produits pétroliers, puis des produits plus lourds : schistes bitumineux, sables bitumineux, de sorte que l'on peut penser à une espèce d'évolution du raffinage des combustibles fossiles qui évoluent d'une façon continue depuis les gaz et les combustibles liquides jusqu'à des produits plus lourds qu'on rendra liquides par un raffinage sans doute plus coûteux de façon à les mettre à la disposition du consommateur.

Au point de vue pollution, lorsqu'on regarde la pollution urbaine, actuellement on s'aperçoit que la voiture électrique n'est pas justifiée. (On y reviendra sans doute dans les discussions) pour des raisons de simple pollution, et que l'on connaît d'autres sortes d'artifices techniques qui permettent de réduire d'une façon extrêmement importante la pollution urbaine.

Du reste, ces questions de pollution urbaine peuvent évoluer d'une façon extrêmement variable suivant que le réseau de circulation urbaine est composé d'auto-
routes à circulation relativement rapide ou au contraire d'un réseau à large densité dans lequel la vitesse de circulation est lente.

Enfin, en ce qui concerne la pollution par le soufre, il est bien évident que lorsqu'on raisonne à cinquante ans, un certain nombre de techniques nouvelles peuvent être envisagées pour abaisser d'une façon importante la pollution.

En tous les cas il semble que l'automobile électrique ne doit pas s'imposer, dans l'immédiat, pour des raisons de simple pollution parce qu'il est possible de combattre cette pollution par des moteurs conventionnels à combustion interne.

M. BOITEUX (F.). - Dans le domaine de la pollution, nous avons à faire face effectivement au problème de la pollution relative au moins au niveau des gros centres de production. Ne parlons plus pour l'instant de la voiture électrique ; nous en parlerons tout à l'heure. Mais, si l'on considère une grosse centrale productrice d'énergie électrique, si elle marche au fuel, elle pollue par sa cheminée, et si elle est nucléaire elle a des déchets à éliminer. Je ne sais pas dans quelle mesure on peut comparer des mètres cubes de déchets solides et des milliers de mètres cubes de déchets gazeux et en conclure que, finalement le nucléaire est plus, ou moins, gênant à cet égard que l'hydrocarbure. En tout cas, il y a là un problème sérieux que nous ne pouvons pas éluder.

M. GANDILHON (F.). - Je reviens à ce qui a été dit en matière de pollution : devons-nous nous attacher systématiquement à ces micro-pollutions que sont les pollutions urbaines actuelles, ou, au contraire, ne devons-nous pas penser à la pollution de caractère mondial, c'est-à-dire l'augmentation du taux de gaz carbonique dans l'atmosphère tout entier qui pourrait peut-être, dans une décade ou un demi-siècle, commencer à poser des problèmes de modification globale du climat terrestre. J'ai lu certaines choses assez impressionnantes à ce titre : ce qui pourrait conduire l'humanité à ralentir la combustion des combustibles au bénéfice nucléaire, en attendant qu'il y ait une sorte de course de vitesse entre la chlorophylle et les forêts, et la combustion des combustibles.

M. BOITEUX (F.). - M. Gandilhon dégage un argument en faveur des déchets nucléaires, parce qu'ils sont solides, vitrifiés et n'encombrent pas l'atmosphère de gaz carbonique, sans même parler du soufre, que la chlorophylle n'arrive pas à combattre.

M. BALACEANU (F.). - Je crois qu'à l'époque carbonifère, l'assimilation chlorophyllienne était forcée par une teneur en gaz carbonique plus importante. En tout cas, on connaît une série d'espèces végétales pour lesquelles, en fonction de la pression partielle de gaz carbonique l'assimilation chlorophyllienne croît avec cette pression, en particulier certaines algues.

M. TUBIANA (F.). - Excusez-moi de revenir, encore, sur le problème de la pollution, mais il est fondamental, surtout si l'on se place dans une perspective un peu lointaine.

On faisait tout à l'heure, des prévisions un peu futuristes sur l'évolution de la consommation de l'énergie et de la population du globe. A échéance plus proche, d'ici l'an 2000 - 2020, il y aura environ 8 milliards d'habitants sur le globe et sur ces 8 milliards, il n'y en aura qu'un qui habitera dans les pays à niveau de civilisation élevée. Or, tous les pays consommeront des quantités massives d'énergie qui seront vraisemblablement d'origine nucléaire ou à base d'hydrocarbure. Est-ce que tous les pays auront le même respect que celui que nous avons à l'heure actuelle - et encore assez relatif - pour ne pas sacrifier les grandes réserves mondiales d'air et d'eau ?

C'est en tout cas un problème vital pour l'avenir de l'humanité car les mers ne sont pas du tout une réserve illimitée d'eau. Si on n'y prend pas garde, le potentiel que représentent les océans sera gaspillé et ce sera irréversible.

M. ROTHERHAM (Grande-Bretagne). - Il est bien connu que la plus grosse partie de la pollution qui existe dans les villes se limite aux niveaux les plus bas. C'est surtout ce qui sort des cheminées, notamment des usines. Mais, à l'heure actuellement beaucoup d'usines n'ont pas d'émissions de soufre car on utilise des produits ou des systèmes chimiques pour s'en débarrasser. Des recherches sont en cours en Europe et en Amérique pour éliminer la pollution, et l'on peut prévoir avec certitude qu'il n'y aura pas à l'avenir de sulfures émis au moment de la préparation d'électricité.

La question du gaz carbonique reste un problème plus complexe, et je n'ai pas l'intention de proposer des solutions, car je ne sais même pas s'il est nécessaire de réduire l'émission de gaz carbonique.

Si nous devions revenir au début de ces débats, c'était à l'origine une comparaison entre l'énergie à base, soit d'énergie nucléaire, soit de matériaux fissiles. Je crois que l'objectif doit être essentiellement de s'assurer que les décisions qui seront prises aujourd'hui et dans les dix ans à venir ne porteront pas préjudice à la situation qui existera à la fin du siècle. Nous n'avons pas besoin de savoir exactement quelles seront les conditions à la fin du siècle, en détail, et même si nous le voulions, nous ne pourrions pas le faire. En conséquence, nous pouvons seulement faire des généralisations extrêmement vagues comme celles qui ont été présentées dans le document qui nous a été soumis. Nous mêmes qui commençons à partir d'hypothèses tout à fait différentes, arrivons à des conclusions pour les actions à entreprendre dans les dix à quinze ans à venir, qui sont virtuellement identiques à celles qui nous sont soumises par M. Laigroz.

Ceci me paraît extrêmement important ; pour cette période qui est à nos portes, il importe de ne pas faire de mauvais investissements, aussi bien sur le plan humain que sur le plan des machines. Il y a de nombreuses façons de faire des prévisions, mais, quelle que soit la manière dont on essaie de les faire, il faut arriver à des décisions valables.

Sur la question de la comparaison de l'énergie nucléaire et des autres énergies, je crois que la décision immédiate est assez facile à prendre, car nous avons beaucoup d'uranium à notre disposition en Grande-Bretagne ; nous nous sommes rendus compte que nous pouvions construire des centrales nucléaires qui, pour les besoins que l'on peut envisager dans les années à venir, produiront de l'électricité à moindre coût que les centrales utilisant le charbon.

Dans ces conditions, la décision est relativement facile ; il est facile de dire que l'on construira plus de centrales nucléaires et moins de centrales utilisant le charbon, et nous ne pensons pas que l'on puisse contester le bien-fondé de cette décision.

M. BOITEUX (F.). - Je remercie M. Rotherham qui a eu la sagesse de nous rappeler à la raison en nous disant : il n'est pas question de prévoir de façon précise ce qui se passera dans cinquante ans, mais simplement de s'assurer que les décisions que nous allons prendre pour les dix prochaines années ne vont pas trop gravement obérer l'avenir à plus long terme. Et c'est bien là, effectivement, l'objet de nos soucis. Il ne s'agit pas de faire de la prophétie gratuite, mais simplement d'essayer de prévoir ce que nous devons prévoir pour ne pas faire d'erreur coupable à long terme.

Je ne pense pas que ce soit tellement sous l'angle du choix entre centrale thermique classique ou centrale nucléaire que le problème soit posé. Il s'agit plutôt de savoir dans quelle mesure la croissance de la demande d'énergie va obligatoirement exiger que l'on aille vers le nucléaire, et donc vers l'électricité,

ce qui obligera l'électricité à envahir un marché des usages thermiques que, jusqu'ici, elle occupe relativement peu. La question est donc avant tout de savoir quel est le domaine promis à l'expansion de l'électricité, et notamment si, par exemple, cette énorme consommation d'énergie que constitue le chauffage domestique est appelée, à terme, à lui revenir ou, au contraire, à rester dans le domaine des combustibles fossiles.

C'est là, je pense, une des grandes questions posées, parce qu'elle commande finalement à la fois le développement de la production d'énergie nucléaire et en même temps les problèmes de transport et distribution. Personnellement je crois que l'électricité est appelée à prendre une place très notable dans le chauffage domestique qui, autant que je sache, représente le quart de la consommation d'énergie en ordre de grandeur, ou le cinquième, en tous cas un marché considérable. L'électricité est appelée, je pense, à prendre ce marché. D'abord, bien sûr, pour des raisons de pollution parce que, malgré tout, lorsque l'on opère au niveau d'une centrale, qu'elle consomme du nucléaire ou des hydrocarbures, elle pollue beaucoup moins que la somme des chauffages domestiques alimentés individuellement ou au niveau des immeubles par des chaudières qui sont toujours, quoi qu'on fasse, mal réglées ; ensuite, pour des raisons quantitatives et de prix en même temps : je pense que l'énergie électrique d'origine nucléaire est appelée à supplanter progressivement, pour ce genre d'usage, les énergies classiques, parce que ces énergies classiques sont handicapées à la fois par des questions de quantités et de prix.

Mais c'est là une opinion personnelle qui peut très bien ne pas être partagée par tous.

M. PATIN (F.). - Je voudrais attirer l'attention, à la suite de ce que vient de dire M. le Président, sur le fait que la localisation des grandes centrales dont nous allons parler tout à l'heure repose en grande partie sur les problèmes de refroidissement. Ceux-ci viennent du fait qu'on sait mal utiliser les calories de faible valeur énergétique. Or, précisément, ces calories de faible valeur énergétique, sont peut-être celles qui pourraient nous apporter la solution du problème du chauffage sous la forme du chauffage urbain, parce qu'il est bien connu que pour réaliser le chauffage on n'a pas besoin de calories de grande valeur. Or, ces calories, nous les gaspillons de plus en plus à réchauffer l'eau des rivières et l'air des campagnes.

Je crois que ce problème doit être posé puisqu'il entraîne celui de la localisation des grandes centrales et par conséquent, en même temps, celui du transport de l'énergie sous ses différentes formes, qu'on la transporte sous forme de matière lorsque les centrales sont au voisinage de la consommation, ou sous forme de courant lorsque les centrales sont au voisinage des lieux où on apportera les matières premières ; pour les grandes centrales, l'avenir est peut-être au bord des mers.

M. GUILLAUMAT (F.). - Aussi bien lorsque j'étais président de l'Electricité de France que depuis que je préside des intérêts pétroliers de l'Etat français, mes conclusions personnelles rejoignent celles de M. Boiteux.

Bien qu'ici nous ne regardions pas les problèmes de financement, de commercialisation et d'achat des différentes ressources, il est certain que dans les cinquante prochaines années, ces problèmes seront considérables. Pour les pays industriels qui sont importateurs d'énergie, c'est-à-dire presque toute l'Europe occidentale, le Japon et peut-être demain les Etats-Unis, le problème de payer son importation d'énergie se posera de telle façon que le nucléaire, dans les nations industrielles, est la seule solution pour maintenir leurs ressources à hauteur de leurs besoins.

M. BOITEUX (F.). - C'est effectivement un point de vue qui n'avait pas encore été évoqué et qui est fondamental, à savoir l'indépendance de l'Europe et en même temps l'équilibre de ses échanges en devises, et je pense que, là encore, l'énergie nucléaire trouve des arguments qui pèsent lourdement en sa faveur.

La question qu'évoquait M. Patin tout à l'heure, nous la reverrons au moment où nous parlerons de la concentration, soit littoral soit ailleurs, liée au problème de l'eau, au réchauffage de l'eau et aux problèmes qu'il a évoqués.

Après avoir consacré un temps un peu plus long que prévu point de savoir dans quelle mesure l'énergie d'origine nucléaire est appelée à prendre une place de plus en plus importante dans notre approvisionnement en énergie, nous avons pu noter, d'abord, qu'il y avait un problème d'échéance. Il est évident que le problème se pose en termes différents suivant que l'on raisonne à 20 ans ou à 50 ans d'échéance.

Ensuite, nous avons noté que l'aspect pollution était un aspect très fondamental du problème, alors que les deux formes d'énergie suscitent à cet égard des inquiétudes, soit par l'évacuation des déchets radioactifs, soit pour l'évacuation, si ce n'est du soufre que l'on saura dominer dans dix, vingt ou je ne sais combien d'années, du moins celle du gaz carbonique, sauf secours chlorophyllien.

Enfin, les aspects liés à l'approvisionnement de cette Europe qui manque de ressources fossiles et qui, par ailleurs, se doit de trouver un équilibre convenable pour ses devises.

Ceci me semble aller en faveur d'un développement très notable de l'énergie nucléaire, très notable ne voulant pas dire exclusif, et là dessus M. Laigroz, très sagement, avait prévu dans son rapport que, malgré tout, les hydrocarbures avaient encore un bel avenir devant eux.

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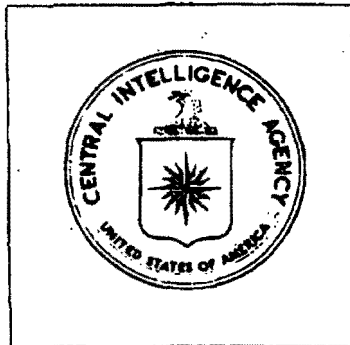
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Annex 558

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*A Study of Climatological Research
as it Pertains to Intelligence Problems*

AUGUST 1974

TABLE OF CONTENTS

	Page Number
PREFACE	
SUMMARY	1
WHAT ARE THE INTELLIGENCE ISSUES?	5
CLIMATIC PHENOMENA AND THE STATE OF THE ART	7
The State of the Art of Climatology	8
Thermal Distribution of Energy	8
Energy Reaching the Earth	9
Earth's Atmosphere	12
Current Approaches to Climatology	15
Lambian School	15
Smagorinsky-ian School	16
Budyko-ian School	19
RECENT MILESTONES	21
The Wisconsin Study	21
People, Places and Approaches	26
San Diego Conference	27
National Climate Plan	29
CONCLUSIONS	31
BIBLIOGRAPHY	33

SUMMARY

The western world's leading climatologists have confirmed recent reports of a detrimental global climatic change. The stability of most nations is based upon a dependable source of food, but this stability will not be possible under the new climatic era. A forecast by the University of Wisconsin projects that the earth's climate is returning to that of the neo-boreal era (1600-1850)—an era of drought, famine, and political unrest in the western world.

A responsibility of the Intelligence Community is to assess a nation's capability and stability under varying internal or external pressures. The assessments normally include an analysis of the country's social, economic, political, and military sectors. The implied economic and political intelligence issues resulting from climatic change range far beyond the traditional concept of intelligence. The analysis of these issues is based upon two key questions:

- Can the Agency depend on climatology as a science to accurately project the future?
- What knowledge and understanding is available about world food production and can the consequences of a large climatic change be assessed?

Climate has not been a prime consideration of intelligence analysis because, until recently, it has not caused any significant perturbations to the status of major nations. This is so because during 50 of the last 60 years the Earth has, on the average, enjoyed the best agricultural climate since the eleventh century. An early twentieth century world food surplus hindered U.S. efforts to maintain and equalize farm production and incomes. Climate and its affect on world food production was considered to be only a minor factor not worth consideration in the complicated equation of country assessment. Food production, to meet the growing demands of a geometrically expanding world population, was always considered to be a question of matching technology and science to the problem.

The world is returning to the type of climate which has existed over the last 400 years. That is, the abnormal climate of agricultural-optimum is being replaced by a normal climate of the neo-boreal era.

The climate change began in 1960, but no one including the climatologists recognized it. Crop failures in the Soviet Union and India during the first part of the sixties

were attributed to the natural fluctuation of the weather. India was supported by massive U.S. grain shipments that fed over 100 million people. To eat, the Soviets slaughtered their livestock, and Premier Nikita Khrushchev was quietly deposed.

Populations and the cost per hectare for technological investment grew exponentially. The world quietly ignored the warning provided by the 1964 crop failure and raced to keep ahead of a growing world population through massive investments in energy, technology, and biology. During the remainder of the 1960s, the climate change remained hidden in those back washes of the world where death through starvation and disease were already a common occurrence. The six West African countries south of the Sahara, known as the Sahel, including Mauretania, Senegal, Mali, Upper Volta, Niger, and Chad, became the first victims of the climate change. The failure of the African monsoon beginning in 1968 has driven these countries to the edge of economic and political ruin. They are now effectively wards of the United Nations and depend upon the United States for a majority of their food supply.

Later, in the 1970s one nation after another experienced the impact of the climatic change. The headlines from around the world told a story still not fully understood or one we don't want to face, such as:

- . Burma (March 1973)—little rice for export due to drought
- . North Korea (March 1973)—record high grain import reflected poor 1972 harvest
- . Costa Rica and Honduras (1973)—worst drought in 50 years
- . United States (April 1973)—“flood of the century along the Great Lakes”
- . Japan (1973)—cold spell seriously damaged crops
- . Pakistan (March 1973)—Islam planned import of U.S. grain to off-set crop failure due to drought
- . Pakistan (August 1973)—worst flood in 20 years affected 2.8 million acres
- . North Vietnam (September 1973)—important crop damaged by heavy rains
- . Manila (March 1974)—millions in Asia face critical rice shortage
- . Ecuador (April 1974)—shortage of rice reaching crisis proportion; political repercussions could threaten its stability

- . USSR (June 1974)—poor weather threatens to reduce grain yields in the USSR
- . China (June 1974)—droughts and floods
- . India (June 1974)—monsoons late
- . United States (July 1974)—heavy rain and droughts cause record loss to potential bumper crop.

During the last year every prominent country has launched a major new climatic forecasting program.

- . USSR reorganized their climatic forecasting groups and replaced the head of the Hydrometeorological Service.
- . Japan is planning to launch a major earth synchronous (U.S. manufactured) meteorological satellite and has secured complete collection, processing, and analysis systems from the U.S.
- . China has made major purchases of meteorological collection and analysis equipment from western industrial sources.
- . India is studying the application of climatic modification to secure a more homogeneous distribution of moisture from an erratic drought/flood monsoon.
- . The U.S. National Academy of Sciences is preparing its recommendation for a National Climatic Research Program.
- . The National Science Foundation (NSF) and the National Oceanographic and Atmospheric Agency (NOAA) have developed a National Climate Plan which will be presented to the Office of Management and Budget (OMB) for funding in FY 76.

Climate is now a critical factor. The politics of food will become the central issue of every government. On July 19, 1974, the Kiev Domestic Service reported massive rains and quoted an old proverb from Lvov Oblast, "The rains come not on the day for which we pray but only when we are making hay." The climate of the neo-boreal time period has arrived.

Annex 559

“Report No.23: Canada’s Energy Opportunities”, *Science Council of Canada*,
March 1975, pages 81-92

23 Science Council
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OTTAWA
INSTITUT CANADIEN DE L'I.S.T.

Canada's Energy Opportunities

ANALYZED

Table of Contents

I. An Initial Perspective	9
II. Present Trends	15
The Energy of Today	17
Oil	17
Natural Gas	19
Coal	20
Hydro-Electricity	21
Uranium	21
Present Energy Use	22
Residential Sector	25
Commercial Sector	25
Transportation Sector	25
Industrial Sector	26
Substitutions	26
Short-Range Considerations: A Summary	27
III. Pricing and Self-Sufficiency	31
IV. Coordination and Planning: The Key Issues	35
The Financial Constraints	37
Personnel Constraints	39
Equipment and Materials Constraints	40
The Planning Problem	41
V. The Future: Demand	45
Technical Directions for Energy Conservation	48
Some Problems Surrounding the Prospect of Reduced Demands	48
Demand Policy – The Needs for Action	50

VI. The Future: Supplies	53
Fossil Fuels	58
Hydro-Electricity	63
Fission Energy	64
Fusion Energy	66
Complementary Sources	68
Solar Energy	68
Biomass Energy	70
Energy from Waste	72
Wind Power	73
Geothermal Energy	74
Tidal Power	75
Hydrogen Technology	76
Direct Energy Conversion	77
Fuel Cells	78
Transportation of Energy	78
VII. Environment	81
Global Considerations	83
Local Impacts	84
Environmental Quality: What are the Issues?	84
Managing Energy and the Environment	91
VIII. The Roles of the Main Participants	93
IX. Technical Directions for Energy Supplies	101
Fossil Fuels	104
Nuclear Power	108
Complementary Energy Forms	109
The Major Program Approach: An Organizational Vehicle	111
X. Epilogue	115
Science Council Committee on Energy Scientific Policies	117
Members of the Science Council of Canada	119
Publications of the Science Council of Canada	123
Index	129

VII. Environment

“‘Power corrupts’ was written of man’s control over other men, but it applies also to his control of energy resources. The more power an industrial society disposes of, the more it wants. The more power we use, the more we shape our cities and mould our economic and social institutions to be dependent on the application of power and the consumption of energy.”* This description of the modern industrial state underlines strikingly our growing dependence on energy.

There is no doubt that an increasing population in search of food, water, fibre, materials and energy will increase total global pollution.

Present trends are increasingly patterning our way of life to a style which relies heavily on a continuous energy subsidy. Because of incentives, regulations and externalities, the market mechanism is partly incapacitated, so that excessive energy demand and growth cannot be viewed as the expression of preference by a democratic society. Not only does this energy demand grow at an exponential rate, but it tends as well to foreclose other, less energy intensive development options by creating an all-encompassing life style from which it is becoming increasingly difficult to withdraw should one so decide. The extensive use of the private automobile, for example, has made urban sprawl possible; low density housing, in turn, has discouraged the expansion of mass transit and reinforces the automobile as the only viable transportation mode. Yet, it is necessary to consider life style in any examination of energy options.

The excessive use of energy, therefore, not only wastes resources by tending to encourage the inefficient utilization of energy, but also contributes to the emergence of a self-generating energy demand and the creation of a society which is totally dependent on the modern technological applications of energy and, moreover, quite helpless without them.

If such dependency is undesirable from an economic and a security point of view, in that it forces us to bank heavily on a “technological fix” to provide needed supplies in the future, it is also undesirable for a second, perhaps more fundamental, reason. The use of energy affects the environment in myriad ways. Energy use may either protect and enhance or degrade and endanger the environment. Although our knowledge of energy’s impact is at present still rather elementary, we do know enough to worry whether, on balance, the continuation of our present ways will cause massive and irreversible environmental damage. Should further research reveal that we are indeed running the risk of permanently harming our environment – some would go so far as saying endangering our very life support systems – the implications for our style of life in general and our energy policy in particular would be immense. Let us therefore examine more closely the interface between energy use and environmental quality.

* E. Cook, “The Flow of Energy in an Industrial Society”, *Scientific American*, September 1971, Vol. 229, No. 3, pp. 134-147.

Global Considerations

Although we use the term “energy consumption” frequently, energy cannot properly be said to be “consumed”. It would be more accurate to say instead that it is transformed. The chemical energy contained in the gasoline that powers a car, for example, is partly transformed into kinetic energy, which moves the car, while the rest is lost as waste heat. Ultimately, all free energy is transformed into heat. This transformation is sometimes explained through the law of entropy, under which high grade energy forms are degraded into lower grade ones.

The world’s growing energy demand is thus responsible for the injection of increasing amounts of heat into the ambient environment, both atmospheric and aquatic. The human contribution to the earth’s energy budget remains relatively insignificant so far on a global scale.

On a local scale, of course, humans are already exerting an appreciable microclimatic effect through the creation of “heat islands” in large urban areas. Indeed, on a cold winter day in Montreal, society’s energy input will often exceed that of solar radiation. Although humanity’s activities are still too dispersed to exert a noticeable impact on climates of large regions, in the future the trend toward large urban aggregations (the Boston-Washington megalopolis, the Golden Horseshoe urban complex) means resulting energy release may soon be sufficiently significant to trigger climatic alterations regionally.

Our reliance on fossil fuels may accelerate this effect through the release of carbon dioxide (CO_2) into the atmosphere. Carbon dioxide is suspected of engendering a “greenhouse” effect: it is transparent to incoming solar radiation, but opaque to outgoing radiation and therefore tends to trap heat close to the earth’s surface. Although evidence of the effect of the increasing CO_2 concentration in the atmosphere is inconclusive, some experts assert that this factor could become significant enough to lead to a general warming trend in the global climate, if fossil fuel consumption develops as forecast. Ironically, this warming trend may be counterbalanced by the cooling induced by the increasing albedo of the atmosphere, due to the growing emissions of particulate matters.

Although controversy still surrounds the arguments on both sides of the “warming against cooling” debate, it is becoming more widely recognized that man’s activities on earth have reached a level where they have the potential of changing the world’s climate. Despite the sobering implications of such a trend, humanity’s tinkering with the global climatic equilibrium is proceeding unimpeded, although we still do not know what the ultimate result of our actions may be.

As one of the world’s intensive users of energy, Canada is contributing in no small measure to humanity’s overall energy activities. Furthermore, as Canada is located in northern latitudes, where the ecological web of life tends to be less complex and more susceptible to disruption, Canadian energy use may exert a relatively greater environmental impact than that in most other countries of the world.

Local Impacts

If the global aspects of the energy-environment interface are difficult to trace, the local impacts of energy use are much better known. The use of energy affects the environment at every step of the exploration - extraction - processing - transportation - conversion - consumption - waste product disposal cycle. The severity of the impact is, of course, a function of the technology used, local environmental conditions and the energy resource in question. A tripling of Canadian energy consumption within the next twenty-five years will thus exert an inevitable, although not necessarily proportional, impact on the environment. The cost of the environmental protection measures directly related to excessive energy use within the next decade is estimated conservatively at $\frac{1}{2}$ of 1 per cent of GNP.

It would be an unnecessary exercise to review here the many ways in which our demand for energy has affected the Canadian environment. *An Energy Policy for Canada** fulfills that role well and lists numerous examples of the environmental impact of energy activities. Among the chief problem areas Canadians have already encountered and will continue to encounter in the future are: open pit mining operations to recover coal and bitumen; construction of pipelines in permafrost; marine oil spills; atmospheric pollution from the burning of fossil fuels; the effects of surface mining and our desire to return the land to its original productivity and scenic quality by careful segregation and disposal of the overburden; thermal enrichment of water bodies close to electricity generating plants; disposal of radioactive wastes; flooding of valleys by hydro-electric projects; aesthetic scars resulting from power lines; etc.

In a report of this kind, it is more useful to identify instead the main areas for research to develop technologies to alleviate the impact of energy use on the environment. An overview of the recommendations for R & D based on the findings in one of our background studies is reproduced in Table III.

Finally, it is important to remember that some energy activities tend to exert a cumulative and synergistic impact on the environment: this makes preliminary impact assessment difficult and usually understates the amount of environmental degradation. Moreover, we should expect the success of more stringent environmental standards to remain largely illusory since no amount of regulation could countervail indefinitely the environmental effects of an energy demand that continued to grow exponentially.

Environmental Quality: What are the Issues?

Knowing the effects of energy activities on the environment does not by itself, of course, allow us to judge environmental quality. While some standards of environmental quality are fairly easily determined (for

* *An Energy Policy for Canada*, Department of Energy, Mines and Resources, Information Canada, 1973.

Table III – Tabulated Environmental Overview

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Mining of coal and uranium	Restoration techniques. Neutralization techniques. Control of 'acid mine drainage' and siltation. Health improvements. Improvements in mine atmospheres.	Developing Available Not available	Increasing Medium	Restoration performance legislation recommended. Strict mining regulations necessary. Restoration performance bond not a strong enough incentive. Require return of land to its original or better productivity. Elliot Lake acid drainage is a continuing concern. Study by Environment Canada, 1974.
Athabasca Tar Sands	Reclamation Pond technology. Effluent treatment.	Undeveloped Under study Undeveloped	High High Medium	Affects life style and livelihood of natives. Affects life style and livelihood of natives. Possible major ecological impacts downstream. Low level SO ₂ concentrations may be acceptable.
Arctic Pipeline	Construction techniques with minimized impact.	Incipient	High	Base line studies in progress are important. Multiple environmental impacts to be considered.
Marine Oil Tankers	Collision avoidance. Clean-up techniques. Ice-infested off-shore operation.	Needs application of available technology	Growing	Ecology of continental shelves, estuaries and oceans important to Canada. International legislation needed. Control of traffic in ice infested northern waters.
Hydro Electric Power	Impact Studies needed.	Incipient	High	Regional impacts can be severe. Careful consideration of all alternatives needed.

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Fossil Fuel Electric Power	Stack Gas Cleanup. Fuel Treatment. Particulate removal.	Researched but unavailable	High	High regional importance, if low sulphur fuels unavailable.
		Unavailable but under development	High	Global climatic effects require intensive study now.
	Air Cooling.	Available but more costly	Growing	Possible beneficial uses of waste heat in Canada require pilot test.
Heavy Water Production	Control of H ₂ S releases. Waste heat disposal.	Under development	Growing	Search for alternative production techniques potentially important from environmental point of view. Use of cooling tower being tried.
Nuclear Fission Power Plants	Reactor accident prevention.	Highly developed	High	Increased research on pathways and health impact questions is needed.
	Routine release minimization.	Improving	High	
	Radioactive wastes control.	Inadequate	Growing	Development of improved techniques important.
Nuclear Fuel Reprocessing & Transport	Routine and accidental release control.	Inadequate	Potentially high	Important if plutonium recycling started. Much development needed. International and social factors involved.
Transmission of Electricity	Aesthetic improvements, undergrounding.	Being developed, costly	Low	Wire can be underground now in cities and sensitive areas. Development of undergrounding techniques and aesthetic treatment of transmission right-of-way should be encouraged.
Home and Industrial Heating	Combustion improvement. Substitute heating methods. Improved construction standards.	Largely undeveloped	Growing	Immediate benefits from improved home design and construction, improved building codes. Solar heating and area heating pilot studies should be tried.

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Automotive Transport	Substitute modes of transport. Improved engine technology. Improved engine, tire, roadway and road planning.	Developing	High	Primarily a social choice problem.
		Under development. Slow improvements.	High	Much improvement possible from advanced technologies.
			High	High impact for people in cities, wildlife in sensitive areas.
Fusion Power	Tritium containment. Cooling technology. Fast neutron flux absorption.	Undeveloped	Unknown yet, potentially high	Holds promise of reducing environmental concerns of large scale fission power or continued fossil fuel use. Possible benefits and problems in Canadian waters. Unlimited fusion power could make thermal effects on climate significant compared to dust, CO ₂ and albedo effects.
Solar Energy Heating	Nil Basic technology is environmentally benign.		Undetermined, potentially high	Environment impacts would be very favourable if economically feasible. Varied pilot studies recommended on environmental grounds.
Solar Energy Biomass Concepts	Largely undetermined as yet.	Undeveloped	Potentially high	Requires careful systems studies and some pilot experiments in promising areas. Possibilities include isolated agricultural communities, coordination with forest product industries, municipal waste applications. Study impact on wildlife.
Tidal Power	Techniques to minimize tidal amplitude changes.	Undeveloped	Locally important	More propensity for environmental damage than benefit. Environmental studies very incomplete.
Geothermal	Minimize release of dissolved minerals, gases.	Partially developed	Possibly high	Potential in Canada undetermined. Could provide environmentally preferable power source. Requires careful environmental impact assessment as geothermal sources considered.

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Magneto-hydrodynamics	Basic technology improves thermodynamic efficiency, seed recovery removes sulphur.	Slowly developing	Moderate	Possible benefit in allowing higher sulphur content fuels to be used, more efficiently, with less thermal and SO ₂ pollution.
Fuel Cells	Basic technology is environmentally benign.	Developing	Possibly high	Permits environmentally benign power and heat in isolated communities. Potential for allowing more dispersed population. Recommended for continued research, pilot studies.
Windmill Power	Basic technology is environmentally benign.	Developing	Could be locally important	Environmentally benign local power sources, possibilities in Arctic, Newfoundland, other isolated areas. Recommended for further research, pilot studies.
Hydrogen (or other synthetic) fuel	Basic technology environmentally benign.	Theoretical only	Could be very important	Major environmental gains possible through elimination of pollutant release in transportation, heating and other activities. Strongly recommended for research and pilot studies in Canada.

Source: Adapted and modified from, G.N. Patterson *et al.*, "Canada's Energy Corridors to the Future", Background Study prepared for the Science Council of Canada, 1974.

example, maximum concentration of sulphur dioxide in the air we breathe) others (like the maximum concentration of nitrogen dioxide in the stratosphere without damaging the ozone radiation shield) are more difficult to research and to set. Most difficult are the aesthetic questions, because they depend on perceptions and preferences which change from person to person, and for the same person over time, even though they tend to be the aspects of environmental quality to which people are most alert. Moreover, some questions, like noise, which may be aesthetic at low levels, become health issues at higher levels. And even when there is agreement as to what constitutes *desired* environmental quality there remain the differences of opinion about what is an *acceptable* point along the road to that goal, considering other trade-offs that may have to be made and considering differences about how fast and at what cost progress toward an environmental goal should be made. It would be desirable, therefore, that an appropriate government department, such as Environment Canada attempt to conduct a continuous analysis of the costs and benefits entailed by their recommendations for environmental management. Such an assessment would help to focus the debate on what constitutes acceptable environmental standards.

Issues of environmental quality are clearly not all to be answered with a "yes" or "no", nor can it be thought that the standards can all be determined "technically" without reference to public preferences and values. As environmental conditions and public perceptions differ so will some of the standards of environmental quality vary for the different areas of Canada. But the regional differences in formulating positive environmental goals should not obscure the need for minimum standards and regulations over all the country to prevent environmental damage. Nor should they hide the proper responsibility of governments in developing publicly-set environmental goals for planning operations within their jurisdictions – no other bodies represent the public interest in the quality of the environment.*

As industries, governments, and individuals in Canada decide and plan how much of what kind of energy is going to be produced where and used for what purposes, it will be important for them to develop and keep in mind a fairly clear set of environmental perspectives and goals which can suffuse the planning, not merely be tacked onto it. In this context environmental aspects of new forms of energy require early and systematic examination. The federal, provincial and municipal governments should avail themselves of the gamut of tools for environmental management – public consultation and education, laws, regulations, incentives, and appropriate research and development. They should also establish criteria and set standards for a cleaner environment, which are technically attainable and do not change frequently.

* For a longer discussion see, Lash, Maasland, Larkin and Filteau, "On Doing Things Differently, An Essay on Environmental Impact Assessment of Major Projects", *Issues in Canadian Science Policy*, Ottawa, Information Canada, 1974, vol. 1.

Industry can usually deal with such standards, but finds it difficult to cope with uncertainty.

Generally, R & D, regulations, and incentives in the short and medium term are needed to encourage beneficial shifts or modifications within existing technologies: the mandatory installation of pollution abatement equipment, as an illustration, or the requirements that fuel oil be desulphured before being burnt, or that plant operations be reduced on severe pollution days. Environmental implications of nuclear power developments and our concerns are reflected in special recommendations on a separate activity required to develop and maintain appropriate safeguards and regulations (Chapter IX, "Nuclear Power"). Long-term policy and R & D, on the other hand, are needed to encourage shifts from one technology to another environmentally preferred one: from homes heated individually by "dirty" fossil fuels to district heated communities with solar energy supplement, for example, or from airplanes to high speed rail for short intercity travel, or from fossil-fuelled cars to perhaps flywheel or hydrogen powered cars or electric mass transit.

The federal government, through the auspices of the Ministry of Urban Affairs and in association with the provinces, by funding demonstration projects, could do much more to test out mixed concepts of energy conservation and environmental protection. The planned new town of Carlsbad Springs near Ottawa constitutes an opportunity to build a community with environmental quality and energy efficiency as prime goals. Much is technically possible and economically feasible today, but is not used because the initial demonstration, which convinces the average developer, has not been forthcoming.

Environmental management, then, is an activity requiring clear notions and standards of environmental quality that may vary from place to place, in order to evaluate effects on the geosphere, biosphere, and sociosphere, so that activities may be planned and regulated accordingly and opportunities for improvement created.

In this section, rather than attempt an exhaustive list of recommendations about energy and the environment, we have tried to present a framework for considering the relationships between them, suggesting, for example, how standards and notions of environmental quality, once set, should be used to influence the planning and operation of energy policies and activities.

While the concrete outcomes of such environmental influences on planning and policy will of necessity vary from jurisdiction to jurisdiction, we applaud the beginnings that several governments have made in this direction, and we urge as strongly as possible that all energy policy makers and planners try to educate themselves in the application of environmental concerns.

Managing Energy and the Environment

The "actors" involved in energy and environment issues are the producers of energy, the producers of energy-using technology, consumers, affected third parties including the concerned public, who are often quite powerless to represent their involvement at present, and the government policy makers and regulators. There are a number of institutional instruments which should be used to encourage and ease the working of these actors toward the creation and maintenance of acceptable environmental quality.

Within the recommended Intergovernmental Planning Group (Chapter IV), there would be a strong section operating specifically with an environmental outlook on energy much broader than mere concern for pollution.

Since decisions about environmental quality involve public preferences on various trade-offs, public comment should be actively solicited in the setting and scheduling of acceptable standards for aspects of environmental quality. Work already done on standard setting should be put in the public domain without delay.

All energy production and transmission projects should receive a formal environmental impact assessment as a regular part of their planning and approval procedures. In special cases, like that of coastal oil developments, the environmental impact assessment could be broadened, with advantage, into a full technology assessment. All assessments must be initiated at the time of the preliminary economic and engineering studies and they must constitute an integral part of these studies, unlike many of the present token efforts, which seem to be intended more as a means of appeasing public pressure than as a meaningful component in the decision-making process. The assessments, too, must be made publicly available.

The adoption of a lifestyle in greater harmony with the goals of environmental quality implies a reduction in the overall growth of energy demand as well as the implementation of stricter environmental standards. To argue that we need still more energy to clean up an environment that has been polluted in no small measure through our careless use of energy constitutes a very narrow view which does not come to grips with the overall problem.

From the discussion in this chapter, it is clear that energy and environmental concerns represent two sides of the same coin. To treat each in isolation cannot succeed over the long term as energy and the environment interact in too many ways. Just as we are now learning to integrate environmental "externalities" in the planning and coordination process, we must ensure that, in the future, the energy variable is included in that process as well. A background study and a commentary

by the Chairman of the Science Council, already published,* describe and recommend a comprehensive approach to shaping the decision-making processes involved in major developments. They stress the need to identify all factors and to consult all groups affected. The Science Council recommends therefore that governments and industry strive to develop a comprehensive management framework that will successfully handle both environmental and energy planning and coordination.

* M. Gibbons and R. Voyer, *A Technology Assessment System: A Case Study of East Coast Offshore Petroleum Exploration*, Science Council of Canada Background Study No. 30, Ottawa, Information Canada, 1974. Also, R. Gaudry, "Introduction", *Issues in Canadian Science Policy*, Ottawa, Information Canada, 1974, vol. 1.

Annex 560

I. P. Gerasimov et al., *Organization of Biosphere Preserves (Stations) in the USSR*, in
SECOND JOINT U.S./USSR SYMPOSIUM ON THE COMPREHENSIVE ANALYSIS OF THE
ENVIRONMENT (U.S. Environmental Protection Agency Washington,
October 21-26, 1975), pages 89-91

SECOND JOINT U.S./USSR SYMPOSIUM ON THE COMPREHENSIVE ANALYSIS OF THE ENVIRONMENT



OCTOBER 21-26, 1975

SECOND JOINT U.S./USSR SYMPOSIUM ON
THE COMPREHENSIVE ANALYSIS
OF THE ENVIRONMENT

Honolulu, Hawaii, October 21-26, 1975
U.S. ENVIRONMENTAL PROTECTION AGENCY
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CONTENTS

	<i>Page</i>
Preface	v
Introduction	vi
Acknowledgments	vii
<i>Paper title, authors</i>	
General Approaches to the Problem of Maximum Permissible Load on the Environment	
Author: Yuri A. Izrael	1
Are We on Track in Assessing Environment Stress on Man?	
Author: Frode Ulvedal	5
Internal Substance Cycling in the Main Types of the Natural Ecosystems over the Territory	
Authors: I. P. Gerasimov; Yu. A. Isakov; D. V. Panfilov	9
Global Balance and Maximum Permissible Mercury Emissions into the Atmosphere	
Authors: B. P. Abramovskiy; Yu. A. Anokhin; V. A. Ionov; I. M. Nazarov; A. Kh. Ostromogil'skiy	14
Human Risk Assessment Based on Laboratory Animal Studies	
Author: D. G. Hoel	22
Environmental Stress and Behavior: Response Capabilities of Marine Fishes	
Authors: Bori L. Olla; Anne L. Studholme	25
Principles of Setting Norms of Anthropogenic Influences on the Vertebrate Population	
Authors: V. Ye. Sokolov; I. A. Il'yenko	32
Extrapolation of Animal Data to Human Response: An Assessment of the Factors Involved	
Author: Thomas J. Haley	41
Determination of Criteria of Harmless Chemical Effects on the Human Organism and the Problem of Permissible Loading	
Author: A. P. Shitskova	47
Projected Health Implications of Major Automotive Emissions	
Authors: John H. Knelson; Robert E. Lee, Jr.	51
Hygienic Criteria of Maximum Permissible Load	
Authors: G. I. Sidorenko; M. A. Pinigin	56
Rationale for the Assessment of Carcinogenic Risks	
Author: Roy E. Albert	61
Genetic Aspects of Permissible Load Determination	
Author: L. M. Filippova	64
Biological Effects of Non-Ionizing Radiation	
Author: Joe A. Elder	68
Pollutants and Progeny	
Author: K. Diane Courtney	75

	<i>Page</i>
The Problem of Comprehensive Evaluation of the Danger of the Emergence of Remote Consequences of the Effects of Various Environmental Factors Authors: N. F. Izmerov; I. V. Sanotskiy	80
The Detection of Naturally Occurring and Man-Made Carcinogens and Mutagens by the DNA Repair Assay Authors: H. F. Stich; R.C.H. San; P. Lam; D. J. Koropatnick	85
Organization of Biosphere Preserves (Stations) in the USSR Authors: I. P. Gerasimov; Yu. A. Izrael; V. Ye. Sokolov	89
Theoretical Foundations of Global Ecological Forecasting Author: S. S. Shvarts	92
The Problem of the Maximum Permissible Effects of the Anthropogenic Factor from the Ecologist's Viewpoint Author: V. D. Fedorov	98
On the Ecosystem's Stability Author: A. M. Molchanov	109
Ecological Modeling and Estimation of Stress Author: Richard A. Park	119
An Ecological-Economic Model of the Use of Nature Author: M. Lemeshev	127
Mathematical Simulation Model of the Lake Baykal Region as a Method for Comprehensive Analysis, Long-Term Forecasting and Determination of the Permissible Yields of the Influence of National Economic Activity on Environmental Quality and the State of Ecological Systems Authors: Yu. A. Izrael; Yu. A. Anokhin; A. Kh. Ostromogil'skiy; F. M. Semevskiy; S. M. Semenov; V. N. Kolesnikova	133
Management Systems for Minimizing Regional Environmental Stress: Research on Applied Aspects of Planning, Implementation and Enforcement Author: Charles N. Ehler	144
Mathematical Analysis of Some Ecological-Economic Models Authors: M. Ya. Antonovskiy; S. M. Semenov	155

ORGANIZATION OF BIOSPHERE PRESERVES (STATIONS) IN THE USSR

I. P. GERASIMOV, YU. A. IZRAEL, and V. YE. SOKOLOV

The system of biosphere preserves (stations) is created to study, control and forecast the state of anthropogenic changes in the biosphere as the habitat of man. Biosphere preserves may become a component part of a global monitoring system (on a background level); they must, above all, ensure national interests. Therefore, the network of Soviet biosphere stations is a component part of a system of national monitoring, that is, an observation and control service for the natural environment of the USSR. The system is based on the national system of observation and control over the pollution levels of the air, water and land of the USSR Hydrometeorological Service and for monitoring the state of man's health, the appropriate service of the USSR Ministry of Health. In the first stage the system of biosphere stations will be an independent experimental subsystem within the framework of national monitoring.

TASKS OF THE BIOSPHERE STATIONS

- Conduct of permanent observations and determination of background indices (parameters) characterizing the current state of the biosphere and its anthropogenic changes.
- Conduct of permanent, periodic and irregular target studies of various ecosystems to develop scientifically based parameters for the control of the state of the environment and its significance to the health and well-being of man.
- Protection of natural ecosystems and the resources that support the life of plants and animals and the development of scientific bases of nature conservation measures (primarily for the system of natural preserves).

In connection with the first two tasks the system of biosphere preserves must more correctly be called the system of biosphere stations.

In addition to these basic tasks, the area of the biosphere stations will be employed for the conduct of various scientific studies for international projects, as well as for a study of the problems of the environment and the conservation of nature.

COMPOSITION OF THE WORK OF BIOSPHERE STATIONS

The fundamental direction of the scientific work of the biosphere stations must be the conduct of systematic observations over the elements of the current biosphere for the chemical, physical and biological indices for the purpose of a reliable establishment of periodic or controlled changes in it and the evaluation of the ecological values of these changes or their causes (particularly anthropogenic).

The composition of these indices must include the geophysical characteristics of solar radiation entering the atmosphere as well as the Earth's surface as the main energy base of all biosphere processes. They must also include the observations over the appearance of flows of radiation energy across the atmosphere. Apparently the main attention must be turned to the role of the growing pollution of the atmosphere as well as the direct effect of heat of man-made origin on the total energetics of the biosphere. An important value must be assigned in these studies to the effect of the man-made actions on the climate and particularly on the gas content of the atmosphere, the consideration of the use of oxygen and the excretion of CO_2 as a result of the consumption of fuel, a change in the process of its photosynthesis, and so forth.

A special section must be composed of observations of the global water balance and the humidity circulation. Here, just as important is the reliable base-line of the man-made changes, as well as the forecasts for the future. The subjects of the study and observation must also include the man-made transformations of the cycles of the most important chemical elements (N, P, K, and others) with an obligatory inclusion in the study of the soil cover.

The list of media and indices subject to measurement and study include primarily:

- Air — carbon dioxide (CO_2) (in the air point and column), carbon monoxide (CO), sulfur dioxide (SO_2), nitric oxide (NO_x), ozone (O_3), (at the source in the air, in the upper atmo-

sphere), dust, radioactivity, transparency of the atmosphere.

—Surface waters, precipitation, ocean water (the latter for ocean stations) — mineral composition, heavy metals, petroleum products, pesticides, polychlorobiphenyls.

—Soil, biota — microelements, pesticides, microbiological admixtures.

The scope of the basic tasks of the research studies at the biosphere stations must include a study of various ecosystems on land and in the oceans and those changes in the abiotic and biotic components of the ecosystem, brought on as a result of man-made changes.

Study of the biotic components (*biota*) must be conducted on an ecosystem basis (composition of the biota and its changes, functional vitality and biological productivity), dynamics of the populations of the indicator species, physiological form (photosynthesis respiration, growth, propagation) and molecular-genetic (mutagenesis, teratogenesis, and others) levels. It must be closely linked to a study of the abiotic factors (radiation balance, heat and water regimes) of the ecosystem and the nature of the anthropogenic factors affecting them (use of natural resources, pollution of the environment and others).

The conduct of geophysical, geochemical and biological studies and observations must be integrated by way of finding and describing the common balances of internal flows of energy and matter in the ecosystems under study, as well as their man-made transformation.

Thus, comprehensive studies both of external factors of the environment and the internal processes and phenomena occurring in the ecosystems must be carried out at the biosphere stations. Moreover, in order to find the man-made changes of these factors, processes and phenomena, studies must be carried out both of natural and to a greater or lesser degree of objects transformed under the influence of man, and appropriate experimental studies are also planned.

In addition to the basic tasks of determining the background indices describing the present state of the biosphere on a global scale, of great significance in accelerating the implementation of the results of these observations will be the close ties of the subsystem of biosphere stations with the national monitoring system and the scientific assessment of various types of economic activity from the point of view of their effect on the biosphere.

STRUCTURE OF THE BIOSPHERE STATIONS AND WORK METHODS

Proceeding from the above-mentioned data, each

biosphere station must have a zoned structure for their territory with the allocation of the following basic zones — *central* (at the level of a global background)* showing the least changed natural ecosystems and where the strictest methods are employed for their protection; a *buffer* (transitory) where under scientific control various forms of land use are carried out and experimented with and comparisons are conducted on the state of the biosphere under the influence of the activity of man with the background state, and (possibly) *educational and demonstrational* where visitors would be allowed.

In the central zones of the biosphere stations the main purpose of the observations and studies must be the background characteristics and the natural bioproduction process (radiation energy, atmospheric and soil moisture, nutritive elements and others), trophic links (biological circuits and their disturbance); in the buffer zones the characteristics of the degree of utilization of natural resources in natural-technical ecosystems above all for the production of the biomass as well as the effectiveness of the methods for the control of the processes of the use of the natural environment and resources, from the point of view of the protection and improvement of the environment for the life and work of man.

In order to obtain general background characteristics of the biosphere use will also be made of sampling methods, including satellites, in addition to the above-mentioned observations.

APPROXIMATE DESIGN OF THE NETWORK OF SOVIET BIOSPHERE STATIONS

The total number of biosphere stations in the USSR need not be great. Initially their number will be limited to six with a subsequent increase. Of these five will be on land and one on the water. The following may be suggested as continental biosphere stations:

—Arctic — located on Franz Josef Land. This biosphere station can be set up on the base of the Observatory im. Krenkel' of the Hydrometeorological Service on Kheysa Island. Rocket soundings of the upper atmosphere for a study of its background composition can be carried out from this base.

—Central Forest Steppe — located in the geographic center of the European territory of the Soviet Union. This biosphere station must be formed on the area of the Kursk Field Base of the Institute of Geography of the USSR Academy of Sciences and the Central Black Earth Preserve. Scientific research has

*This zone must be no closer to sources of anthropogenic impact than 50 to 100 km.

been conducted on this territory over many years and they will, to a substantial degree, correspond to the above-mentioned program; in addition, this territory is used as an aerospace range for the study of the natural environment and its resources following a Soviet-American agreement.

- Central Asian Desert — located in the sands of the Karakum and set up on the base of the Repetekiskiy Station of the Institute of Deserts of the Turkmen Academy of Sciences. Scientific research has also been carried out for many years on the territory of this biosphere preserve partially corresponding to the above-presented program.
- South Siberian Tayga — located on the territory of the Baykal preserve and the areas adjacent to it where a variety of scientific studies are being carried out with the active participation of the Institute of Limnology and the Institute of the Geography of Siberia and the Far Eastern Siberian Branch of the USSR Academy of Sciences.
- East Siberian Tayga — located in central Yakutiya near the pole of cold for Eurasia. This biosphere preserve can be established with the active participation of the Institute of Geocryology of the Siberian Branch of the USSR Academy of Sciences.
- The Ocean biosphere preserve can be composed of the ocean station within the system of the North Atlantic meteorological stations serviced by the scientific research ships of the Hydrometeorological Service.

In order to compare the state of the biosphere against the background level and the level of the existing impact of man, it is necessary to select around each biosphere preserve a representative network of test sites where it will be possible to assess in a complex manner the man-made changes in the

environment (taking into consideration the direction and intensity of the processes) and in a number of cases to conduct purposeful experiments.

The Central Forest Steppe biosphere preserve has a wealth of opportunities in the selection of such sites since it is in the proximity of the Kursk Magnetic Anomaly and the chemical enterprises of the city of Belgorod as well as vast agricultural complexes.

The Central Asian Desert biosphere preserve has within 80 km to the east the city of Chardzhou with a developing petrochemical industry, other enterprises and developed oasis agriculture with the intensive application of fertilizers and various pesticides.

The South Siberian Tayga biosphere preserve is situated near wood chemistry complexes and the Cheremkhovskiy Coal Basin the area of influence of which will provide extremely important data on the degree of man's impact on the environment.

The East Siberian Tayga biosphere is near the city of Yakutsk and a number of mining enterprises.

In addition to this initial system of Soviet biosphere preserves it is proposed to establish a scientific-methodological research-station on problems of biosphere monitoring near Moscow in the area of Pushchino and the Prioksk-terrace preserve. In organizing scientific studies this station can rely on the scientific institutes of the USSR Academy of Sciences located in Pushchino and specifically the Institute of Soil Science and Agrochemistry of the USSR Academy of Sciences.

Implementation of the proposed plan for the development of biosphere preserves will aid in the solution of a number of scientific-methodological problems facing the national and the planned global systems for monitoring the state of the biosphere, assess its existing global background state, and determine the tendencies in changes of this state in the future.

Annex 561

V. D. Fedorov, *The Problem of The Maximum Permissible Effects of the Anthropogenic Factor From The Ecologist's Viewpoint*, in SECOND JOINT U.S./USSR SYMPOSIUM ON THE COMPREHENSIVE ANALYSIS OF THE ENVIRONMENT (U.S. Environmental Protection Agency Washington, October 21-26, 1975), pages 98-108

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CONTENTS

	<i>Page</i>
Preface	v
Introduction	vi
Acknowledgments	vii
<i>Paper title, authors</i>	
General Approaches to the Problem of Maximum Permissible Load on the Environment	
Author: Yuri A. Izrael	1
Are We on Track in Assessing Environment Stress on Man?	
Author: Frode Ulvedal	5
Internal Substance Cycling in the Main Types of the Natural Ecosystems over the Territory	
Authors: I. P. Gerasimov; Yu. A. Isakov; D. V. Panfilov	9
Global Balance and Maximum Permissible Mercury Emissions into the Atmosphere	
Authors: B. P. Abramovskiy; Yu. A. Anokhin; V. A. Ionov; I. M. Nazarov; A. Kh. Ostromogil'skiy	14
Human Risk Assessment Based on Laboratory Animal Studies	
Author: D. G. Hoel	22
Environmental Stress and Behavior: Response Capabilities of Marine Fishes	
Authors: Bori L. Olla; Anne L. Studholme	25
Principles of Setting Norms of Anthropogenic Influences on the Vertebrate Population	
Authors: V. Ye. Sokolov; I. A. Il'yenko	32
Extrapolation of Animal Data to Human Response: An Assessment of the Factors Involved	
Author: Thomas J. Haley	41
Determination of Criteria of Harmless Chemical Effects on the Human Organism and the Problem of Permissible Loading	
Author: A. P. Shitskova	47
Projected Health Implications of Major Automotive Emissions	
Authors: John H. Knelson; Robert E. Lee, Jr.	51
Hygienic Criteria of Maximum Permissible Load	
Authors: G. I. Sidorenko; M. A. Pinigin	56
Rationale for the Assessment of Carcinogenic Risks	
Author: Roy E. Albert	61
Genetic Aspects of Permissible Load Determination	
Author: L. M. Filippova	64
Biological Effects of Non-Ionizing Radiation	
Author: Joe A. Elder	68
Pollutants and Progeny	
Author: K. Diane Courtney	75

	<i>Page</i>
The Problem of Comprehensive Evaluation of the Danger of the Emergence of Remote Consequences of the Effects of Various Environmental Factors Authors: N. F. Izmerov; I. V. Sanotskiy	80
The Detection of Naturally Occurring and Man-Made Carcinogens and Mutagens by the DNA Repair Assay Authors: H. F. Stich; R.C.H. San; P. Lam; D. J. Koropatnick	85
Organization of Biosphere Preserves (Stations) in the USSR Authors: I. P. Gerasimov; Yu. A. Izrael; V. Ye. Sokolov	89
Theoretical Foundations of Global Ecological Forecasting Author: S. S. Shvarts	92
The Problem of the Maximum Permissible Effects of the Anthropogenic Factor from the Ecologist's Viewpoint Author: V. D. Fedorov	98
On the Ecosystem's Stability Author: A. M. Molchanov	109
Ecological Modeling and Estimation of Stress Author: Richard A. Park	119
An Ecological-Economic Model of the Use of Nature Author: M. Lemeshev	127
Mathematical Simulation Model of the Lake Baykal Region as a Method for Comprehensive Analysis, Long-Term Forecasting and Determination of the Permissible Yields of the Influence of National Economic Activity on Environmental Quality and the State of Ecological Systems Authors: Yu. A. Izrael; Yu. A. Anokhin; A. Kh. Ostromogil'skiy; F. M. Semevskiy; S. M. Semenov; V. N. Kolesnikova	133
Management Systems for Minimizing Regional Environmental Stress: Research on Applied Aspects of Planning, Implementation and Enforcement Author: Charles N. Ehler	144
Mathematical Analysis of Some Ecological-Economic Models Authors: M. Ya. Antonovskiy; S. M. Semenov	155

THE PROBLEM OF THE MAXIMUM PERMISSIBLE EFFECTS OF THE ANTHROPOGENIC FACTOR FROM THE ECOLOGIST'S VIEWPOINT

V. D. FEDOROV

THE PROBLEM

"Here we have a firm rule," the Little Prince later told me.

"I got up early in the morning, washed, got myself in order, and at once set about putting my planet in order" (p. 20).*

But the planet of the Little Prince "was only a bit larger than himself" (ibid., p. 18) and to keep it in order, it was enough for him to root out the baobabs and to clean out the volcanoes so that they burned quietly, without any eruptions.

Of course, for us, the people of Earth, it is much more difficult to keep our planet in order than it was for the Little Prince. And this is explained not so much by the incomparably greater dimensions of the Earth as compared to asteroid B-612, as by the absence of a single view on the order of things among the numerous inhabitants of our planet. In the age of the social disorder, the world's people, for direct advantage, began to sacrifice the natural wealths which could not be replaced. Thereby people placed themselves "outside general ecology," so that the consequences of their actions began to threaten the existence of man as a biological species. At the same time, the forms and scopes of human activity became an important ecological factor that transformed the face of the biosphere, as a consequence of which further biological evolution became directly dependent on the uncontrollable consequences of technical progress.

It is practically impossible in a single address to examine, even superficially, the numerous aspects of the problem of the interaction of nature and man, the problem of the place and transforming role of man in the biosphere. Some of the questions connected with the sphere of inhabitation concern the sinister consequences of the reasonable actions which were undertaken in the biosphere by man without sufficient consideration of their indirect or

distant consequences. One of these problems is the problem of waste products, the most important aspect of which is the determination of the effects which waste products have on the productivity and future of biosystems. All the subsequent parts of this article are devoted to the discussion of this major problem.

THE PRODUCTION OF "WASTE PRODUCTS" AS A BIOSPHERE PROCESS

In the biosphere, processes connected with life are constantly occurring, and, if the scope of these processes is sufficiently great to change "the face of the earth," they are called *biospheric*. It is possible to provide a sufficiently clear classification of biospheric processes by dividing them into two categories:

- those connected with the evolution of life, as a continuous series of successively more complex forms, which in the final analysis has led to the formation of man as a biological species
- those connected with the evolution of man as a social being leading an intelligent way of life, i.e., the social evolution of man.

If this classification proves acceptable, then the biosphere from the standpoint of a systems approach should be defined *not simply as the place where interdependent processes connected with the evolution of life are realized*, but more precisely as *the system of connections within a space of the planet between the evolution of nonintelligent and intelligent life*, i.e., between the natural and human populations which coexist in geological time. These connections may be very diverse in their essence — from resource and trophic to moral and aesthetic.

To the biospheric processes connected with man's existence may be ascribed:

- the production of food based on livestock breeding and agriculture,
- the production of energy — hydroelectric stations, atomic and thermal power stations,

*Antoine de Saint-Exupéry, *Le Petit Prince* (Russian translation by N. Tal'), Moscow, Izdatel'stvo Tsk VLKSM Molodaya gvardiya, 1963.

- the production of housing (the construction of cities, or the so-called process of urbanization),
- the production of material wealth which facilitates the daily life of man, as a result of the development of light and heavy industry,
- the production of culture — the creation of spiritual values.

In the opinion of V. I. Vernadskiy [1] man's activity on the planet should lead to the conversion of the biosphere into a noosphere, of the sphere of activity of the human intellect. However, even given very great optimism — a feeling inherent to the physically and morally healthy man — we cannot today combine the evaluation of the state of the biosphere with the definition of a noosphere as "the triumph of the human intellect." Rather, more cautious and therefore more correct is the definition of the biosphere as the sphere of action of the processes of the production of food, energy, housing and culture, which are aimed at the creation of the conditions for the material and spiritual evolution of man, i.e., a technosphere. The existing loss of the metaphor in the definition of a "noosphere" is undoubtedly connected with one important circumstance — all the listed biospheric processes entail not only the production of a target net product, but also the production of a certain amount of associated products called "production wastes." In this, the elimination or reduction of "production wastes" would significantly increase the cost of the process of manufacturing an individual net product and, consequently, would raise its net price. At present no country is in a position to unilaterally agree to an increase in the net price of products, which would lead to a catastrophic decrease in the country's national income. Therefore, the problem of organizing "nonwaste-producing" production remains today an idea fashionable in intent and good in essence, which does not have a sufficient material basis.

On the contrary, the cheapening of the production of the net product inevitably exacerbates the problem of "production wastes." And when the nonspecific process of accumulation of "wastes," which accompanies directed production, reached biospheric scopes, human society began to worry, forcing national governments to put to scientists the question: what are the possible consequences for man and the biosphere of the accumulation of "production wastes"? "Bad!" the scientists of different continents answered unanimously. But since we have not succeeded in fundamentally changing the state of affairs with the production of wastes, inasmuch as the impelling reasons for decreasing the net price of output have not been eliminated, and it is all the same necessary to do something for the

future of our children and grandchildren, the scientists were faced with a less clear cut problem, which may be formulated precisely enough in everyday language as follows:

"Well, fine . . . since there are, and will be wastes, nothing can be done. . . . But tell me then, how much waste can enter the biosphere without this, in the final analysis, having an effect on our health and the future of our children?"

The question is correctly posed and at the proper time. And even when we, scientists, give it an intelligible answer, it is still not at all evident that human society will draw the correct conclusions from it or, more precisely, will find in itself the strength to follow the advice, which is based on precise knowledge of things and the state of affairs.

"PRODUCTION WASTES" AS ANTIREPRESSORS OF BIOSPHERIC PROCESSES

Any process, regardless of its physical nature, can be described by the parameters "input," "processing speed" and "output." With respect to biospheric processes, the conditions of the "input" are determined by the concentration of basic components (C) — in the form of the basic raw material and its diversity, as well as their reactivity (K) — with consideration for their accessibility and with consideration of the time and difficulty of delivery to the point of production. The "processing speed" depends not only on C and K, but also on the organization of production with consideration for possible change (usually growth) in its scope. Finally, the conditions of the "output" are determined by the amount of the net product (P) and its quality (Q), as well as by the production of a certain amount of wastes (O), which reduce the net price p. With respect to biosystems, of primary significance is the "quality" of the wastes, in the sense that when the quality of wastes is better, the lower their toxic properties.

Let us note that the net product under the conditions of intensive production (more precisely, overproduction) may act as a repressor of the process, or repression will be slowed as a result of reducing the net price of the product owing to a change in the ratio of P and O in favor of the latter. Thus, "production wastes" at a specific stage of development of society act as antirepressors of biospheric processes, decreasing the net price of the net product. This should indicate that the exacerbation of the problem of wastes also has the value of a warning, since it precedes repression of the processes of production of the net product.

This short digression into reality should illustrate the obvious situation, that the problem of future

evolution of the biosphere in essence has already ceased to be a purely ecological problem. In it the economic, social, ecological, and other aspects are woven into one whole, into one system, making the problem biospheric. Hereafter we will not examine the general outlines of the entire biospheric system — at the center of attention will be, above all, ecological problems and the problem of the permissible influence of wastes on biosystems. However, some general principles going beyond the framework of ecology will nevertheless be formulated as concepts, which make it possible to better elucidate the features of the biospheric model.

MODEL OF THE BIOSPHERE

Figure 1 schematically depicts the biospheric model. The features of the model are:

- The model envisages the consumption of the energy of the sun and the resources of the biosphere — the former is negligible, the latter is approaching the level which will limit the scope of biospheric processes.
- The model concerns the historical aspect of the development of the biosphere, as a developing, self-organizing system striving for equilibrium.

The biospheric model has many features in common with the model of ecological succession:

- The prevalent importance of "input" at the early stages of development of the biosphere*, when the system develops "as if" there are unlimited resources in an unlimited space, i.e., under the conditions of exponential growth. Such a system is essentially nonequilibrium and upon rough approximation may be regarded as an open exposed system, see Figure 1A. Natural ecosystems can easily handle a small amount of wastes, mostly household wastes, without appreciable disturbances in the biosphere.
- The "equal importance" of input and output in a balanced equilibrium system*, when factors limiting development come into force. Exponential growth in this case is replaced by growth dependent upon the repressing (the increasing role of the products of output as repressors of biospheric processes), limiting (the exhaustion of irreplaceable resources) and injurious (the harmful effect of wastes) mechanisms of the system. Feedback, which envisages a slowing of reaction, makes it possible upon a rough approximation to regard the sequence of the processes being realized in the biosphere as a closed loop of transformations in an essentially equilibrium isolated system (Figure 1B). In

order that such a system might stably exist for a long period of time, there should be envisaged the possibility of replenishing the source of resources (most reasonably, through the connection of S and R), as well as of the appearance of regulatory connections between P and O, E-I and E-II, as well as P and E-II (Figure 1C).

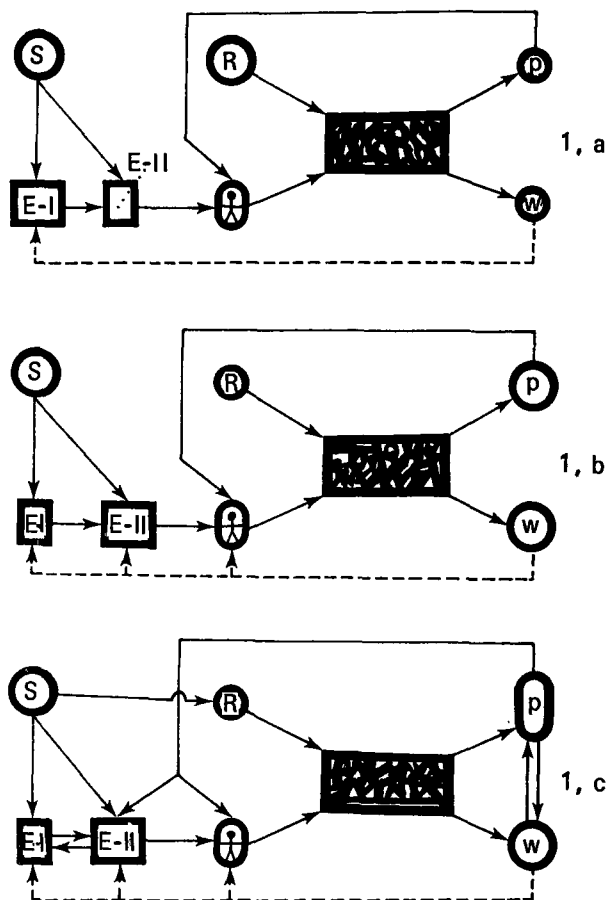


Figure 1. Schematic of biospheric model.

Both stages of the "biospheric succession" reflect only the most vivid features of the states of the developing system, when there passes through the system a flow of energy that substantially changes the entropy of the components forming it [2]. Finally, it would be interesting and might be even important to establish the location of the biosphere of 1975 on the path of its conversion into an equilibrium system. Of course, we are still far from a solution to the questions of replenishing resources through solar energy, and enormous organizational difficulties are preventing the establishment of connections between P and O, E-I and E-II. However, we can state that tendencies to "close" the proces-

ses in the biosphere are at hand. Indeed, local crises of overproduction of individual types of net products, the problem of the negative effect of wastes on man and natural ecosystems irrefutably attest that the general contours of a closed system are appearing very distinctly. True, the currents of transformation in such a system are still not balanced, and one might believe that the appearance of a closed loop of transformations makes it possible to define the present state of the biosphere as intermediate between the two extreme, above-described, states.

The biosphereic model makes it possible to determine the sphere of questions belonging to the competence of ecologists and, in particular, the participants of this conference. The central issue is the question of the maximum permissible loads of "wastes" (in the broad sense of this term), which can be borne by man as well as by natural and artificial ecosystems, without the risk of collapse of the basic biological structures determining the appearance of biosystems. It is important to emphasize that at issue, are irreversible and unbalanceable changes of biosystems, as a result of which, either the biosystem collapses and ceases to be a system, or its structural changes are so substantial and stable that we have the right to speak of the "rebirth" of the old system into a new one, with its inherent new totality of values that determine its new appearance. Here, it is easy to see that the possibility of "rebirth" pertains exclusively to ecological systems, while the irreversible degradation of systems, which is caused by the effect of wastes, concerns all biosystems without exception, including the human organism. Thus, the potentially dangerous effect of wastes threatens above all the health of man. This influence may be direct, if the "wastes" directly cause different functional disturbances in the human organism, being the cause of illnesses. The study of this type of influence of wastes goes beyond general ecological research and belongs to the competence of public health services. The effect of wastes may be caused by their entrance into an organism along with food of plant and animal origin. In this case, the field of activity remains outside ecology, since the pollutants pass from the environment into ecosystems being utilized by man, accumulate in the bodies of organisms, migrating along the trophic chain all the way to the finished product in the form of a biomass of organisms used by man for food. The latter act not simply as passive carriers of pollutants from the environment to man. By accumulating and transforming pollutants, animal and plant organisms, in turn, experience the effect of pollutants, which in the final analysis influences the dynamics of the sizes of populations

of natural ecosystems, i.e., changes their structure. In this case, of especially great importance is, within the ecosystems utilized by man, the separation of the species on which "man is supported" (i.e., uses for food), from the other species which coexist with the former. Here, strictly practical considerations stimulate the interest of ecologists not in studying the structure of communities in general, but in studying the fate of individual populations that are valuable for food. Thus, the paths of the effect of wastes, which "lead" to man, in essence are ecosystemic, and we should substantiate some new concepts of the approach in the study of the biospheric model, and of its "ecological unit."

TWO USEFUL CONCEPTS IN THE STUDY OF BIOSYSTEMS

The *first* concept — the concept of "alternative mechanisms" — is based on the postulate which can be formulated in the following way: *any final formation in biosystems is capable of emerging in more than one way*. This tenet implies the existence in a living thing of alternative mechanisms of formations (emergences). The concept "formation" sounds somewhat abstract and should be made specific with respect to different types of systems in a different way. Thus, for a-type biological systems [3], a "formation" should be considered any intermediate or final product of the processes (substance, compound) which participates in forming the structural components of the "biological spectrum" — gene, cell, organ, etc. Indeed, of the several hundred induced biochemical reactions in an organism, it is hardly possible to name an example of the sequence of "conversions" of intermediate products, which result in a synthesis of any component, a sequence that would not be duplicated by another sequence, with the component synthesizing the same component. For r-type biological systems, we can regard as the final formation the climactic state of a community that is in equilibrium with a complex of factors, which determines the living conditions of each specific biotope. Here the "serial stages" on the path to the climax can differ substantially for the biotope of one type. With respect to the biospheric model it is also possible to postulate the existence of alternative means which regulate the rate of the processes of interaction between the elements of the system.

As is evident from Figure 1, the wastes from biospheric processes are capable of having a negative effect (dotted lines) directly on man's health through the food chain, entering man's organism along with food (I); on the productivity of exploited natural ecosystems, i.e., a reduction in man's food base (II); as well as on the fate of natural

ecosystems which are little or not at all exploited by man, i.e., on biospheric processes connected with the evolution of nonintelligent life on the planet (III).

Figure 2 depicts in conformity with the concepts of alternative mechanisms the elementary unit of the interacting elements of the system.

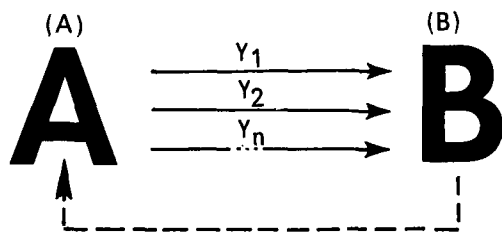


Figure 2. Individual units of the interacting elements.

From the laws of chemical kinetics, it follows that the observable rate of the process of formation, which depends on the concepts of the initial product (A) and the product being formed (B), in reality will be some additive resultant magnitude $\bar{v} = v_1 + v_2 + \dots + v_n$. Therefore in some domain of the values, given $\bar{v} = f(A, B) = \text{const.}$, the change in v_1 will be offset by a change in v_2 , and vice versa. The existence of alternative mechanisms which maintain the constancy of the characteristics of the final output of the process make it possible to apply to the work of the individual unit of the interacting elements (Figure 2) the generalized concept of homeostasis [4]. If we accept that the concept of homeostasis extends to the mechanisms of maintenance of the constancy of some characteristics ($\bar{v}$) owing to the inconstancy of others (v_1 and v_2), then the homeostasis of the system is "a mechanism of regulation, which orders in time a change of the features of the system in the direction of the stability of the group of characteristics pertaining either to the processes (r-system—for example, all ecological systems), or to their results (a-system—for example, the organism of man)" [3].

The second concept — the concept of the "statistical norm" — is based on the postulate which is formulated in the following manner: *the totality of values characterizing the "output" of the processes regulated in the system by homeostatic mechanisms, in the norm are subject to Gaussian distribution.* This tenet implies the possibility of control over the processes being realized in individual sectors of the biospheric model. With the aid of the criterion of correspondence (χ^2) or approximate methods of verification, which are connected with the calculation of the index of asymmetry $g_s = M_3/s^3$ and excess $E = M_4/s^4 - 3$, where M_3 and M_4 are the

empirical central moments, and s is the standard deviation, one is easily convinced of or has doubts about the adoption of the hypothesis of normality. If the magnitudes of g_s and E are small and the hypothesis "passes," it can be assumed that the totality of values characterizes the state of the "norm." Then the negative influence of the existing level of "wastes" can be considered offset by other processes of the system and, consequently, within the framework of the maximum permissible effect. On the other hand, if the hypothesis of normality "does not pass," then the magnitudes of the values $g_s > 0$ and $E > 0$ may be regarded as indices of the deviation from the norm, i.e., be a measure of "pathology." Such sectors in the system require man's operational interference, since they should be considered to be outside the limits of the permissible effect of wastes.

Finally, for the case when the factors distorting the result of the measurement cause an effect proportional to the very result of the measurement for example, in the case of a sudden one: (a) of a massed effect according to the "old" connection of the contour — the so-called "emergency overloading of the connection," (b) the emergence of a "new" connection in the contour — for example, a direct negative influence of a "waste" on some biospheric process, the totality of values is usually subject to the log-normal distribution, when not the results themselves of the measurement, but their logarithms follow the Gaussian distribution. In this case it is not the absolute, but the relative errors of measurement that are stable on the average, and, as an evaluation of the average value, the most representative is not the mean arithmetical (v_a), but the mean geometrical value (v_g). Then a convenient index of the "deviation from the norm" might be the ratio of the mean arithmetical value to the mean geometrical value, i.e. [5],

$$v_a / v_g = \frac{\frac{1}{n} \sum_{i=1}^n x_i}{\sqrt[n]{\frac{n}{\pi} \sum_{i=1}^n x_i^2}}$$

Both concepts — alternative mechanisms and statistical norm — are especially suitable for the case of the equilibrious model of the biosphere, see Figure 1B, when the currents of substances are balances, which increases the homeostasis of the system as a whole. This makes it possible to introduce into the evaluation of the state of the biosphere, certain integral system characteristics such as reliability, stability and others, for whose analysis

there are developed approaches and appropriate mathematical apparatuses. However, for the "intermediate" state of the biosphere of 1975, see Figure 1B, the above-formulated concepts are more useful, not so much when studying the biospheric model as a whole, as when analyzing its individual parts, which pertain to the processes regulated by homeostatic mechanisms. Among the nodal sectors we should place the natural ecosystems that are exploited and unexploited by man (E-I and E-II). Here the central problem, whose resolution rests on the shoulders of ecologists, is connected with the task of examining the force of resistance which can be exerted by ecosystems (owing to the homeostatic mechanisms) against the effect of wastes with consideration for the toxicity of the latter (the problem of the "ecological" quality of wastes). The ability of ecosystems to resist the effect of wastes has the goal of establishing the maximum permissible level of their introduction into the ecosystem, i.e., the level at which the main indicators characterizing the state of the ecosystems (above all their productivity and stability) remain within the limits of the norm. In the final analysis the solution of this basic strategic task of applied ecology is inevitably reflected in the truly scientific determination of the permissible scale of "production" of wastes in the biosphere, i.e., the formulation of ecological conditions of the maintenance of the equilibrium of the biosphere.

THE STRATEGIC AND TACTICAL TASKS OF APPLIED ECOLOGY WITHIN THE FRAMEWORK OF THE BIOSPHERIC MODEL

In formulating the strategic task it can be said that within the framework of the biospheric model it reduces to the need to study the consequences for the biosphere as a whole of the changes caused by wastes in its ecological unit (E-I and E-II). In spite of the obvious simplicity of the formulation, the solution of this task apart from a purely practical interest also has a philosophical aspect, concerning the problem of "the whole" and "the parts." There are two alternative views of the features of the interrelation of "the whole" and "the parts."

The *first* asserts that the *whole* does not represent anything that is not in the parts. The *second* asserts that the whole is nothing more than the sum of the parts. The systems approach, which is so popular and constructive in science today, unequivocally speaks in favor of the latter point of view, placing an equal sign between the concepts "the whole" and "the system." Indeed, if we regard a system as a totality of the orderly interacting and interdependent components (elements), then it is

easy to realize that it is precisely the *connections* between them that give rise to new features, and these "new" features are formed into new characteristics inherent to the system as a whole, and then the entirety of the interacting elements (parts) forms a single whole, i.e., a system. Therefore:

- The study of the connections in the system in a definite sense is more interesting and promising for comprehending the whole than the study of the features of the elements (parts) forming the system.
- The analysis of the system, which is preceded by a breakdown of the connections between the elements (i.e., the breakdown of the whole into its parts), does not make it possible to effectively study the integral feature of the system and, consequently, modeling — as a methodological device — is a most important device for studying systems.
- With respect to ecological systems, a third consequence could be formulated, which follows from the postulate "the whole = the system." Any biological study belongs to ecology only insofar as it helps to understand the phenomenon being studied in the ecosystem. Study undertaken in another connection — of the same feature of living beings or of the same biological phenomenon — ceases to be ecological and pertains in each individual case to other appropriate sections of the biological sciences.

In particular, the latter consequence clearly outlines the sphere of phenomena pertaining to the department of ecology as the science of ecosystems or, more precisely, the science of the systems of the superorganism level of organization, within whose limits the society of organisms and the environment function together as a single whole.

It is interesting that the basic tactical task of applied ecology so to speak "in the ecological context" also concerns questions of the interrelationship of "the whole and the parts," and can be formulated by analogy with the strategic task as

—*The need to study the consequences for the ecosystem as a whole of the changes caused by wastes in its individual sections.*

In other words, the task reduces to the determination of the "tenacity" of ecosystems as a whole, given local damages — of individual functions within the entire society being examined or the complete "mortification" of a part of the society within some space. Diverse wastes are the damaging factors. They function as a measure of the "tenacity" of ecosystems, as the diverse indicators of

stability, which pertain to the ecosystem as a whole or to its parts.

The tactical task of applied ecology can be easily formulated, which facilitates the subsequent analysis of the situation and development of regulatory and preventive measures for protection of ecosystems from harm. Let the state of the ecosystem be defined by the total combination of values pertaining to the processes with homeostatic mechanisms of regulation. "In the norm," the magnitude of the values are subject to Gaussian distribution and, as dependent variables — $Y_1, Y_2, \dots, Y_m$ — they characterize some set function from the arguments $X_1, X_2, \dots, X_n$, which are independent variables. The latter characterize the total combination of disturbance characteristics for specific types of pollution. Thus, the task reduces to finding the equations of $X_1, X_2, \dots, X_n$, for which the values of $Y_1, Y_2, \dots, Y_m$ remain distributed normally, see Figure 3.

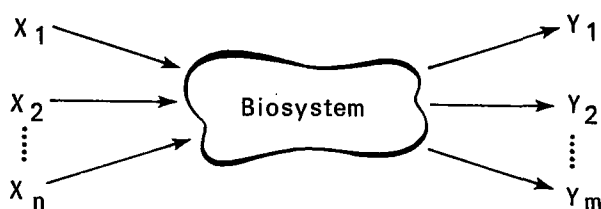


Figure 3. Specific characteristics pertaining to individual disturbance sources (x_n) and individual responses (y_m) in the system.

Useful in this case is the study of dependencies of the type:

- $y_m = f(x_n)$, where y_m and x_n are specific characteristics pertaining to individual disturbance sources and individual responses in the system respectively;
- $a_n = f(\Delta x_n)$, where a_n is the index of the asymmetry of the values of the function, and Δx_n is the change in the level of the disturbance factor;
- $a_n = f(A_n)$, where A_n is the index of the asymmetry of the disturbance factor, if a priori it is known or can, with a sufficient degree of reliability, be assumed that "in the norm" the disturbed factor is also distributed normally.

When resolving the formalized task in general form we should pay attention to the features of the study of dependent and independent variables in ecosystems.

FEATURES OF THE EFFECT OF THE DISTURBANCE FACTOR

We can single out two extreme cases pertaining to the features of the effect of disturbance factors of the environment on ecosystems.

The *first* pertains to an increase in the background level of individual types of the application (the section) of the disturbance source in the biospheric model, and even in that part of it which pertains to ecological systems. The increase in the overall background of individual types of production wastes within the connections foreseen by the model makes ecologists quite helpless in the matter of predicting the expected consequences in the fate of ecosystems. For example, the discovered tendency for a rapid increase in CO_2 in the atmosphere of our planet is capable of resulting in the most unforeseen and, perhaps, unpleasant consequences. The latter are so diverse in their nature and direction, that to make a reliable prediction does not seem possible.

Only within model experiments is the ecologist capable of studying individual details as, for example, will the increase in CO_2 concentration intensify the process of photosynthesis? Another useful method might be the creation of so-called "preliminary" models, i.e., extremely simplified copies of the real world, which make it possible to find the "nodal points" in the control of the behavior of systems.

If given the background effect we succeed in finding gradients for the individual disturbance factors, then the possibility arises of making, in accordance with the gradient, a biological analysis of the changes in the structure of ecosystems through the selected indices — $Y_1, Y_2, \dots, Y_m$. The main emphasis here should be made on the change in the relative abundance of populations and, of course, on the change in the species composition of the ecosystem, which is connected with the disappearance of individual species. With this approach the finding of the correlations between the level of the disturbance factor x_i and the change in the biological indicators y_j is the main method of finding the connection between the dose of the influence and the observable response (dose-effect).

The *second case* concerns the local damage to connections or sectors in ecosystems by specific types of wastes. Usually the magnitude of the emission is clearly insufficient to cause background changes within a large ecosystem (biome) or even a biosphere. Mercury and its compounds, which are used as a fungicide in disinfection of seeds and are later discharged into bodies of water with waste water, may serve as an example of such a

pollutant. The mercury compound is transformed in the environment into highly toxic methyl mercury, which accumulates in living organisms and, entering man's food together with a product (usually fish) can serve as a source of poisoning of the population.

It is methodologically simpler to study the effect of local pollutants than that of background pollutants, since the organization of the experiment affords effective opportunities for the study of the connection of x_i with the diverse responses of the system — $Y_1, Y_2, \dots, Y_m$.

During this study in the experiment of the selected indicators of the state (i.e., Y_m), one should consider the *simultaneous* effect on ecosystems of many disturbance variables, some of which may pertain to background, some to local and, finally, some to attendant factors of the environment (changes not caused by the negative influence of disturbances such as the seasonal changes in light and temperature).

For predicting the "fates" of the behavior of ecosystems it is absolutely necessary to consider and quantitatively evaluate the interaction of the disturbance sources frequently even of a different physical nature. Thus, the strategic base of the study of ecosystems, in which the effect X_n and the response Y_m should be connected by a quantitative dependence, can be formed by a multifactor experiment, which is planned on the basis of economical and mathematically substantiated patterns of experience. The latter envisages the possibility of studying the simultaneous and independent influence of a large set of variables on biological systems of a different degree of complexity [6]. Such an experiment has the goal of studying the probable, expected situation which may be forecast on the basis of the tendencies of changes in the environment, which are found when registering the changes in time and space of the individual disturbance factors of the environment [7]. As a result of the arrangement of the experiment there can easily be obtained polynomial models of the description, which contain quantitative evaluations of the effect of the variables [8]. These evaluations in the future may be useful for obtaining approximate evaluations of the coefficients in differential equations when constructing dynamic models.

CRITERIA OF THE BIOLOGICAL RESPONSE

In the preceding section, when discussing the features of disturbance factors, it seemed to be implied that ecologists are capable of differentiating quite simply:

On the one hand, the response Y_1 , which is caused by a pollutant (the harmful source, indica-

ted in Figure 1A by the line of dashes), from any other changes in the ecosystem, which are not connected with pollution (for example, seasonal changes, successions); and, on the other hand, are able to differentiate a response-caused pollution and leading to irreversible changes in the system (collapse or rebirth into a new ecosystem) from a response caused by the effect of a pollutant, with which the system is capable in the end of dealing. In this case we are in a position to study the question: what reserve of durability does an ecosystem have in respect to the *harmful* effect of disturbance factors? An answer may be obtained if the indicators selected for study and control (i.e., the dependent variables) are sufficiently representative for a determination of the state of the ecosystem. Unfortunately, the establishment of the priority of responses in a series presents many difficulties. Thus, it is possible to state that if the number of independent variables, whose effect is studied in the experiment, can be sufficiently large, but unquestionably limited, then the number of registered responses in the series $Y_1, Y_2, \dots, Y_m$ presents many difficulties. Thus, if the number of independent variables, whose effect is studied in the experiment, can be sufficiently large, but unquestionably limited, then the number of registered responses in biological systems can be practically endless, since any feature of a living thing can serve as the object of control. Therefore, when selecting from the infinite series Y_m a limited number of indicators, one should rely on some specific principle of selection, i.e., a necessary discriminating criterion.

Let us examine two approaches and their appropriate criteria.

The *first approach* is the professional-specialized approach, when specialists in a narrow field (for example, botanists, biophysicists, hydrobiologists) have specialized knowledge that encompasses all existing aspects or features of the object of study. Corresponding to this approach is the *intuitive criterion* of discrimination in ranking according to the importance of the features being studied. This criterion reflects in vague form the accumulated (at times even unrecognized) experience of the specialist in resolving what is more and what is less important in the normal object of study. As an example we can cite the point of view of a hydrobiologist who makes an a priori ranking of dependent variables. Thus, when regulating water ecosystems there is, above all, suggested the idea of using as a response the most ordinary and traditional indicators of hydrobiology: growth (productivity), expenditure (respiration, life-long rejection of organic material), state (consumption and assimilation of food, rate of accumulation in hydrobiotas of indi-

vidual pollutants) and others. It is completely evident that the creation of regulatory systems based on traditional indicators is in principle of little effect, since any biologist specializing in a narrow field is capable of developing a substantiated scheme of control over "his own" object. Such studies are intended for long periods of time by specialists with a high level of training and, having entered on this path we would in essence have to admit to the need for reforming (reorienting) in the direction of solutions of the tactical task of applied ecology of all the biological sciences and disciplines cooperating with ecology.

The *second approach* can be called the systems approach. It is this approach that determines the content of modern ecology. The concept of levels should unquestionably be recognized as the main concept of the systems approach. To solve the tactical task of applied ecology it is useful to slightly expand the "ecological spectrum" of levels of organization, which is limited by populations and communities. Thus, for the needs of regulation it is useful to single out the following five levels of biological organization:

- subcellular — Y_I
- cellular (organism) — Y_{II}
- population — Y_{III}
- trophic grouping (associative) — Y_{IV} (simple community) — Y_{IV}
- community — Y_V — (complex community).

The first two levels are outside the sphere of ecological study, yet the information about subcellular and organism disturbances, evidently, can be useful not so much for evaluating the state of ecosystem according to the selected Y_i , as for establishing the "harmfulness" of the factor disturbing the system, since the information from Y_I and Y_{II} is often necessary for obtaining evaluations characterizing the environmental quality, i.e., the "toxicity" of individual independent variables.

It is easy to see, however, that the introduction of the concept of levels of organization is capable of somewhat narrowing the spectrum of biological levels, owing to the discrimination of a series of levels — gene, tissue, organ and others. However, within each level the number of possible indicators is excessively great. In order to significantly reduce the number of selected variables, we should use in addition the above-formulated concepts of "alternative mechanisms" and "statistical norm," which make it possible to introduce the discriminating criterion of the selection of dependent variables. In fact, being based on the concept of hypostasis, this criterion may be called *conceptual*. By using the conceptual criterion it is possible to formulate the

following requirements of discrimination, which are made on the dependent variables within each level of organization.

The *first requirement* — to control the state of biosystems one should select indicators which pertain only (!) to processes with homeostatic mechanisms of regulation.

The *second requirement* — given that the first requirement is observed, preference would be given to the Y_i that characterize the *nonspecific response* with respect to various factors that disturb the biosystems (for example, elevation of the body temperature of an animal with various "diseases" of the organism, or a decrease in species diversity within a trophic grouping under the influence of pollutants that are diverse in their nature).

The *third requirement* — given that the first two are observed, preference should be given to the integral indicators Y_i and first of all to those which can be quickly and reliably measured by instruments. Thus, an example of such integral indicators in a living biomass would be the content of ATP (adenosine triphosphate) and chlorophyll, which characterize respectively the amount of living material and the amount of energy going into the system.

It should be noted that work on the selection of indicators is being actively conducted in laboratories of the department of hydrobiology of Moscow State University. Preliminarily it can be reported that a suitable indicator that satisfied the above-formulated requirements for levels I-V could be:

- for Y_I —the membrane potential of cells, which can be measured with microelectrode equipment,
- for Y_{II} —an increase in intensity of respiration,
- for Y_{III} —the evaluation among individuals of the population of the bilateral symmetry in the distribution of features, the time of generation, the ratio of sexes, the ratio of age groups,
- for Y_{IV} —species diversity, chlorophyll content,
- for Y_V —ATP content, ratio of the products of different trophic groupings.

The listed indicators should be regarded as illustrative examples. The selection of indicators substantiated by the conceptual criterion is continuing, and their priority is being discussed. But even now it is becoming evident that their number can be substantially limited. Thus, the formulated concepts and requirements make it possible to transfer the subsequent discussion to the question: in what way is it possible to interpret the evaluation of the ranked series of indicators, Y_i , with respect to the evaluation of the state of the entire ecosystem?

HORIZONS OF APPLIED ECOLOGY

Vladimir Vladimirovich Mayakovskiy had one childhood, well-known poem, "What Is Good, What Is Bad."

The poet dealt with the problem, using specific examples of bad and good human deeds. It is easy to follow the parallels between the poet's solution of the problem and the position of ecologists. Ecologists can also cite examples of what is "bad" for the ecosystem — both from observable tendencies of the change in indicators (for example, a decrease in productivity or diversity) and from the features of the dispersion of the evaluations of the selected indicators, Y_i , which "in the norm" should be distributed normally. This means that the ecosystem as a whole is "healthy," or at least is successfully resisting the negative effect of disturbance factors. In this case it is possible to consider it stable, and therefore all the values of the evaluations of stability, derived by "any means," outline the domain of the values of the "norm" of the ecosystem. This, if you please, is a type of "ecological zero," the source of reference of the health of the ecosystem. Much more likely is the situation when a part of the indicators Y_i within levels I-V, attest to a "pathology," while the remainder of the indicators attest to the "norm."

What is to be done in this case? What judgment does the ecologist have the right to pronounce?

Today this question is entirely unelaborated, and we have the right to consider it as one of the most difficult, most vital and most important for the solution of the tactical task of applied ecology.

"Pathology" of some indicators and the "norm" of others place before the ecologist a strictly medical task, which is resolved by the therapist — this is the task of "diagnosing" the disease. It can be postulated that definite regular combinations of "norms" and "pathologies" of individual indicators are specific for different types of "diseases" of ecosystems, or even are specific with respect to the different physical nature of the disturbance factors or pollutants (i.e., to the specific nature of "wastes" in the broad sense of this word). Then the set of features in the responses Y_i for all levels I-V, under the influence of one pollutant (for example, organotin compounds) will differ significantly from the features of the "behavior" of the responses, under the influence of another pollutant (for example, chlorinated phenols). If this is correct—and in my opinion it should be correct—then a list of the symptoms of each disease can be compiled. And then the establishment of a diagnosis of a disease is equivalent to the establishment of the nature of the "pathogen" of the disease, i.e., the nature of the disturbing influence. Therefore, the study by ecol-

ogists of the specific effect of specific wastes according to the selected indicators will make it possible to make a classification of diseases according to the type of changes occurring in ecosystems. In turn, the establishment of the origins of the negative influence of wastes on the ecological unit will make it possible to regulate the rates and scopes of the industrial, agricultural and domestic wastes being admitted into the biosphere.

If we succeed in making a "classification" of the disease of the ecosystems according to the selected indicators, then the next stage of the ecological study of ecosystems within the framework of solving the tasks of applied ecology would be the "clinical" study of the individual illnesses, i.e.,

- observation of the development of the disease, i.e., of the deterioration of the state of ecosystems, and
- observation of recuperation, i.e., improvement of their state.

Undoubtedly, this would require the organization of a broad range of experimental studies on different types of ecosystems, so that the "clinic" of the individual illnesses would be studied thoroughly and comprehensively.

This "medical" stage of the ecological studies is today still in an embryonic state, but given the present rate of development of science and, primarily, the interest of society in the problems of applied ecology, we can hope for its relatively speedy completion. For time does not wait, and mankind must reduce to a minimum, the inconveniences caused by the conversion of the biosphere from the "intermediate" stage of 1975 to an equilibrious state, when the technosphere of today will be transformed into a noosphere, the advent of which was heralded by V. I. Vernadskiy [1]. However, today the state of the biosphere and the position of man in it seem serious enough to cause the people on earth to be wary. Therefore, in ending this report I will permit myself once more to recall the delightful children's book, which was written for adults:

"And here on the planet of the Little Prince there are terrible, vicious seeds. . . . These are the seeds of the baobabs. The soil of the planet is completely infested with them. And if the baobab is not recognized in time, you will never get rid of it. It will take over the entire planet. It penetrates it to the core with its roots. And if the planet is very small, and there are many baobabs, they will tear it to pieces" (ibid., p. 20).

Our planet — the planet of people — like the planet of the Little Prince, is also choked with "terrible, vicious seeds." But these are not baobab

seeds, these are the "wastes" of economic processes. It is impossible to permit these seeds to sprout and tear the biosphere "into pieces," as it happened with one planet, on which lived a lazy-bones. Once he did not weed out three little bushes in time . . .

Although the people of the planet Earth are by no means lazy, I would like to end my presentation with the words of Antoine de Saint-Exupery (ibid., p. 22):

"I can bear to preach to people. Yet few know the threat of the baobabs . . . that is why this time I have made up my mind to betray my self-control.

" 'Children.' I say, 'Beware of the baobabs.' "

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Annex 562

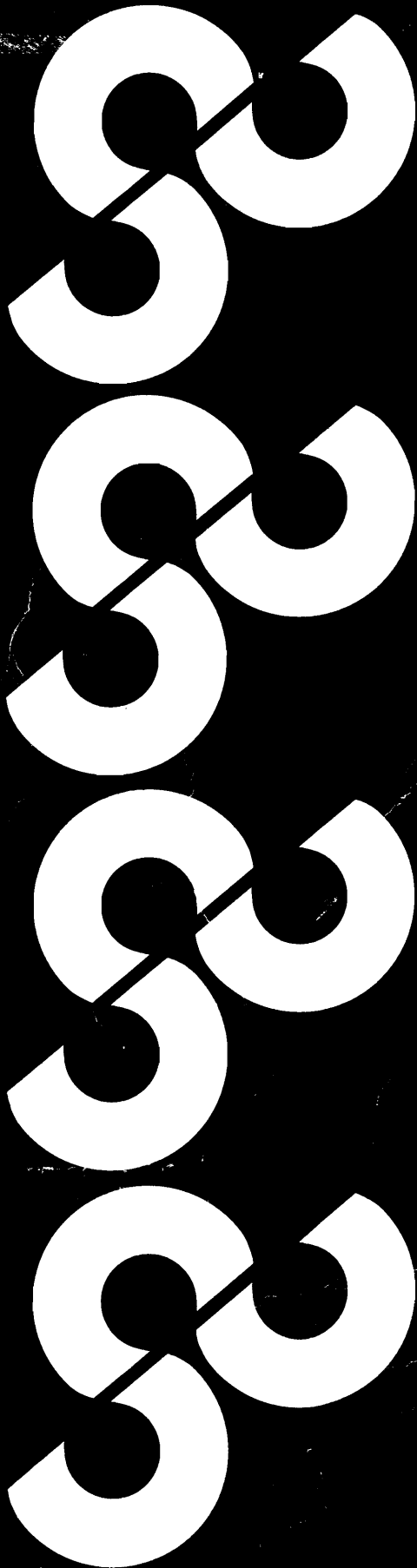
“Report No.27: Canada as a Conserver Society: Resource Uncertainties and the Need for New Technologies”, *Science Council of Canada*, September 1977, pages 9-15

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September 1977

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Canada as a Conserver Society

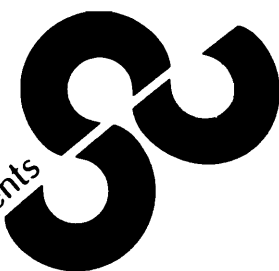


Table of Contents

I. Background of the Study	9
II. Introduction: Perspectives on the Development of Canada	17
III. The Principal Policy Thrusts of a Conserver Society	23
Concern for the Future	24
Economy of Design	28
Diversity, Flexibility and Responsibility	30
Recognition of Total Costs	34
Respect for the Regenerative Capacity of the Biosphere	36
IV. Some Areas of Application	39
Energy Efficiency and Conservation	40
Ways to Conserve Energy	41
Renewable Energy	46
Materials	50
New Business and Employment Opportunities	55
Further Questions	62
V. Recommendations	71
Things to do Immediately	72
Transportation	72
Shelter and Community	74
Renewable Energy Sources	76
Materials Conservation	77

Industry and Employment	80
Citizen and Community	82
Things to Think About	83
Transportation	83
Shelter and Community	84
Renewable Energy Sources	85
Materials	85
Other Questions	87
VI. Epilogue	89
Notes	93
Members of the Science Council Committee on the Implications of a Conserver Society	97
Members of the Science Council of Canada	99
Publications of the Science Council of Canada	101
Index	105

I. Background of the Study

Over the past decade we have been rapidly changing our images of the future. Space-ships there still may be, but probably only for a very small minority. Our science-fiction visions of limitless energy and luxurious life-styles must be tempered by realism. The continuation of growth trends of the recent past in the industrialized countries, plus growth in the rest of the world toward comparable levels, would imply a doubling of total energy use every 16 years. Present known reserves of petroleum will be virtually exhausted by the turn of the century.¹ More will be discovered, but even if additional supplies are found, equal to twice all those discovered up to now, the time to exhaustion would be extended a mere 16 years. For that time to be 32 years, an *additional four* times as much would be needed. It is hardly a sustainable future.

Burning such large amounts of fossil fuels could raise the carbon dioxide level in the atmosphere and raise the average temperature of the earth's climate – such unassessable and drastic changes are now a matter of real concern for the next century. Similarly, even if nuclear fission and fusion were to supply vast quantities of energy, we can now foresee the possibility that the generation of such quantities, approaching 1 per cent of the total solar input over significant areas of the earth, could seriously affect global weather patterns within one or two hundred years. Whether in the long range future the human race will find ways to manage the global system to compensate for these effects – as, for example, by deliberately distributing dust in orbit around the earth to marginally reduce solar input – can only be speculated at this time. What is clear is that we have reached a point on some exponential growth curves where we suddenly sense the approach of the 29th day.²

More subtle, but perhaps even more important than the appreciation of approaching direct physical constraints (energy, materials, pollution) are two other levels of perception that have been developing. One is the sense of human beings as biological creatures, immersed in vital ecological relationships within the earth's biosphere. We do not yet understand many of these relationships – for instance, the multiple predator-prey interactions in a complex insect-bird-bacterium-plant ecosystem. Some of our interventions may be going too far too fast, and setting in train deleterious changes that cannot be reversed. This perception suggests that we proceed with greater respect for the earth as an ecological system of finite capacity, with system equilibria that have evolved over millions of years. There is a growing feeling that we must temper some of our “bulldozer” enthusiasms while we devote much more effort to improving our scientific understanding of living ecosystems. We can then better foresee the consequences of what we do, the impacts of which can be global in scale.

The second level is of the impact of technology on the human being as a social and economic creature. The process of industrialization, the drive to high productivity and a high material standard of living are having some worrisome side effects. The diagnosis is uncertain: we do not know how much of our social malaise, or our economic anxieties, are contingent on high, perhaps unnecessarily high, throughput, high rate of change, or – like the case of the biological ecosystem – are the result of pursuing particular purposes and expectations without

understanding their indirect consequences. We do not, at this point, know how many of our societal problems can be attributed to the way technologies are designed and organized, and how many will require changes in attitudes, expectations or social structures.

Suffice it to say that present indications are that we face a period of exceptionally rapid change and transition, the extent and depth of which are not yet clear. The future will not be simply an extrapolation of the past. Some of the changes that we foresee as inevitable – in energy use, in materials, in ecology, and in social behaviour – are embodied in a concept we have termed the *conserver* society. The meaning of a conserver society and some of its implications are developed in the following pages. The concept of a *conserver society* has not come upon the Science Council suddenly. Most of the principles involved have been developing steadily over a considerable time. While the concept is often linked with discussions following the report, *Limits to Growth*, done for the Club of Rome (1972), or with the considerable public notice of the term “conserver society” that seems to have arisen almost spontaneously over the last two years,³ its roots really go back to the growing awareness of problems of the environment characteristic of the 1960s. Science Council reports as long as nine years ago raised concerns that can be identified as having a “conserver” orientation.

Report No. 3, *Major Program of Water Resources Research in Canada*, (September 1968), drew attention to the ecological role of water systems and the needs for sound management of our resources (p. 29). In Report No. 4, *Towards a National Science Policy for Canada* (October 1968), a number of conserver-oriented recommendations can be found, viz., (p. 14), the call for the “development of sound programs for the use, conservation and replenishing of resources,” and the need for “control of existing and threatened health hazards already created by the misuse of science and technology, e.g., pollution.” (p. 15)

In Report No. 7, *Earth Sciences Serving the Nation* (April 1970), it was noted that (p. 34): “the great majority of Canadians have scarcely a rudimentary knowledge of the earth on which they live. The fast-growing interest in our physical environment, the mounting pressures concerning landscape preservation and anti-pollution, the need for improved urban planning, and the importance of natural resource development in Canada highlight the relevance of earth sciences for Canadians.”

Other conserver oriented references can be found in Report No. 8, *Seeing the Forest and the Trees* (1970) (pp. 10, 14, 19). In Report No. 9, *This Land is Their Land* (1970), came the call for making environmental improvement a new national goal. Elsewhere in the same report was discussed (p. 9) the need to create an Environmental Council, the desirability (p. 9) of creating a Department of Renewable Resources, the need to increase research on chemicals and biocides (p. 19), the importance of developing long-term ecosystem studies (p. 19) and, finally, the need to more fully develop the environmental sciences.⁴

Report No. 11, *A Canadian STOL Air Transport System – A Major Program* (December 1970), contained a comprehensive discussion of external costs and technological impacts on environmental quality (p. 17). The report noted that:

"The noise, pollution, congestion, questionable land usage and ugliness associated with the expansion of the automobile-highway system, and similar problems associated with larger and faster conventional aircraft systems, are sometimes referred to as "external costs", and they raise questions of the validity of extrapolating these types of technological growth into the future. It is questionable whether the benefits provided by supersonic flight, high-capacity jumbo-jets and multi-lane super-highways sufficiently justify the degradation of the environment and the problems of congestion which they create. Alternatives are being sought, and the dedicated promotion of technology for its own sake is being halted."

Thus was expressed a concern, not only for environmental effects but for other consequences of choosing one technological path over another.

Report No. 14, *Cities for Tomorrow* (September 1971), moved from predominantly natural environments to the urban environment, to social effects, and problems of waste. An entire chapter was devoted to recycling (pp. 48–56). The broad context in which recycling is discussed anticipates some of the concerns regarding economic growth, its measurement, and its relationship to the quality of life that are raised in the *Conservator* study.

Concern for the environment and a discussion of the relationship between societal activities and the health of the environment can be found again in Report No. 16, *It is Not Too Late – Yet: A look at some pollution problems in Canada's natural environment; an identification of some major concerns* (June 1972).

The term *Conservator Society* itself was used for the first time in Report No. 19, *Natural Resource Policy Issues in Canada* (January, 1973). This report contained a wide variety of recommendations regarding both policy and the need for new institutions specifically designed to protect and control resources development. For example (p. 32):

"At an appropriate federal-provincial meeting, the Secretariat of the Canadian Council of Resource and Environment Ministers should be strengthened and renamed a National Resource Management Authority. The structure of the Authority should permit the concern of all levels of government, industry, labour, professional organization and citizens' action groups to be expressed and considered during analysis by the Authority of policy alternatives which are later to be considered by the CCREM.

This National Resource Management Authority should develop and coordinate long-range policies for integrated management of resources and the environment, and should be concerned with the development of policies for the prudent and efficient use of both renewable and non-renewable resources. These proposed policies and their background studies should be published and freely available to the public.

Further, this National Resource Management Authority should increase support for programs to heighten public awareness, and encourage mechanisms for community involvement in decisions affecting resources and the environment."

The Report re-stated the need for recycling cited in the earlier *Urban Report* and recommended that (p. 38): "industrial institutions incorporate the concepts of durability and recycling in process and product design and, in cooperation with all levels of government, establish

effective programs for the recycling of municipal, industrial and agricultural wastes.”

Finally, the term “conservator society” occurs in the recommendation (p. 39): “that Canadians as individuals, and their governments, institutions, and industries, begin the transition from a consumer society pre-occupied with resource exploitation to a conservator society engaged in more constructive endeavours. Ideally, Canada could provide the leadership necessary to work toward more equitable distribution of the benefits of natural resources to all mankind.”

Recommendations and policy discussions with a “conservator” orientation can be found in other reports following No. 19. In particular, *Strategies of Development for the Canadian Computer Industry* (No. 21, September 1973) raised fundamental questions regarding the impact of powerful new technologies.

In Report No. 23: *Canada's Energy Opportunities* (March 1975), Council made the following statement on shaping energy demand (p. 46): “Faced as we are with a different and expensive supply problem we should ensure henceforth that supply projections strongly influence policies for the shaping and moderation of demand and we should promote an energy conservation ethic throughout Canadian life.”

On page 47 of that same report, the following was stated (The Conservator study was by now in progress): “A strategy to eliminate waste and to promote efficiency of use in our energy system would be an integral part of any attempt to create a conservator society.”

In Report No. 25, *Population, Technology and Resources* (July 1976), the following statement appeared: “We see Canada in the longer term becoming a conservator society using food, energy and resources frugally and using transportation and communications technology to permit a very wide choice of lifestyle, often in smaller communities.”

The proposal for a specific study on “The Implications of a Conservator Society” was adopted at the 42nd meeting of the Science Council in June 1973. In the meantime the Club of Rome study on *Limits to Growth* had appeared and was being widely and heatedly discussed. In the fall of 1973 the Arab-Israeli war, the Arab oil boycott, and subsequent coordinated action by the OPEC nations to raise the price of oil roused the world to awareness that the period of relatively inexpensive and apparently unlimited fuel resources was rapidly coming to an end.

The study was set back in getting under way by the untimely death of the Chairman-designate of the Committee, Mr. W. J. Cheesman. The first formal meeting of the new Committee was held in March 1975. One of its first tasks was to define more exactly what was meant by “conservator society”. A provisional definition was developed:

The concept of a Conservator Society arises from a deep concern for the future, and the realization that decisions taken today, in such areas as energy and resources, may have irreversible and possibly destructive impacts in the medium to long term.

The necessity for a Conservator Society follows from our perception of the world as a finite host to humanity, and from our recognition of increasing global interdependence.

A Conserver Society is on principle against waste and pollution. Therefore it is a society which

- promotes economy of design of all systems, i.e., “doing more with less”;
- favours re-use or recycling and, wherever possible, reduction at source;
- questions the ever-growing per capita demand for consumer goods, artificially encouraged by modern marketing techniques, and
- recognizes that a diversity of solutions in many systems, such as energy and transportation, might in effect increase their overall economy, stability, and resiliency.

In a Conserver Society, the pricing mechanism should reflect, not just the private cost, but as much as possible the total cost to society, including energy and materials used, ecological impact and social considerations. This will permit the market system to allocate resources in a manner that more closely reflects societal needs, both immediate and long term.

The scope of the study presented difficulties. Not only would it represent a synthesis of many related ideas that had been developing through previous studies, but it would aim to probe deeply into the inter-relations of technology, industry, commerce and human psychology, their implications for the quality of Canadian society and for the future. The thrust of events tended to move energy conservation to centre stage, but these other fundamental concerns, relating to certain structural and inflationary features of our high-consumption throw-away culture, poised against the need to come to terms with our biosphere, remained important.

Their roots run deep. Recent writers have expressed great concern for the economic, political, and social tensions developing in the Western political systems, and between them and the less-developed world, under the pressures for growing affluence. Some writers go so far as to claim that a high level of affluence (in a limited world) is incompatible with democracy. For example, some of the images that shape our aspirations may be derived from minority lifestyles that intrinsically cannot be enjoyed by a majority. To the extent that “being rich” depends on being able to command relatively cheaply the personal services of others, everybody cannot be rich.⁵ The more recent reports commissioned by the Club of Rome have taken the direction of emphasizing that the “limits” creating problems for the world today may not be so much physical or environmental, as social.⁶

These are apocalyptic times, full of prophets. Whether they speak truth, or false opinion, is difficult to judge. But these kinds of questions are beyond the scope or competence of the Science Council to answer. We have tried to stick to practical matters, with an incremental approach, to identify some of the technological paths that lead in the right direction, toward sustainable relationships with material resources and the biosphere. Whether those paths, about which in our view we do not have much choice, imply other changes can only be decided by Canadians through democratic discussion. That is why we have emphasized public interactive processes in the course of the study.

Several background studies on such topics as renewable energy supplies, recycling, rising costs of minerals, and effects of advertising

were commissioned when the Committee felt the need for specific information or reviews. Generally, the flood of information and the ferment of ideas related to these problems and issues have been so prolific worldwide, over the last three years, that the greater task has been to bring them into the orbit of our thinking and place them in perspective. Mention should be given to relevant work in federal and provincial government agencies, such as the Office of Energy Conservation in Energy, Mines and Resources, Environment Canada, Central Mortgage and Housing Corp., National Research Council, the Ontario Department of Environment, the Man & Resources Institute in P.E.I., and others too numerous to mention. A useful study was done on "The Selective Conserver Society" by the GAMMA group at the Universities of Montreal and McGill,⁷ contracted from the federal Department of Supply & Services, with the involvement of several departments and the Science Council.

As part of the Science Council study, many of these activities were brought together and reviewed, with bibliographic material, in an informal journal, *Conserver Society Notes/Carnets d'Epargne*, distributed approximately quarterly by the Science Council to a mailing list of over 1500 interested respondents. The first issue was published in October 1975. "Notes" became an important instrument in the public dialogue initiated by the Committee and its staff. A position paper, "Toward a Conserver Society – a Statement of Concern" was put out by the Committee in February 1976. It was published in *Science Forum* (June 1976), *Québec Science* (June 1976) and, in an edited version, in *Canadian Consumer* (June 1976), the magazine of the Consumer's Association of Canada. The statement was, in large part, well received. In March 1977 it was, in its entirety, read into the U.S. Congressional Record. The statement outlined the need for a transition to a Conserver Society and some of the characteristics of such a society in general terms. The intent of the present Report is to be more specific.

However, it is important to emphasize that we are not attempting to set out a complete blueprint for a new society, nor to specify the exact modes of transition or how long they may take. The Report should be seen as our view of some new directions related to science and technology that the conserver principles imply, and some actions in those directions that agencies at all levels – government, business, labour, and private citizens – can take.

It should not be construed, as it sometimes has been, that these prescriptions for re-directing and modifying Canadian patterns of growth are aimed at slowing, or freezing in the *status quo*, the productive system in which large number of Canadians have done well, and in which large numbers of less well-off Canadians still hope to realize their aspirations. To the contrary, within finite resources and limited environmental regenerative capacity, it is only by being more efficient, more intelligent, more far-sighted, and by changing the style of some technologies, that we shall all find room for continuing growth and distributive justice. What applies within Canada applies also to Canada as one of the more developed countries, in relation to other parts of the world.

Annex 563

“Proposal for a multiannual research programme in the field of climatology (Indirect action - 1979-83)”, *Commission of the European Communities*, 11 September 1978, pages 2-7, 10-18

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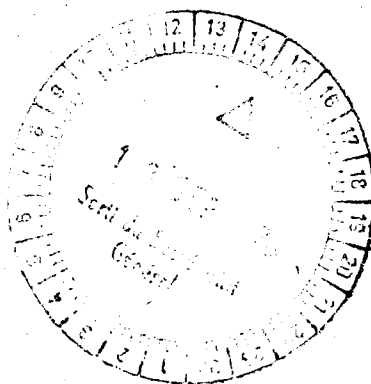
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Brussels, 11 September 1978

Proposal for a
multiannual research programme in the
field of climatology (Indirect action -
1979-83)

(submitted by the Commission to the Council)

COM(78) 408 final



CONTENTS

	<u>Pages</u>
0. <u>SUMMARY</u>	i-iii
1. <u>INTRODUCTION</u>	1
2. <u>PRESENT STATE OF THE ART</u>	2
2.1. RESEARCH ACTIVITIES WORLDWIDE AND IN EUROPE	2
2.2. PRESENT STATE OF KNOWLEDGE ABOUT CLIMATE AND PROBLEMS RAISED THEREBY	5
3. <u>MOTIVATION FOR A CLIMATOLOGY PROGRAMME OF THE EUROPEAN COMMUNITIES</u>	8
4. <u>DETAILED DESCRIPTION OF THE PROGRAMME</u>	10
4.1. GENERAL REMARKS	10
4.2. RESEARCH AREAS	10
4.2.1. <u>Research Area I : "Understanding Climate"</u>	10
4.2.1.1. Objectives	10
4.2.1.2. Research Themes under Research Area I	11
I.1. Reconstruction of Past Climates	11
I.2. Climate Modelling and Prediction	12
4.2.2. <u>Research Area II : "Man-Climate Interactions"</u>	13
4.2.2.1. Objectives	13
4.2.2.2. Research Themes under Research Area II	13
II.1. Climatic Variability and European Resources	13
II.2. Man's Impacts on Climate	15
4.3. SPECIAL ACTIVITIES	17
4.3.1. Objectives	17
4.3.2. Specific Instruments and Services	18
(a) A European Interdisciplinary Group for the Study of Climatic Impacts	18
(b) Inventory, Coordination and Enrichment of European Climatic Data Sets	18

5. <u>IMPLEMENTATION, FUNDING AND MANAGEMENT</u> <u>OF THE PROGRAMME</u>	19
APPENDIX Some noteworthy weather extremes since 1960	20
PROPOSAL FOR A COUNCIL DECISION	22

It should be emphasised that the gaps that exist in our present knowledge do not concern facts, but rather their causes and times of occurrence. Thus no scientist could possibly prove today that such and such disaster is awaiting us at a given date in the future. But science has gathered proofs enough that climate can cause disasters. It is therefore imperative that on one side we refine our means of investigation into the causes of climatic changes so as to reach a point where we can get early warnings of them ; on the other side we should improve our concept of "likelihood of occurrence" by giving it a precise and an as high as possible probability value for specified times and places.

In other words, we have to decide whether we can afford to remain unprepared for likely, serious climatic changes in a possibly near future, or whether we can go on polluting chemically and thermally our atmosphere without minding of the possible consequences on climate. Growing needs may be met by technological progress, but the latter involves a greater use of energy, meaning a greater chemical and thermal pollution of our environment. Should climate be adversely affected by those by-products of technological expansion, we might have to face a kind of climatic barrier to long-term energy growth.

2. PRESENT STATE OF THE ART

The present "state of the art" concerning climate and its relevance to human life may be conveniently treated under two headings :

1. Research activities underway, both world-wide and in Europe.
2. Present state of knowledge about climate and problems raised thereby.

2.1. RESEARCH ACTIVITIES WORLDWIDE AND IN EUROPE

2.1.1. International Projects

During the last decade there has been a significant increase in research on climate on a worldwide basis. The problems connected with the understanding of the present and past climates

and the possibilities for predicting future climatic states have not only resulted in significant individual efforts but have also inspired national and international programmes dealing with various aspects of the climate problem.

A truly international programme, the Global Atmospheric Research Programme (GARP), sponsored jointly by the International Council of Scientific Unions (ICSU) and the World Meteorological Organisation (WMO), has among its objectives the study of those physical processes in the troposphere and stratosphere that are essential for an understanding of the factors that determine the statistical properties of the general circulation of the atmosphere which would lead to better understanding of the physical basis of climate.

A number of other climate programmes exist. These have to a large extent been created because of the renewed interest in climate modelling during the last decade induced partly by the possibility of man's impact on climate and partly by the implications of some of the early primitive climate models. A programme especially devoted to the assessment of man-climate interactive impacts is being organized by the WMO.

2.1.2. U.S.A. Projects

The scientific community in the USA has expressed its recognition of the need for climatic research by a well formulated plan for climatic studies during the next decades. The plan is summarised in the book "Understanding Climatic Change, A Program for Action", published by the U.S. National Academy of Sciences (1975).

This plan contains a wide spectrum of projects dealing with a Climatic Data Analysis Programme (CDAP), a Climatic Index Monitoring Programme (CIMP), and a Climatic Modelling and Applications Programme (CMAP). It is further recognised that these essentially national programmes must be seen in an international setting. To further the aims of the climatic part of the GARP programme, it was also recommended to create an International Climatic Research Programme (ICRP).

Another "U.S. Climate Program Plan" has been prepared by a Drafting Group of the Interdepartmental Committee for Atmospheric Sciences. It largely overlaps the former one by covering such topics as Climate Variability and National Activities, Diagnoses and Projections of Short-Term Climate Variability, Climate Data Management, Observations for Climate Research, etc.

An important plan for a Carbon Dioxide Effects Research and Assessment Program has been drawn by the Department of Energy. It aims at removing uncertainties from predicted future carbon dioxide concentration and at assessing its possible consequences, not only climatic, but also biological, social and economical.

There are in addition a number of more specialized programmes which are all closely related to some aspects of climatic research. Because the oceans dominate the climatic behaviour on a long time scale, it is important that the oceanographic community is engaged in those aspects of oceanography which are relevant to climate

problems. Examples of such field studies are the Mid-ocean Dynamics Experiment (MODE), the North Pacific Experiment (NORPAX), and a POLYMODE experiment, jointly sponsored by the U.S.A. and the U.S.S.R. Other examples are the Climatic Impact Assessment Programme (CIAP) which was concerned with the impact on the climate by various air pollutants, and the Climate Dynamics Programme of the Advanced Research Programme (Department of Defence, U.S.A.).

2.1.3. U.S.S.R. Projects

Less detailed information is available from the U.S.S.R. about their programme for climatic research but it is known through the GARP planning meetings, that the U.S.S.R. scientists are keenly interested in climatic problems. Indeed, one of the first climatic models was presented by a Russian scientist (Budyko).

2.1.4. Projects in the EC Countries

(a) Climate modelling

It is convenient to separately consider the efforts in the modelling of climate which are made by use of general circulation models (GCMs) and those carried on with models where the weather systems are treated on a statistical basis.

At present, the only GCMs in Europe which can be used for climatic studies are those of the British Meteorological Office (BMO) and the ECMWF*. The BMO models have been applied to long-range prediction, and have been used for analyses of specific circulation anomalies and also for studies of man-made climatic changes. The GCMs at the ECMWF are closely related to and based on models developed in the U.S.A. and are used for medium-range predictions.

There are GCMs under development at the Deutscher Wetterdienst (Offenbach) and in France (Etablissement d'Etudes et de Recherches Météorologiques, Boulogne ; Laboratoire de Météorologie Dynamique, Palaiseau). The Joint Universities Group in Reading has made particular efforts in analysing the behaviour of GCMs which may prove fruitful for an assessment of the reliability of results obtained with GCMs. Ocean circulation models are under development in France (Laboratoire d'Océanographie Physique, Paris) England (DAMPT, Cambridge ; Joint Universities Modelling Group, Reading) and in Germany (Max-Planck Institute, Hamburg).

Some of the parametrized models presented so far in Europe exhibit a certain skill in the simulation and analysis of the present mean state of the atmosphere (Wien-Nielsen, ECMWF). Some are concerned with the testing of a specific scheme for the parametrization of weather systems (e.g. Imperial College, London). The work at the Max-Planck Institute in Hamburg concentrates on studying the slowly varying parts of the climate system. Simplified models are in the stage of development in France and Belgium (e.g. Laboratoire de Météorologie Dynamique, Paris)

Some of these models concentrate on the study of selected mechanisms in the general circulation and the problem of seasonal prediction has been attacked.

* European Centre for Medium-range Weather Forecast, Bracknell, UK

(b) Reconstruction of Past Climates

Sporadic studies of climate in the historic past have been made in a number of European academic institutions and national meteorological services, and the results have been published in various scientific periodicals and weather service publications. Because the data and techniques for reconstruction of the past climatic record involve many branches of learning, this kind of research appears best done in the full interdisciplinary setting of academic institutions. The advanced computational facilities and expert staff in the laboratories of leading meteorological services, on the other hand, are ideally suited to pursue research of a theoretical nature, such as climate modelling, numerical predictions and the exploration of the potential effects of man's activities on the climate regime.

There is an obvious need for a large amount of co-operation between these two angles of climatic research which is at present (except in the United States) not fully met. Also, disproportionately less work and support has so far gone into the reconstruction of the climatic record: a record that shall be long enough to cover many times the evolution of long-term processes that may be important to prediction over the coming decades.

At present only a few groups and institutes exist in Europe where the observed record of climate beyond 100 years back is worked on by meteorologists. Small groups or individual scientists in the national Meteorological Services and Universities in Europe have recently published papers that indicate activity in this field. One European research unit, the Climatic Research Unit at the University of East Anglia, is almost totally committed to the reconstruction of past climates. The foremost objective of the work in this Unit is the reconstruction of past climates on a global scale with specific attention to the Atlantic/European sectors. The work is largely carried out by a team of atmospheric scientists in collaboration with other scientists at a full multi-interdisciplinary level.

2.2. PRESENT STATE OF KNOWLEDGE ABOUT CLIMATE AND PROBLEMS RAISED THEREBY

The following considerations apply in general to all climatological research throughout the world.

2.2.1. General Research on Climate

Climate is at present understood in its broad characteristics, but we have relatively little knowledge about the major processes of climatic change. In other words, the mechanism of climate is not

understood in any detail sufficient for instance to allow climatologists to forecast climatic conditions.

It is therefore essential that the scientific community be allowed to increase substantially the amount of data available about the various components of the climatic system. Without these data, theories would remain largely unchecked and even the best model would be of little use.

Overall available data are so far only fragmentary and do not allow us to decide for example which are the most important causes of climatic variations, or which are the most sensitive of the many processes involved in the interactions of various components of the climatic system.

We also ignore how much of the long-term variations, so far known to have occurred, depends on cyclic regularities (of which the causes should be ascertained), and how much on purely random processes.

All these questions must clearly be answered before we even attempt to consider the ultimate question of climate predictability. This last and all-important problem will be solved only after :

- (a) both theory and dynamical models have been further developed and applied ;
- (b) the data bases now available have been greatly extended, both in space and in time.

2.2.2. Research on Man-Climate Interactions

When we come to consider the vast and hitherto largely unexplored field of man-climate interactions, the same situation of a poor or insufficient knowledge is encountered. In this case however it is not only a question of a lack of scientific evidence : climatic variability, either natural or man-induced, may create serious problems for our present economic and social structure.

Our economic and social stability is strongly climate-dependent. The climates of our planet have always been changing, and without any doubt they will continue to do so in the future. What we do not know is how large these future changes will be, and how rapidly they will occur.

A major climatic change would bring about worldwide economic and social readjustments, since the evolution of the global patterns of food production and population has been so far largely controlled by climatic conditions.

At present, world grain reserves are only a few percent of annual consumption ; the occurrence of an unfavourable climatic period, coupled with the increasing food demands of an exploding population, could play havoc. We do not have therefore to wait for a new ice age in order to see our agricultural system devastated. A major social or economical disaster could be brought about by a relatively minor climatic change, such as one of those that have so often occurred, even in the recent past.

Similar considerations apply to water resources, whether we consider them from the standpoint of domestic use, or irrigation, or electric power generation, or industrial use. Here too population growth, the expansion of towns and industrial development are putting an increasing strain on a resource which is already becoming scarce. Thus while unfavourable climatic conditions could make that scarcity greater, one might on the contrary wish that they were favourable in order to cope with demands and build up reserves.

Although we know that water and food resources depend on climate, we ignore the precise relationships defining that dependence in a quantitative way. Hence an urgent need for well-planned scientific research.

The problem is made more serious by the possibility that climate changes may be the consequence of human activities. Man is steadily modifying many of the factors which are known to determine climate. Such modifications may be small, but for climate, in general, there is no a priori way of deciding the magnitude of the effect from that of the cause, since positive feedback mechanisms could act as amplifiers of seemingly small initial perturbations.

Man is for instance changing the chemical composition of the atmosphere by all kinds of pollutants, and in particular by burning fossil fuels that steadily increase the concentration of carbon dioxide. Man is destroying forests, which also increases the atmospheric carbon dioxide content while altering the surface albedo and thus affecting the earth's radiation balance. Man is also pouring large quantities of heat into the atmosphere, thus perturbing the planet's energy budget.

2.2.3. Summing up

All this points to a situation which in general terms can be briefly described as follows :

- (a) We know that climate is essentially changeable ; we do not know the precise causes of its changes.
- (b) We know that climatic changes may occur at any time ; we also know that man might have a role in determining them ; we do not know when or where they could occur.
- (c) We know that even relatively small changes might produce important effects ; we do not know the quantitative relationships linking climatic changes to the possible changes in the variables important to man's life and well-being.
- (d) We need therefore to concentrate our efforts towards the aim of eliminating as many as possible of our present uncertainties, so as to avoid as many as possible of the threats that climatic variability may have in store for us.

4. DETAILED DESCRIPTION OF THE PROGRAMME

4.1. GENERAL REMARKS

Climate may be considered both (i) by itself as one of the many facets of the natural world and (ii) as a part of man's environment, and as such in interactive relationships with man's activities.

On these grounds two research areas have been naturally considered for the present programme, the first having its main emphasis on climate's mechanism, the second on the interactions between man and climate.

In dealing with climate mechanism, under Research Area 1, explicit mention has been made of mathematical models as an obvious means of dealing with the problem. Elsewhere more experimental methods may have been stressed.

It should be understood however that no constraint is put in general on the means whereby a given problem could be solved. Various methodological approaches are in principle applicable to the several research items described later on. They include for instance :

- (a) Experimental research ; measurements and monitoring activities ;
- (b) Statistical evaluations of climatological records ;
- (c) Simulation, diagnosis and projection studies, as regards both long- and short-term climatic variability and impacts.

To properly implement the programme, it has been found advisable to also suggest the establishment of :

- (i) a group of climatic experts especially appointed to study the possible impacts due to the interactive relationships between man and climate ;

- (ii) a system of data storage, enrichment and management, whereby up-to-date climatic data may be freely and rapidly accessible to all researchworkers concerned

4.2. RESEARCH AREAS

4.2.1. Research Area I : "Understanding Climate"

4.2.1.1. Objectives

The general objective of this research area is that of gaining a deeper insight into the mechanism and therefore the behaviour of climate, the ultimate goal being climate prediction, especially on a usefully short-term (weeks to decades) scale. To achieve that goal it is necessary :

- (i) To reconstruct the past record of climate in as much detail, over as much of the Earth and as far back in time as data and interpretative techniques permit ;
- (ii) To analyse that record so as to be able to determine the causes of the changes observed ;
- (iii) To improve theoretical understanding and knowledge of the development of climate, the circulation processes in the atmosphere and oceans and the interactions involved, and the nature of the impact of external influences.

Clearly these observational and theoretical attacks are closely interlinked and need to be pursued hand in hand, by also taking advantage of data obtainable through research work in Research Area II.

4.2.1.2. Research Themes under Research Area I

I.1. Reconstruction of Past Climates

The past variability of climate on long time scales can provide valuable information on the dynamics of the climate system. Furthermore, in order to obtain reliable statistics, the sampling period of a continuous statistical process should be considerably longer than the fluctuation periods of interest. There is a convincing evidence that climatic changes and variability have been significantly better in the past than in the short period of instrumental observation on a global scale (ca. 100 years). There is also a growing evidence of quite abrupt climatic changes which would be really catastrophic to mankind if they would repeat. For these reasons the analysis of past climates should be an important contribution to the present Programme.

There exists a wealth of unexplored historical information on climate in Europe which should be collected and organized. These include both (a) Natural Records and (b) Observational and other Historical Records.

- (a) includes for example fossil types of data such as tree-rings ; year-layers in lake sediments, river estuaries and ice-sheets ; concentrations of stable isotopes of oxygen, carbon, nitrogen etc. in the wood substance of tree-rings and in the ice of ice-sheets ; pollen analysis ; analysis of insects and marine microfaunes in the sedimentary records, etc.
- (b) includes for example records of measurements made in the past about meteorological parameters, as well as reported data about floods, frosts, harvests, disasters caused by weather, etc.

Such records should be explored and analysed in such a way as to bring to light the circulation processes in the atmosphere and the oceans, and any external influences (solar, tidal, volcanic or other) which underlied the changes made evident by the records themselves.

I.2. Climate modelling and prediction

The ultimate goal of climate modelling is climate prediction, and it is obvious that society is interested in climatic predictions of time scales from the limit of detailed weather predictions (say, two weeks) to many years. Apart from the immediate relevance to society, this time scale interval is also more promising for theoretical studies than the longer time scales because of the better availability of data.

Studies aimed more specifically at the problem of forecasting climate should therefore be encouraged, and in this context three main possible growth points can be identified :

(a) A System-Analysis Approach

The techniques of system analysis should be used in order to provide extrapolation techniques useful for periods of the order of magnitude of one month.

A technique currently used at present consists in selecting a so-called "historical antecedent" to a present situation from climatic archives.

Assuming the two situations to be identical, they should have an identical evolution. The problem is here to identify and correctly select those parameters that can act as useful predictors of climatic change. The technique of system analysis should be used for the selection of such predictors, with the advantage that the choice would be guided by synoptic as well as by dynamical criteria.

(b) Atmospheric Circulation Models

An attempt should be made at developing numerical models of the atmospheric circulation directed specifically at the problem of climate prediction. Appropriate simplifications of the detailed general circulation models could be guided by the use of special analyses of global atmospheric data and by the existing General Circulation Models. One would in this way develop and test numerical models with relatively few degrees of freedom compared to the detailed GCMs, and perform analyses of atmospheric data relevant to the design of such models. Test cases should include not only "normal" climatic conditions, but also spectacular excursions like the drought in north-western Europe during 1976. Care should be taken to include in such models a proper treatment of the physical processes at the air-land and air-ocean interfaces, a hydrological cycle and a treatment of the upper mixed layer of the ocean.

(c) Slowly varying elements

As the periods of the prediction of the atmosphere become longer, it is almost certain that the detailed atmospheric description will play a lesser role, while the oceans and the other slow-response parts of the climatic system will play a greater role. It has thus been realised recently that prediction models for the longest time scale must concentrate on the evolution of the slowest-response parts. Models of this nature are in their infancy, but give great promise for further development.

One should therefore try to develop models for climate predictions concentrating on the parts of the climatic system with the slowest response (continental ice sheet, deep circulations of the oceans, changes in vegetation and snow cover over land and of drifting sea ice). It will be required to include the physics of the slowly-varying components, their interactions and the specification of the statistical representations of the faster-response components of the system. The models should be tested and attempts should be made to make experimental forecasts for 100 years.

4.2.2. Research Area II : "Research on Man-Climate Interactions"

4.2.2.1. Objectives

If one considers short-term needs and impacts, the present one is probably the most important field of research. Recent problems concerning the availability and distribution of food, water and energy have raised the general level of concern about the impacts of climate on man's resources, as well as about the possible impacts of human activities on climate.

The objective of the research work to be performed in this area should therefore be that of assessing in an as precise and quantitative way as possible (1) the relationships between climate variability and the availability, spacewise and timewise, of important resources, and (2) the impacts that certain human activities could have on climate.

The assessment of such relationships and impacts will be typically the result of an interdisciplinary study. For this reason, besides the implementation of specific research projects within the present Research Area, the establishment of an Interdisciplinary Group is proposed (see below under "Special Activities").

4.2.2.2. Research Themes under Research Area II

Since man-climate interactions can be considered both ways, Research Area II includes naturally the following two research themes.

II.1. Climatic Variability and European Resources

(a) Impacts on Land and Water Resources

Climatic variability affects land and water resources in many-fold ways. This clearly applies to such natural hazards as droughts and floods, as well as to surface and ground water demands for energy, domestic and agricultural purposes.

Proper land and water resources management, especially in view of hazard reduction, requires therefore that one is able to obtain a knowledge of the frequency and magnitudes of past and present climatic changes.

Water resource planning is based at present on statistical and probability predictions. Therefore the extension of the historical records concerning run off should allow improved estimates of the probability of future streamflow magnitudes. This kind of information is important in forecasting the availability of domestic water, irrigation water and hydroelectric power.

Research should therefore be focussed on the quantitative relationships between specific changes in climatic variables and the occurrence and availability of surface and ground water. Recharge processes, which are known to be sensitive to climatic conditions, should be investigated in this respect.

Soil moisture and vegetation are mutually linked : the effects of changes in either of these should be studied in relationship to specified climatic conditions.

Rainfall outlooks, limited at present to one month ahead, should also be improved upon and cast in terms of probability or ranges of expected values in order to be properly used. Spatial and temporal correlations, known as teleconnections, should be systematically explored to these purposes.

The agricultural community needs monthly or seasonal rainfall and temperature predictions for the growing season several months in advance, in order to plan crop types, seed varieties and fertilizer needs. Suppliers may need longer times, and government planners and policy makers may want even longer periods, possibly one year in advance.

Extensive new observations of the relevant parameters should be gathered and diagnostically analysed in order to help the construction of new statistical prediction formulas and the generation of further hypotheses for testing with proper models. The highest priority should be given to research aimed at developing yearly projection techniques.

(b) Climatic Hazards Evaluation

A special field of endeavour is the evaluation of the probability of occurrence of such extraordinary yet economically and socially important events as disasters, like floods and droughts, caused by climatic conditions.

Flood hazard planning could be improved by the extension of our knowledge about past flood recurrence, using evidence from the geological records, coupled with the evaluation of changes in the surface run off characteristics.

Similar considerations apply to snow hazards, such as snow avalanches in mountain regions and snow hazards to buildings and communications in regions where snowfalls are normally light or infrequent.

Droughts are also a kind of hazard that properly oriented climatic research could help predicting and being prepared against, especially in view of a proper management of water resources.

(c) Impacts on Energy Requirements, Use and Production

Climate has a profound influence on the amount of power required, and even on the means whereby power is generated (for instance electrical energy from water reservoirs, solar energy in sunny regions). Conversely, power generation and use may affect climate, through thermal or chemical pollution of the atmosphere.

Apart from general climatic effects, a knowledge of the climatic conditions likely to be experienced by any given region is necessary for planning both site selection and plant design and operation. Especially needed is a better capability of relating the dispersion of airborne pollutants, especially those of a toxic kind, with ambient climate conditions. Such information is particularly lacking for irregular zones such as mountain-valley complexes, coastal regions and forest areas.

Besides their relevance to hydroelectric power production, water flow forecasts and precipitation outlooks are important for cooling plants necessary to nuclear and fossil power plants, since about 60% of the energy produced is dissipated as heat. For this reason the rainfall and run off prospects of any given region have a marked influence on energy production.

Finally, climatic forecasts or outlooks have an obvious relevance to the planning of energy production in view of heating and cooling needs.

II.2. Man's Impacts on Climate

It has been recognized that man's activities can affect the climate of the earth, possibly in an unfavourable way. Inadvertent climate modifications are here meant, and among the various possible research fields the following have been selected.

(a) Atmospheric Chemical Pollution, with a special emphasis on Carbon Dioxide release

Direct contamination of the atmosphere is one of the most obvious of man's influences on his environment, one moreover that can have direct effects on climate.

Particles and certain trace gases influence the heat balance of the atmosphere by changing the flux of solar and infrared radiation. Particles are also involved in the initiation of condensation and freezing in clouds.

Among gaseous products, by far the most important for its possible impacts on climate is carbon dioxide, which man has been pouring into the atmosphere since the beginning of the industrial era. Thus CO_2 concentration has increased from about 290 ppm by the year 1860 to about 320 ppm by 1970, that is about a 10% increase in 110 years. But since CO_2 concentration is growing exponentially, the next 10% increase would only take 20 years, and a 100% increase would occur after 50 years, that is by 2020.

Such a doubling of the CO_2 global concentration could effect an increase of the temperature near the earth's surface by about 2°C . Such a warming would constitute a serious climatic modification which could lead to irreversible effects, such as the destruction of the Arctic Sea ice with a drastic shift of all climatic belts northwards. While a disappearance of the floating Arctic sea ice would have no immediate effect on sea level, the possibility of a large-scale surge of Antarctic shelf-ice has been suggested, which would cause a danger of inundations over low coastal regions.

Various hypotheses have to be tested in this connection ; for instance, the earlier assumption of a permanent 50% storage in the ocean and the biosphere of the released fossil CO_2 may be untenable. Increased deforestation may prevent the biological storage of important quantities of CO_2 , while the storage in the oceanic upper mixing layer could only last a few decades, because of the low mixing rate with the cold layers below the thermocline. Large amounts of CO_2 could therefore be released by the oceans sooner or later and this process would be intensified by a slow acidification (due to pollution) and warming (due to the "greenhouse effect" of CO_2 itself) of the upper mixing layer. On this basis a fivefold increase in the CO_2 concentration after 100 years cannot be excluded if the use of fossil fuels were to continue unchecked at the present growth rate.

On the other hand, scientists are not unanimous as regards the temperature impact of such an increase. Estimates of the mean temperature rise due to CO_2 vary, and the net temperature change which could result against the observed cooling trend since 1940 is not certain.

It appears therefore that one of the highest priorities in the present Programme should be assigned to the CO_2 accumulation problem in order to assess precisely :

- (i) past and present CO_2 concentrations ;
- (ii) sources and sinks of CO_2 , and their evolution in time ;
- (iii) exchange rates between the various compartments of the climatic system ;
- (iv) climatic and other environmental impacts.

The assessment of such factors should be arrived at through both applied research and proper modelling. Monitoring should be provided by a number of stations suitably chosen or possibly established to the present purpose.

(b) Release of Energy

Thermal pollution is also a cause for concern, since man is thereby significantly contributing to the energy budget of the earth by burning fossil fuels : coal, gas and petroleum products. The rapidly increasing contribution from nuclear power plants must also to be included in any future projections. For 1970 the global energy production has been estimated at about 6×10^{19} cal/year. Distributed evenly over all continents this energy amount corresponds to a small fraction of the net solar radiation at the earth's surface ; but the annual growth rate of energy production has been gradually rising, with an average global increase of about 4-5% annually, according to UN data. This is equivalent to a rise by a factor of 3 to 4 in 30 years. There will be therefore many areas in the world in which the additional energy input will approach the order of magnitude of the natural net radiation. The EC energy output for 1976 can be calculated from EC data (1) to have been 7.5×10^{15} Kcal, which corresponds to about 0.6 Wm^{-2} . An assumed growth of 3% per year would bring the average energy output to about 1.2 Wm^{-2} by the year 2000 and to about 5.2 Wm^{-2} by the year 2050, the solar radiation at the earth's surface being about 100 Wm^{-2} . Those being average values, clearly urban and industrial areas would add much more to the natural radiation input. For instance, the value for West Berlin has been about 21 Wm^{-2} during the years 1965 to 1968, and it was already 19 Wm^{-2} for Sheffield in 1952 (2)

The effects of urban and regional heat sources on continental and global climate are however uncertain ; we can speculate that there is a possibility that such areas may sooner or later trigger some changes in the local or large-scale weather patterns. A certain amount of research work should be directed towards the assessment of the possibility and the magnitude of such changes.

4.3. SPECIAL ACTIVITIES

4.3.1. Objectives

The objectives of the work to be performed under "Special Activities" correspond to four basic needs, namely :

- (i) to correlate in a panoramic and synthetic view the data collected under Research Areas I and II ;

(1) Overall Energy Balance Sheets (1963-1976), Statistical Office of the European Communities, Luxembourg, December 1977.

(2) Inadvertent Climate Modifications, SMIC Report, MIT (1971)

- (ii) to provide suitable diagnoses and projections concerning climatic variability and impacts ;
- (iii) to provide suitable instruments and services for climatological research.

4.3.2. Specific Instruments and Services

(a) A European Interdisciplinary Group for the Study of Climatic Impacts

Scientific disciplines applied to climatological research may be or become so highly specialized that the necessary comprehensive view of the whole may be lost in individual efforts. Yet, due to the highly interactive nature of all climatic or climate-related factors, climatological research is typically one where a panoramic view has to be maintained at all costs. Hence the necessity of establishing an Interdisciplinary Group whose task should be to take care of needs (i) and (ii) stated above. The Group should include a number of European Experts in various disciplines selected on the basis of their relevance to and complementarity in climatological research.

(b) Inventory, coordination and enrichment of European Climatic Data Sets

Climatological research in general and projection studies in particular will require extensive data collections. Various centres in Europe possess or are building up such data collections either from modern observations or from natural or historical records. To make the best possible use of such a work in the frame of the present Programme, it appears essential

- (i) that an inventory of the existing European data sets, sources and formats be established and regularly updated ;
- (ii) that practical means be devised to favour the exchange of data between the various centres, and their general availability to the scientific community ;
- (iii) that new, useful data sets from outside the EEC Member States be acquired.

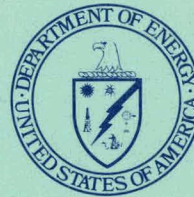
Annex 564

“Summary of the Carbon Dioxide Effects Research and Assessment Program”, *United States Department of Energy, Office of Health and Environmental Research*, July 1980, cover slide, “Effects on Climate”, “Implications of CO₂ Induced Climate Change”

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Summary of the Carbon Dioxide Effects Research and Assessment Program



United States
Department of Energy
The Carbon Dioxide Effects
Research and Assessment Program

CO₂

MASTER

Effects on Climate

Carbon dioxide, although virtually transparent to short wave solar radiation (visible light) strongly absorbs long wave radiation (heat) at certain wave lengths in which other atmospheric gases are transparent. Thus, when carbon dioxide increases, more long wave radiation is trapped in the earth atmosphere system than would otherwise be the case. Some of this radiant energy increases evaporation. The increase of atmospheric water vapor resulting from the increased evaporation amplifies the "greenhouse" effect because water vapor also strongly traps long wave radiation. Because of differences in incoming solar radiation with latitude and because of the complex nature of the earth's surface (water, land, ice), the CO₂ induced warming is not uniform over the globe.

The accompanying diagram shows the results of a numerical simulation (a computer model) of the effects on global temperature of a doubling of atmospheric CO₂. It shows the temperature differences, averaged longitudinally, between a "run" with current values of atmospheric CO₂ and a "run" with twice that amount. Note particularly the larger than average increases of temperature in the polar regions and the decreased temperatures in the stratosphere. Other, more recent models suggest that, in addition to the temperature changes, a doubling of atmospheric concentration values may result in decreased soil moisture in the mid-latitudes, increased precipitation in the Arctic, and changes in atmospheric circulation.

Source: S. Manabe and R. Wetherald, "The effects of Doubling the CO₂ Concentration on the Climate of a General Circulation Model," *Journal of the Atmospheric Sciences*, Volume 32, 1975, p. 3

Implications of CO₂ Induced Climatic Change

Carbon Dioxide Effects
Research and Assessment Program



United States
Department of Energy

- **Should carbon dioxide increase and climate change to the degree now thought possible, the hydrosphere, biosphere, lithosphere, and cryosphere would all be affected.**
- **Some of these effects, such as the melting of the Arctic Ocean's icepacks or increases in evaporation and cloudiness, would constitute geophysical "feedbacks" to the climatic system thus increasing or decreasing the magnitude of the climatic change.**
- **Other environmental changes might not affect the geophysical processes but would be important in themselves. Examples of these changes are changes in the viability of crops, in the species composition of the "wild" biosphere or in the chemistry of the upper layers of the oceans.**
- **It is thought that these changes in climate and the environment would not be globally uniform.**
- **The impact of unprecedentedly large, regionally uneven environmental changes would almost certainly affect all aspects of the global economic, political, and social systems in an unknown but potentially profound manner.**

Annex 565

Bonneuil et al., “Early warnings and emerging accountability: Total’s responses to global warming, 1971-2021”, *Global Environmental Change*, 2021, pp. 1-10



Early warnings and emerging accountability: Total's responses to global warming, 1971–2021

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ABSTRACT

Building upon recent work on other major fossil fuel companies, we report new archival research and primary source interviews describing how Total responded to evolving climate science and policy in the last 50 years. We show that Total personnel received warnings of the potential for catastrophic global warming from its products by 1971, became more fully informed of the issue in the 1980s, began promoting doubt regarding the scientific basis for global warming by the late 1980s, and ultimately settled on a position in the late 1990s of publicly accepting climate science while promoting policy delay or policies peripheral to fossil fuel control. Additionally, we find that Exxon, through the International Petroleum Industry Environmental Conservation Association (IPIECA), coordinated an international campaign to dispute climate science and weaken international climate policy, beginning in the 1980s. This represents one of the first longitudinal studies of a major fossil fuel company's responses to global warming to the present, describing historical stages of awareness, preparation, denial, and delay.

1. Introduction

Since World War Two, the Anthropocene has witnessed an intensification of humans' alterations of the Earth system, as well as an increase in environmental alerts and concern (McNeill and Engelke, 2016; Krausmann et al., 2017). Key to this "Great acceleration", annual fossil fuel extraction has increased sevenfold in the last 70 years resulting in the top 20 fossil fuel firms producing more than one-third of all greenhouse gas emissions since 1965 (Heede, 2014; Institute, 2020). Since 1945, few industries have been exposed to the intensity of environmental scrutiny and public criticism that the oil industry has faced, relating to pollution from refineries, smog, leaded gasoline, oil spills, and poor monitoring of extraction sites. When climate change emerged as a policy issue in the 1960s, oil and gas majors were already practiced in managing environmental perceptions by the public, risk research, and regulatory action by governments (Markowitz and Rosner, 2002; Jenkins, 1954).

Much has been documented in recent years on how major fossil fuel companies such as ExxonMobil (Banerjee et al., 2015; Supran and Oreskes, 2017) and Royal Dutch Shell (Mommers, 2018) have navigated

climate alerts and controversies via a mixture of internal knowledge development and external public relations activities, with industry associations and coalitions such as the American Petroleum Institute and the Global Climate Coalition playing major roles (Brulle, 2018; Franta, 2018, 2021). These studies have met with great interest due to their analysis of varying strategies among oil majors (Skjærseth and Skodvin, 2003), importance for understanding the history of climate action and inaction, and usefulness for informing current and planned efforts to address climate change. Relatively little, however, has been documented on Total, a company established in the 1920s that a century later has become the world's fourth largest dedicated oil and gas company by market capitalization behind ExxonMobil, Chevron, and Royal Dutch Shell. Although the company's current climate strategy has been scrutinized (Choquet, 2019), its historical response to global warming and to evolving climate science and policy remains an unaddressed topic.

In this paper, we address this research gap by reporting new archival research and primary source interviews documenting Total's long exposure to climate warming research and subsequent industry coordination, public communication, and lobbying activities regarding climate change. While filling this empirical gap, we also aim to contribute to the

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literature on the global effort deployed in the past fifty years by the fossil fuel industry to produce ignorance, sow doubts on the legitimacy of climate science, struggle against regulations, and maintain legitimacy within the global energy transition. We do so by shedding light on the early exchanges of knowledge and incipient strategies that were articulated within IPIECA (International Petroleum Industry Environmental Conservation Association), an industry association in which Total was actively involved and which has received less attention than the American Petroleum Institute (API) or the Global Climate Coalition (GCC).

Scholarly research on the history of major fossil fuel companies is often limited by restrictions on access to company archives. In contrast, Total's archives, located at the company's headquarters in Courbevoie, France, are partially accessible to researchers and provide an unprecedented look at the history of the company. In addition to these archives, we also interviewed former Total executives, who shared with us their recollections of the company's history with regard to climate change. As a result, we report detailed information that may be obtained regarding other fossil fuel majors should they also provide access to scholars.

Environmental historians have shed light on the history of the Anthropocene, revealing that environmental warnings and awareness predate the late-20th-century discursive turn toward sustainability. In this context, the Anthropocene can be understood as a history of evolving mechanisms of willful blindness and rationalizations that normalized socio-ecological trajectories and business strategies that accelerated alterations of the planet (Bonneuil and Fressoz, 2016). The history of oil majors' engagement with climate science (Boon, 2019) offers an empirical ground to understand such diverse and evolving mechanisms.

In science and technology studies, the social and cultural "study of the production of ignorance" has helped to understand ignorance as resulting from the organized work of social actors ("agnogenesis") rather than a mere absence of knowledge (Proctor, 2008). In the climate context, the concept of agnotology has mostly been harnessed in order to describe cases in which industrial actors have attacked the scientific consensus and organized lobbying campaigns (Oreskes and Conway, 2010), as well as to highlight strategic rhetorical framing techniques (Supran and Oreskes, 2021) and disparities between internal knowledge and external communication (Supran and Oreskes, 2017). But an exclusive focus upon the most aggressive ways of producing ignorance may leave understudied other forms of agnogenesis that may be less overt, strategic, intentional, or more banal, such as "willful blindness" that may become normalized within firms (Bovensiepen and Pelkmans, 2020). Furthermore, in addition to overt climate science denial, public relations activities such as pronouncements of corporate stewardship and endorsements of climate science have been documented by scholars as instrumental to corporate efforts to avoid responsibility and resist regulations (Rajak, 2020). The case of Total's multiple and changing stances toward climate science and policy in the last half century helps illustrate these diverse and multifaceted mechanisms. While we show for the first time that overt denial of climate science was endorsed by Total from at least 1989 to 1994 (for an opposite finding, though lacking internal company sources, see van den Hove et al., 2002), we also document a temporal sequence of multiple and subtler forms of agnogenesis, such as willful ignorance, responsibility-shifting, strategic philanthropy, promotion of peripheral solutions, and corporate controversy management. Thus, this paper contributes to interdisciplinary efforts to understand the evolving approaches oil majors have taken to climate change, climate science, and mitigation policies.

2. Climate warnings in an era of growing environmental awareness, 1965–1986

Prior research has shown that segments of the petroleum industry, including major companies (Mommers, 2018; Andersson, 2020; Aronowsky, 2021) and the American Petroleum Institute, the primary trade

association for the industry in the United States, received warnings about global warming as early as the 1950s and commissioned research on the topic by the end of the 1960s, which indicated that a continued expansion of fossil fuels would cause significant global warming by the end of the century with adverse consequences for the world's societies (Franta, 2018; Robinson and Robbins, 1968). Total (est. 1924) was a member of the API in the late 1960s through its North American subsidiary and therefore may have had access to this information⁽¹⁾.

Our current research was sparked by our discovery of direct proof of Total's awareness of climate science in 1971. In that year, the company's magazine, *Total Information*, contained an article entitled "Atmospheric pollution and climate" (Durand-Dastès, 1971). The article stated:

"Since the 19th century, humans have been burning increasing amounts of fossil fuels. This results in the release of enormous quantities of carbon dioxide [...] The overall amount of carbon dioxide present in the atmosphere, therefore, has increased significantly. [...] The increase has been around 15% over the last 150 years, which is not negligible. And [...] if the consumption of coal and oil keeps the same rhythm in the years to come, the concentration of carbon dioxide will reach 400 parts per million around 2010 [...]."

"This increase in concentration is quite worrying [...] carbon dioxide plays a large role in the thermal balance of the atmosphere [...] air richer in carbon dioxide absorbs more radiation and heats up. It is possible, therefore, that an increase in the average temperature of the atmosphere is to be feared. The calculated orders of magnitude are obviously small (from 1–1.5 °C) but could have important impacts. Atmospheric circulation could be modified, and it is not impossible, according to some, to foresee at least a partial melting of the polar ice caps, which would certainly result in significant sea level rise. The catastrophic consequences are easy to imagine." (Durand-Dastès, 1971, p. 18)

The article's predictions were quite accurate: carbon dioxide concentrations reached 400 parts per million in 2015. Printed at about 6000 copies, the magazine, *Total Information*, was the company's internal and external communication outlet, read by executives, employees, and commercial partners and was available to the public at the French National Library. The above mentioned article was part of a special issue on the environment with a foreword signed by the company's CEO, which noted that "the defense of the environment is often accompanied by rather strong criticism of large industries including oil companies" (Granier de Liliac, 1971⁽²⁾).

2.1. Putting early climate warnings in context

The significance of this early warning becomes clearer if placed in its international scientific and political context. The involvement of carbon dioxide in the greenhouse effect had been known to some scientists and discussed in media since the 19th century, but in the context of the Cold War, when the entire globe from the sea-bed to the upper atmosphere was studied as a potential strategic theater, research on the Earth system accelerated (Doel, 2003; for a detailed chronology including press clippings, see Johnson, 2016). From 1950 to 1971, at least five lines of research solidified the hypothesis of anthropogenic global warming (Weart, 2003; Edwards, 2010; Howe, 2014; Somerville et al., 2007). First, a reconstruction of the Earth's global temperature since 1800, collected since the 1920s and digitized in the 1960s, highlighted an overall warming trend since the end of the 19th century and a slight cooling trend from 1945 to 1970. Second, a continuous annual increase in atmospheric carbon dioxide was measured at Mauna Loa Observatory starting in 1958. Third, observations and estimates from the US Geological Survey concluded in the late 1950s that the Arctic ice cap had shrunk by 12% in area and 40% in thickness since 1945, with sea level

rising 30–60 cm per century, and that the eventual abandonment of some coastal towns may be necessary (Fleming, 1998, p. 132). Fourth, “general circulation” models were developed in the 1960s, using the first supercomputers to model the Earth’s climate in three dimensions, which estimated in 1967 that a doubling of atmospheric carbon dioxide from 280 to 560 ppm would produce an average global warming of 2 °C (Manabe, 1967, discussed in Weart, 2003, pp. 107–113). Finally, a fifth line of work documented positive feedback between warming and melting ice and snow through changes in Earth’s albedo (Budyko, 1969, discussed in Weart, 2003, p. 86).

These lines of inquiry occurred in a context of growing environmental alerts and movements, and global environmental issues steadily gained prominence in the public sphere (Mahrane et al., 2012). The Earth, which could now be seen from space as a fragile and finite blue ball, had to be managed accordingly. A variety of scientific assessments performed in the 1960s and 1970s helped to bring global warming to US and international attention. In the United States, a report submitted in 1965 to the White House by the President’s Scientific Advisory Committee on the state of the environment warned that:

“By the year 2000 the increase in atmospheric CO₂ will be close to 25%. This may be sufficient to produce measurable and perhaps marked changes in climate, and will almost certainly cause significant changes in temperature”. (President’s Science Advisory Committee, 1965, p. 126–127)

Shortly after its release, the President of the American Petroleum Institute mentioned the report in a speech at the organization’s annual meeting (Franta, 2018) and President Johnson wrote to Congress that “This generation has altered the composition of the atmosphere on a global scale through [...] a steady increase in carbon dioxide from the burning of fossil fuels” (Johnson, 1965 quoted by Oreskes and Conway, 2010, p. 171). Additionally, a synthesis carried out at MIT in 1970, *Man’s Impact on the Global Environment* (known as the SCEP Report), affirmed the Earth could warm by 0.5 °C by the year 2000 and by 2 °C in the 21st century (SCEP, 1970, p. 12). In the wake of this study, MIT brought together 30 global atmospheric and climate specialists for two weeks in Stockholm in the summer of 1971, yielding the *Inadvertent Climate Modification Report: Report of the Study of Man’s Impact on Climate* (known as the SMIC Report). The report, which also examined the potential for global cooling from aerosol pollutants, stated:

“We know enough of the theory of climate and the construction of climatic models to recognize the possibility of man-made climate change and to have some confidence in our ability to compute its magnitude (...). We have a conviction that mankind can influence the climate (...). We hope that the rate of progress in our understanding can match the growing urgency of taking action before some devastating forces are set in motion.” (SMIC, 1971, p. 15 and 27)

Climate change also arose as an international concern at the 1972 UN Conference on the Human Environment in Stockholm, where two of the 109 final recommendations called for research and vigilance regarding anthropogenic climate change (Ward and Dubos, 1972, 191–195; United Nations, 1972, recommendations no. 70 and 79).

In the French scientific community and public space, the climate issue was less prominent than in the United States. Yet the word was spreading in French decision-making circles. In 1968, a high level symposium on technological forecasts and economic planning held discussions comparing the problem of nuclear waste with “the increase of carbonic gas in the whole atmosphere which might, in a decade or half a century, start to pose problems of global modifications in terrestrial climate” (*Collège des techniques avancées et de l’aménagement du territoire* (CTAAT), 1968, p. 51). In the face of this dilemma, top scientists, senior public administrators and heads of major French

companies including the CEO of Elf-ERAP (then a state-owned French oil company, absorbed by Total in 1999) agreed on the need to develop nuclear energy both for economic and climatic reasons (id.). In 1970 and 1972, two articles on global warming appeared in the journal of the French land planning administration DATAR, the driving force behind the creation of the French Ministry of Environment. The second of these articles reported the findings of the SMIC Report and noted that

“We know enough today about climate theory and the construction of climate models to see that humans can very well cause climate change. [...] In the final analysis, therefore, we can only predict what might happen if humanity continued to act in a certain way, much as it is doing now.” (anon., 1972, p. 35)

Around the same time, a variety of popular environmental works in English were translated into French, including *The Closing Circle* by Barry Commoner (translated 1971), *Only One Earth* by Barbara Ward and René Dubos (translated 1972), and the *Limits to Growth* report (translated 1972), all of which mentioned the alteration of the global atmosphere and its possible impacts on climate. Additionally, *L’Utopie ou la Mort* (“Utopia or Death”), a French environmental best-seller warning of “irreversible climate changes” and sea level rise, was published by Dumont (2020), [1st ed. 1973], p. 78), who represented the green movement in the 1974 French presidential election.

Often, these warnings of global warming were accompanied by discussions of potential global cooling. By the early 1970s, scientific articles had noted the potential for aerosol particles, especially industrial pollutants such as sulfur dioxide, to block a fraction of incoming solar radiation. Additionally, since past interglacial periods of around ten millennia were followed by relatively rapid glaciation, the slight cooling trend observed between 1940 and 1970 could lend itself to extrapolations of an imminent ice age, a scenario promoted by various popular magazines in the 1960s and 1970s and included in a CIA report in 1974. Yet a meta-analysis of the scientific literature from 1965–1979 shows that most studies predicted warming, with discussion of the cooling hypothesis dwindling by 1973 (Peterson et al., 2008). By 1979, the scientific consensus regarding the existence and magnitude of future warming as a function of greenhouse gas emissions was reflected in the authoritative assessment directed by MIT’s Jule Charney, which reviewed prior work and estimated a doubling of carbon dioxide concentrations would produce a global warming of about 3 °C (Charney et al., 1979).

2.2. Total facing climate warning in the 1970s

The discussion above indicates that the 1971 article published in *Total Information* was not an isolated warning but rather a moment in which the French oil company’s top executives were exposed to a growing body of scientific work on global warming. In an interview for this article, Durand-Dastès, a specialist of the climate-monsoon nexus in India and one of the French academics then most familiar with climate research, recalled the time when he wrote for *Total Information* and noted the importance of the growing body of transnational scholarship:

“I remember having the SMIC report in my hands. [...] I read a lot of meteorology, one of the key areas for climatology, and a lot of American scientific literature[...] The assertion of global warming of 1–1.5 °C in coming decades if emissions followed their trajectory was more or less common in all scientific journals. I was reading the *Quarterly Journal of the Royal Meteorological Society*, *Tellus*, and so on.” (Interview with François Durand-Dastès, August 6, 2020)

When asked to elaborate on what he meant by “catastrophic consequences” of a climatic warming, he added:

"The deltas are always the sites of disasters. We all knew that increasing the greenhouse effect could not fail to produce major consequences, but I never imagined it would develop so quickly. In 1971, it was foreseeable that the rising oceans would cause problems in the deltas, and I was familiar with those of South Asia. [...] Cyclone Bhola in 1970 had hundreds of thousands of victims, the Andhra Pradesh cyclone in 1977 had 10,000 dead [...] there were catastrophic cyclones hitting hundreds of thousands of people at the time I was writing this article. The great floods were episodes of conjunction between a typhoon and a high tidal coefficient, but it seemed obvious to me that against a background of global warming, it was going to get worse." (id.)

Confronted with multiple warning signals in France, the US, the international arena, and its own magazine, how did Total and Elf (the two major French oil companies which merged in 1999) react? At that time, the French petroleum industry was exposed to growing public criticism following the Feyzin refinery accident in 1966 (in which 18 people died) and the *Torrey Canyon* oil spill in 1967. Total responded by portraying environmentalists as "caught in the trap of nostalgia for a past that was not as pristine as it is assumed" and asserting that "it is technology and not outdated regrets that will ensure or restore a certain quality to the living environment" (Truchot, 1975, p. 20).

With the creation of a French ministry for environment in 1971, French oil companies also feared new regulations on air pollution. This critical scientific, social, and policy context led Total and Elf to establish new structures for managing environmental affairs. In 1971, Elf created its Information and Research Center on Nuisances (CIRN) (Elf, 1974) while Total created a division that would later become its Department for Environment⁽³⁾. A former staff member in the early years of that division recalls:

"At that time [...] oil companies were frowned upon [...] we had to make it known that we were doing something, that we were not just terrible polluters [...] so we put the label 'environment' or 'fight against pollution' to what we were already doing." (Interview with former Total employee, 23 Sept. 2020)

French oil companies also developed collective business strategies: in 1971, UCSIP, the French oil industry business council, published a booklet responding to environmental alerts and criticism. This booklet acknowledged a "slow increase in the average CO₂ content of the atmosphere" that

"should normally lead to a slight warming effect on the Earth's climate by the end of the century, although not as great as that needed to bring about the apocalyptic effects predicted by some futurologists (melting of polar ice, vast regions submerged...). However, the impact of human activity in the direction of a warming of the climate is very controversial, because of the opposite effects caused in particular by the increase in dust content and the possible increase in the cloudiness of areas of intense aerial activity." (Union des Chambres Syndicales de l'Industrie du Pétrole (UCSIP), 1971, p. 24–25)

At an international level, executives from Elf and Total participated in meetings of petroleum industry groups such as CONCAWE (Conservation of Clean Air and Water in Europe, which since 1963 had coordinated the response of the refinery sector to pollution regulations) and IPIECA (established in 1974 as stakeholder to the UN Environment Program).

While French environmentalists advocated for a move toward renewable energies, Total, like most other oil majors, strongly invested in coal following the oil shock of 1973. The company joined forces with BP to develop the rich Ermelo coal mine in South Africa in 1976, created Anthracorp Inc. in 1979 to mine coal in the U.S.⁽⁴⁾, and invested in expanding the coal import capacity at the French port of Le Havre

(Ramoisy, 1987, p. 39 and 90–91).

Although scientific research on climate change intensified throughout the 1970s, French oil companies exhibited public silence on the issue. Magazines from Total and Elf, which we reviewed from 1965–2010, did not address climatic change a single time from 1972–1988, even following the 1979 World Climate Conference in Geneva, which was covered in *Le Monde*, or the US National Research Council Report of the same year, which led the journal *Nature* to describe global warming as "the most important environmental issue in the world today"⁽⁵⁾. Whether Elf and Total's external silence was reflected internally among R&D staff and executives remains for future research⁽⁶⁾. The API (which included European oil majors) and Exxon, in comparison, both established internal research programs on climate in the late 1970s, and Shell commissioned private research on climate by 1981, despite also exhibiting relative silence in public (Banerjee et al., 2015; Franta, 2021)⁽⁷⁾.

In any event, by 1984, discussion spread throughout the global petroleum industry of the business threat posed by global warming. Bernard Tramier, Environmental Director of Elf from 1983 to 1999 (and later of TotalFinaElf from 2000 to 2003), remembers how Exxon alerted the industry:

"The moment I remember really being alerted to the seriousness of global warming was at an IPIECA meeting in Houston in 1984. There were representatives from most of the big companies in the world there, and the people from Exxon got us up to speed. [...] They had remained very discreet about their own research [on global warming] [...] Then in 1984, perhaps because the stakes seemed to have become too great and a collective response from the profession required, they shared their concerns with the other companies." (Interview with Bernard Tramier, Nov. 5, 2020)

In early 1986, Tramier sent an annual report to Elf's executive committee. In it, he described global warming as certain to occur and a key issue requiring a defensive strategy by the industry:

"The problems related to the interactions of various pollutants in the upper atmosphere will become of concern in the coming years. The case of ozone is already known, but the accumulation of CO₂ and CH₄ in the atmosphere and the resulting greenhouse effect will inevitably modify our environment. All models are unanimous in predicting global warming, but the magnitude of the phenomenon remains undetermined. The first reactions have been, of course, to 'tax fossil fuels', so it is obvious that the oil industry will once again have to prepare to defend itself." ⁽⁸⁾

The meeting of Elf's executive committee on March 4th, 1986 appears to have marked a turning point in the firm's awareness of anthropogenic global warming. While the topic may have been discussed previously among Elf's executives, it was now present in the minutes of a meeting attended by its top managers, informed through official channels that continued extraction of fossil fuels would "inevitably modify our environment."

3. International coordination to delay fossil fuel controls, 1987–1996

For a coordinated, international defense, the French petroleum industry turned to IPIECA. In 1987, the organization held a symposium in Baltimore to review the state of climate science and potential policies. The following year, while meeting at Total's headquarters in Paris, it created the "Ad Hoc Group on the Greenhouse Effect," soon renamed the "Working Group on Global Climate Change" (Interview with Brian P. Flannery, Feb 1, 2021). The group was chaired by Duane LeVine, Exxon's manager for science and strategy development, and also included Elf's Tramier, Brian Flannery from Exxon, Leonard Bernstein

from Mobil, Terry Yosie from the API, and other representatives from the world's major oil companies. It had three lines of work: 1) "to draw up the state of the science of climate change induced by the possible accentuation of the greenhouse effect, including the main areas of uncertainty," 2) to study "no regrets" response strategies that would benefit the industry, and 3) to consider efficiency improvements and substitutions between different fossil fuels (e.g., coal to gas) as industry-friendly responses to global warming (LeVine, 1990). The group, including Tramier from Elf, sent a dossier on climate to the IPIECA member companies, which included a strategy paper from LeVine, stating:

"Although some declare that science has demonstrated the existence of PEG [potential enhanced greenhouse] climate change today... I do not believe such is the case. We will require substantial additional scientific investigation to determine how its effects might be experienced in the future." (LeVine, 1989, p. 1)

For the industry to defeat public policies that could "shift ... the energy resource mix" away from fossil fuels, "reduce CO₂ emissions by 20%," or "even [require] abandoning resources" (LeVine, 1989, p. 16), LeVine recommended emphasizing uncertainties in climate science, the need for further research, the costs of policy action, and alternative environmental policies that would not threaten the industry's core business. IPIECA's 1990 "briefing document" to its members also included a paper from the API, "Position on Global Climate Change," which echoed LeVine's conclusions (in LeVine, 1990; see Rich, 2019, p. 246). Another part of IPIECA's agenda was to postpone any significant controls on CO₂ emissions until detection research could provide what the group called a clear "verification of climate change" (Flannery, 1992, p. 20), even though a 1982 internal Exxon document had noted that the statistical detection of global warming might take decades and then come too late ("once the effects are measurable, they might not be reversible," the document observed) (Exxon, 1982). When such detection was finally reported in the IPCC's second assessment report in 1996, the industry attacked both the IPCC and individual scientists connected to the work (see Oreskes and Conway, 2010, p. 200-210).

IPIECA organized a symposium in Rome in April 1992 to push its agenda before the upcoming UN conference in Rio de Janeiro. After Bernard Tramier (Elf) opened the conference as IPIECA's new chair, the industry representatives, policy makers, and scientists in attendance were told:

"it is unlikely that we will be able to detect or to refute predictions of climate change from an enhanced greenhouse effect for at least a decade. Also, it is unlikely that we will have confidence in predictive capabilities for many years. [...] model-based projections are controversial, uncertain, and without confirmation." (Flannery, 1992, p. 2)

Tramier recalls this period:

"Exxon had taken hold of the issue, and that suited us, because we [French companies such as Elf and Total] did not have the knowledge or the means to have weight in the scientific community, the Intergovernmental Panel on Climate Change [IPCC], or the UN process. [...] We were a follower of Exxon [...] we agreed that we didn't know enough [scientifically] for emission reductions or [carbon] taxes to be enacted, and we let Exxon do the rest [...] What we did not want was for drastic decisions to be taken before being certain of the reality and the extent of anthropogenic warming. For us, the idea of a 20% reduction in emissions [called for at a June, 1988 inter-governmental conference in Toronto, Canada] was premature and should not be codified in Rio [the UN conference in 1992]. [...] What we feared was that in this kind of conference, for reasons of diplomacy and communication, the world would take measures harmful

to the industry." (Second interview with Bernard Tramier, Nov. 24, 2020)

Hence, the French petroleum industry endorsed the strategy spearheaded by Exxon, which was implemented not only by the API and the Global Climate Coalition (Brulle, 2018, Banerjee et al. 2015, Rich, 2019), but also by IPIECA member companies. Tramier was president of IPIECA from 1991 to 1994 and approved funding of scientific research that could sharpen the industry's ability to emphasize climate model limitations and potentially make global warming appear less alarming, such as work on aerosols and clouds at the Hadley Center in the UK and studies on carbon uptake by oceans at Columbia University in the US (IPIECA, 1992, p. 9). Additionally, in the early 1990s, Elf began placing young, freshly graduated engineers within climatology laboratories in Hamburg and the United States, including UCLA, MIT, and NCAR in order to monitor the latest developments of climate science (Interview with Jean-Paul Boch (Elf), Nov. 20, 2020). Jean-Paul Boch, the company's representative in the IPCC and climate negotiations explained, "I placed VSNs [volontaires du service national à l'étranger, national volunteer service researchers] where I needed information and access." (id.)

While endorsing Exxon and IPIECA's strategic production of doubt, the French petroleum companies also promoted uncertainty in their own communication and public relations. In 1992, as the Rio conference approached, Total's environmental director, Jean-Philippe Caruette, emphasized doubt in Total's corporate magazine, now called *Énergies*:

"Certainly, there is a relationship between the temperature and the carbon dioxide content of the atmosphere, but this relationship does not allow an extrapolation leading to more or less catastrophic scenarios on global warming of the planet [...]. And above all, there is no certainty about the impact of human activities, including the combustion of fossil fuels." (Caruette, 1992, p. 13-14)

During the Rio conference, Total distributed a booklet lamenting that "warming of the Earth [...] polarizes all the attention and gives rise to apocalyptic descriptions of the future," while asserting that "the considerable progress made in climatology since the beginning of the century has not allowed us to dispel the uncertainties regarding the greenhouse effect" and insisting that energy policies should "ensure the growth of [developing] countries, even if it means increasing greenhouse gas emissions to start."⁽⁹⁾

Elf followed suit, declaring the day after the summit:

"Thus, to the still-unknown question of the greenhouse effect, we cannot answer hastily by taxing only European industrialists because we think, without being sure, that carbon dioxide emissions could lead to warming of the planet in the years to come." (Elf, 1992, p.1)

Two months later, François-Xavier Ortoli, Honorary President of Total, spoke at the Congress of the World Energy Council in Madrid, saying scenarios predicting 2-5° C of global warming in the 21st century were dubious because:

"natural sources are much greater than man-made emissions [...] we still have much work to do to understand the complete carbon dioxide cycle, the role of the ocean depths and the biosphere. Scholars are divided on this. Hippocrates says yes, Galen says no. There is some doubt."⁽¹⁰⁾

In March 1993, Francis Girault, director of foresight, economics and strategy at Elf and close advisor to the company's CEOs (first Loïk Le Floch-Prigent and later Philippe Jaffré), wrote an internal report addressed to the company's board called "Greenhouse effect (proposal for an action plan)"⁽¹¹⁾ in which he explicitly advocated for an aggressive strategy of doubt. In order to resist "hasty decisions" regarding fossil fuels, Girault proposed in his plan that the company promote the notion

that “there are scientific doubts about the greenhouse effect,” as well as identify and support “renowned scientists who can intervene positively in the debate”.⁽¹²⁾ Tramier recalls, “Girault feared the climate issue would result in a tax for us, and he was anti-tax [...] We had to rely on arguments, so he relied on those that said the climate problem was not serious” (Second interview with Bernard Tramier, Nov. 24, 2020). Another Elf engineer from the Environment Division remembers more simply, “Francis Girault was on an Exxon-style track” (Interview with Jean-Paul Boch, Nov 20, 2020).

This campaign to oppose fossil fuel reductions by strategically promoting scientific uncertainty takes on fuller significance when placed in context of the enormous battle waged by both Total and Elf against energy or carbon taxation in the early 1990s. In 1989, an “eco-tax” was proposed by the European Commissioner for the Environment and in October 1991 was put on the table by the European Commission (Aykut and Dahan, 2014, p. 235–243). At the same time, French Prime Minister Rocard wrote to his environment minister that “Climatic changes that could result [from greenhouse gases], even if they are still poorly understood in terms of their scope and regional consequences, call into question the current conditions of life on Earth” (GIES, 1990, p. 2). In December 1990, France sent a memorandum to the European Commission that promoted both common quantified targets for industrial countries to reduce their emissions and a fiscal instrument on fossil fuels (i.e., an eco-tax) (Gouvernement Français, 1990). But a year later, the new French Minister for Industry, Dominique Strauss-Kahn, sought to block the eco-tax. Meanwhile, European oil companies had aligned themselves in opposition through EUROPIA, the European Petroleum Industry Association created in 1989, and found allies in the nuclear industry and other heavy industrial sectors. In May 1992, the eco-tax proposal was weakened by the European Commission, who made its implementation conditional on similar policies by the US and Japan, and then blocked entirely the European Council of Industry Ministers. The following month, the President of the European Commission openly pointed to “critics who [had] come [...] first from the oil producers.”⁽¹³⁾ *The Economist* described the battle against the eco-tax as “the most ferocious lobbying ever seen in Brussels” (Ikwe and Skea, 1994; Skjærseth and Skodvin, 2003, 158–195; Liberatore, 1995) and an internal report written at the end of 1992 by Elf’s Francis Girault shows that the company actively participated in defeating it⁽¹⁴⁾. In his report, Girault welcomed the tax’s recent failure, crediting the company’s lobbying activities carried out through “hidden direct contacts with the ministerial cabinets and administrations, both in France (Prime Minister, Finance, Environment, Research, European Affairs) and in the European Economic Community”⁽¹⁵⁾. Tramier recalled that Total was “better than us [Elf] in developing lobbying activities in Brussels, where a full-time employee was positioned” (Interview with B. Tramier, Nov. 5, 2020). The failure of the eco-tax undermined Europe’s position at the Rio summit, contributing to limiting the scope and ambition of the UN process, which Girault viewed as a success for the company⁽¹⁶⁾.

When a weakened version of the eco-tax was relaunched in 1994 by the European Commission, Elf and Total again cracked down on it. An internal report presented to the Elf Management Committee estimated “a CO₂ tax would cost around 4 billion FF [French francs] per year to the group,” reported that “the actions carried out by the industry have been effective, since today the European eco-tax project has not seen the light of day,” and recommended the company continue “to mobilize against the eco-tax”⁽¹⁷⁾. Elf’s CEO, Philippe Jaffré, privately wrote to the French Minister of Foreign Affairs, Alain Juppé, to voice the company’s hard opposition as the French presidency of the European Council approached⁽¹⁸⁾.

By 1993–1995, Tramier and some of Elf’s other top managers began to feel ill at ease with the company’s hard line. In Europe, climate change denial was becoming increasingly counterproductive for oil companies in the face of scientific advances and scrutiny from civil society (hence the eventual departure of Shell and BP from the Global Climate Coalition). Moreover, with the eco-tax proposal buried, oil firms

could afford to engage in more subtle corporate environmental messaging, in the wake of the “sustainable development,” “corporate responsibility,” and “total quality management” turns that the business world had taken since the late 1980s (Bernstein, 2001).

Instead of disputing an overwhelming scientific consensus, the new strategy proposed by Tramier consisted of showing good will to go green. This comprised internal audits and measurements to see where GHG emissions could be inexpensively reduced – an effort that applied, however, only to the company’s operations and not to its products. Second, with the Kyoto protocol in sight, the company promoted market based instruments. In this way, voluntary actions and a carbon permit trading system would make technology standards or other “command and control” regulations seem unnecessary. Third, efforts towards energy efficiency had to be made more visible. Elf’s environmental director suggested internally “a joint action between Elf and Renault for the development of vehicles consuming less fuel,” which would provide positive environmental publicity while also “tak[ing] advantage of the notoriety given by F1 [racing]”⁽¹⁹⁾. Finally, Elf and Total also turned to environmental conservation to burnish their image: Elf sponsored French botanist Francis Hallé’s Canopy Raft Missions to study the forests of Cameroon and Venezuela in 1989 and became a partner of French national and regional parks, while by 1991 Total reoriented its patronage, which until that point had been focused on arts and culture, toward the preservation of biodiversity and the sea⁽²⁰⁾.

4. Acceptance and delay, 1997–2006

The years around the 1997 Kyoto conference mark a decisive shift in the political history of climate change. Multiple large petroleum companies, including BP and Shell, left the Global Climate Coalition, which had practiced overt climate denial since its formation in 1989, with a senior Shell employee later explaining that the company “didn’t want to fall into the same trap as the tobacco companies who have become trapped in all their lies.” (Rich, 2019, p. 186) Perhaps recognizing the reputational and legal risks of overt denial, as well as the potential inevitability of an international agreement, petroleum companies shifted their position toward publicly accepting the findings of the IPCC and promoting the industry as a rational, scientific actor. At Elf, Tramier’s strategy of nominal acceptance prevailed over Girault’s strategy of overt denial, as the former recalls:

“at one point Jaffré [Elf’s CEO] (...) summoned me to his office to ask me to present what I was proposing. I told him that the trends that would emerge from Kyoto would presumably be an objective of a 5–10% cut in emissions, and that ‘we at Elf could make 15%’ without excessive expenses. Elf made this announcement of a commitment to reduce its emissions by 15% a few days before Kyoto.” (Interview with Bernard Tramier, Nov. 5, 2020)

Jaffré announced the company’s turn in the French newspaper *Le Monde* in November 1997:

“Whenever we are faced with a subject that gives rise to great fear, such as the hole in the ozone layer or the consequences of genetic engineering, our attitude is scientific. First, we have Cartesian doubt. Then we turn to the scientific community, in which we trust.” (Le Monde, 1997)

In the same interview, Jaffré announced that Elf would aim for a 15% reduction in its emissions by 2010 (compared to 1990). This cut would come from operations that were relatively inefficient and therefore easier to clean up, with Jaffré noting that “reducing a ton of CO₂ costs us 30 FF in Guinea compared to 230 FF in France [...] Elf subscribes to the American approach for reducing emissions, trusting the mechanisms of the market.” Finally, Elf’s CEO continued to promote the notion that global warming was not an urgent problem, noting, “The phenomenon

could, in fact, spread over a century or so. A century on the scale of the planet is very short. [...] But on the scale of the capacity for human action, it is long.” (Le Monde, 1997)

In 1999, Total absorbed Elf and Petrofina, a Belgian oil company. At the same time, the merged company faced a series of high-profile socio-environmental crises, including the sinking of the oil tanker *Erika* off the French coast in December 1999, the explosion of the AZF chemical factory in Toulouse in September 2001, and a lawsuit filed against Total in April 2002 regarding alleged forced labor in Burma. After the merger, Total temporarily dropped Elf’s voluntary emissions targets, but the achievement of a 10% cut in the company’s operational emissions between 1990 and 2000 was nevertheless announced in its 2001 annual report (TotalFinaElf, 2001).

In 2002 the company held its first official internal seminar dedicated to “sustainable development.” There, in a question and answer session with top managers, the company’s new CEO, Thierry Desmarest, continued to promote uncertainty:

“Of course, the scientific evidence is not always convincing and is sometimes questionable. This said, I think we have reached a point where a certain level of precautionary principle needs to be taken into account. Thus, in terms of global warming, a certain moderation in emissions levels of pollutants is, at the stage of our knowledge, desirable.”⁽²¹⁾

While Desmarest’s support of a “precautionary principle” suggested a heightened level of care, in effect it rhetorically framed climate policies as discretionary precautions rather than needed preventions. This approach of acknowledging the existence of global warming while downplaying its urgency and scientific certainty continued throughout the early 2000s. In 2002, Total’s first sustainability report framed climate change in ambiguous terms, noting, “without the greenhouse effect there would be no life on our planet,” and “water vapor is the main greenhouse gas.” (Total, 2002, p. 20) The report’s glossary described the greenhouse effect as a “natural phenomenon” and equivocally reported that emissions due to human activities “*could be* the origin of climate change” (our emphasis, Total, 2002, p. 108), thus ignoring the detection confirmed by the IPCC’s Second Assessment Report in 1996. The 2003 report also emphasized “uncertainties” and described the greenhouse effect merely as “the hypothesis most commonly accepted by specialists and national governments within the IPCC” (Total 2003, p. 102. The 2004 report attributed the intensifying greenhouse effect to vague “human activity,” insisted “uncertainties [...] persist on the origin and evolution of the phenomenon,” (Total 2004, p. 69) and suggested the evidence for anthropogenic climate change consisted primarily of a mere correlation between greenhouse gas concentrations and average global temperature, both deflecting attention away from the company’s products and ignoring the causal links provided by physical science and statistical attribution research.

Throughout these years, Total kept a vigilant eye on the elaboration of the EU Emission Trading System (EU ETS), which was initiated after the Kyoto Protocol and finally adopted in 2003. The institutional architecture of the EU ETS was based largely on BP’s internal trading system, with Elf and Total playing only a minor role in its design (Cartel 2013; Skjærseth and Wettstad, 2008) ⁽²²⁾.

Thus, rather than overtly attacking the scientific consensus on climate change, Elf and Total instead emphasized equivocal descriptions of global warming and downplayed the robustness and significance of the available scientific evidence. Meanwhile, the company continued to spend the bulk of its capital expenditures on upstream oil and gas production (more than \$30 billion from 2000 to 2005; figures aggregated from TotalFinaElf 2001, Total 2004) without reporting the sum of its few, scattered investments in non-fossil energy sources. This fossil-fuel-focused strategy was broadly in line with those of other major fossil fuel companies, including ExxonMobil, although European companies such as BP generally promoted their minimal activities in renewables more

heavily than their US-based counterparts (Cox, 2008).

5. Maintaining public legitimacy in the face of environmental criticism: 2006–2021

2006 opened a new phase for Total. As the countdown to the COP15 in Copenhagen began, global warming received increased public attention, and the institutionalization of climate policies in France accelerated with the adoption of a national emissions reduction goal of 75% by 2050 (2005 Law on Energy Policy Orientations). In this context, Total organized a climate change conference in order to present itself as receptive to the scientific community, responsible to the public, and able to move in new directions. Held in September 2006, the conference drew over 280 professionals, featured climate researchers as keynote speakers, and benefited from significant media coverage. In his opening speech, Desmarest, Total’s CEO, publicly affirmed the company’s acceptance of climate science ⁽²³⁾:

“In the case of the scientific debate, there is a *convergence of views of experts* as to the reality of the phenomenon of warming. The uncertainties no longer relate to the phenomenon itself, but to its magnitude. This lack of precise vision is, moreover, in part attributable to the lack of knowledge of what our climate and energy policies will be in the future. [...] The IPCC perfectly fulfills its unifying mission and the seriousness of its reports is not in dispute.” (Total 2006)

From then on, Total consistently recognized the legitimacy of the IPCC. With this embrace, however, the company also reframed its own purported role: climate change was to be theoretically diagnosed by science but practically solved by business, without the two spheres interfering with one another. In this way, Total promoted its legitimacy to evaluate the climate compatibility of its own business plans and the suitability of climate policies more broadly. Thus, as it vocally supported the IPCC, the company invested more than \$60 billion in upstream oil and gas operations from 2005 to 2009, again without reporting significant aggregate investments in non-fossil energy sources (Total, 2005a, Total, 2005b, Total, 2008a, Total, 2009).

Concurrently, Total continued to solidify its public image. In 2007, as European leaders agreed on the landmark 20–20–20 targets, which would pave the way for the first 2008–2009 EU climate and energy policy package (Böhlinger 2014), the company created a “Gas & Renewables” division and appointed the former research director of the French national research center CNRS (the oceanographer Jean-François Minster) as its Senior Vice President for Scientific Development. The following year, Total endowed a “Sustainable Development” chair at the Collège de France (Total, 2008b), which was soon held by British climate economist Nicholas Stern.

Yet in this period the company also came under increased public scrutiny. The NGO *Friends of the Earth* (2008) published “*Total: la mise en examen*” (Total: the indictment). This report constituted one of the first systematic critiques of Total’s activities in relation to their climate impact and clearly framed the interests of the petroleum industry as antagonistic to the preservation of the climate system. Moreover, in late 2009, the failure of COP15 in Copenhagen led the transnational climate movement to diversify its strategies and engage more directly with economic and political actors linked to the fossil fuel industry. Civil society actors explored the implications of the “carbon budget” concept (Lahn, 2020) and warned that the market valuations of investor-owned oil and gas majors were inconsistent with global climate goals (Carbon Tracker Initiative, 2011; McKibben, 2012). In this context, in 2011 a coalition of Total’s shareholders organized to file a resolution at the company’s annual meeting requesting disclosure of the environmental and climatic impacts of the company’s Canadian tar sands operations. Yet Total’s board and CEO, Christophe de Margerie, successfully maneuvered to prevent the shareholders from filing the resolution

(PhiTrust, 2011). Meanwhile, Total continued to invest heavily in oil and gas. From 2010 to 2014, the company injected approximately \$127 billion in upstream exploration and production (Total, 2014, Total, 2015a, Total, 2017), while channelling no more than \$3 billion toward non-fossil energy sources from (upper limit reconstructed from a cross referencing of Total, 2010, Total, 2011, Total, 2014).

As the COP21 conference in Paris approached, Total redoubled its efforts to promote itself as a climate leader. The company announced it would sell Total Coal South Africa – its last operating subsidiary in the coal industry, with an output of 12 million tons produced in 2014 – in June of 2015 (Novethic, 2015). Three months later, it spearheaded the creation of the Oil and Gas Climate Initiative (OGCI), an industry organization endowed with \$1 billion by a dozen petroleum companies to promote voluntary climate actions for the period 2017–2027 (Bach, 2019), and in June 2015, Total joined other European petroleum companies in publicly challenging the UN to implement an international carbon price (Total, 2015b).

Total also began emphasizing future reductions in product carbon intensity. In 2016, three months after the Paris Agreement was signed, the company's CEO, Patrick Pouyanné, presented "One Total 2035," a roadmap for reducing the carbon intensity of its products (Les Echos, 2016). Yet the 2015–2019 period was marked by sustained capital expenditures of \$77 billion in upstream oil and gas production; in comparison, investments in non-fossil energy sources did not exceed \$5 billion (figures aggregated from Total, 2017, Total, 2018, Total, 2019). Without binding controls on the evolution of its energy mix, Total promotes itself as environmentally responsible through future scenario reports, which the company has issued since 2016. Regular updates to these reports generate a flow of complex, technical information that is difficult to interpret or challenge (Choquet, 2019), helping Total to put the burden of proof on its critics and keep the upper hand in climate controversies. In 2021, Total announced it would rename itself to TotalEnergies and expand its investments in non-fossil energy sources (the same name used by Total in its 1977 advertisements, when the company claimed to invest in solar energy without making actual changes to its oil-based business model) (Total, 1977). It remains to be seen how Total's announcement will be acted upon.

6. Conclusion

We have documented half a century of Total's shifting responses to global warming. In 1971 the company published a scientific warning about climate change but was muted in public about the issue for the remainder of the decade. By the mid 1980s, climate change produced heightened concern among the world's oil majors, and Exxon, through the industry association IPIECA, led efforts to organize petroleum companies internationally to dispute climate science and weaken controls on fossil fuels. As part of this effort, French companies Total and Elf began to promote uncertainty regarding climate science, both independently and through IPIECA, while successfully lobbying against policies to reduce greenhouse gas emissions. At the same time, both Total and Elf sought to build environmental credibility through voluntary commitments and environment-themed public relations.

By the late 1990s, the French petroleum industry shifted away from openly disputing climate science but continued to expand its investments in upstream oil and gas production and employed rhetorical strategies that emphasized uncertainty, downplayed urgency, and deflected attention away from fossil fuels as the primary cause of global warming. By the mid 2000s, the merged entity Total intensified its efforts to build scientific credibility, endorsing the IPCC and hosting a conference on climate change. The company began to promote a division of roles between science and business, in which science describes climate change and business claims to solve it, reinforcing its claim to legitimacy in determining appropriate public and corporate policies. This framing enables Total to portray itself as a socially responsible petroleum company by wrapping continued investments in fossil fuel

production in an attractive "energy transition" narrative.

Our study sits at the intersection of environmental and business history and contributes to the field of agnotology - the study of culturally induced ignorance or doubt. While much commentary on the politics of climate change has framed relationships to science in terms of dichotomous acceptance or denial, the history of Total highlights the multi-dimensional and graded character of positions regarding climate science, such as publicly embracing climate science while deflecting attention away from fossil fuel products. Examining these multidimensional postures may aid in understanding historical and ongoing responses to global warming.

7. Notes

(1) We found representatives of Total Leonard in the API board of directors lists for 1965–1967 and 1974.

(2) The editorial was actually drafted by the secretary general and pillar of the group, Vincent Labouret: see Archives Total, 50ZZ507/58.

(3) Total Archives, 92AA091/160.

(4) <https://wiki.total/en/country/total-south-africa>. On Total's links with the apartheid regime, see Deneault, 2017.

(5) National Research Council (NRC), *Carbon Dioxide and Climate: a Scientific Assessment: Report of an Ad Hoc Study Group on Carbon Dioxide and Climate*, National Academy of Sciences, Washington, DC, 1979; N. Rich, op. cit, 2019, p. 53–59; Howe, 2014, p. 115–117.

(6) Neither Total internal press review fascicles nor Elf R&D department archives mention climate issues by 1973–1980 (see Total Archives 09AH0416 and 07AH0077/28–33). Elf and Total, being smaller than Exxon, BP or Shell, did not have the same R&D capacity to follow this issue.

(7) For Shell, see Shell Internationale Petroleum Maatschappij B.V., *The Greenhouse Effect*, 1988, p. 86. Online: <https://www.industrydocuments.ucsf.edu/fossilfuel/docs/#id=khfl0228>

(8) Total Archives. 11AC0783/106 - B. Tramier. *L'environnement dans le groupe Elf Aquitaine – Bilan 1985. Document préparatoire à la réunion du comité exécutif du 4 mars 1986*. Feb 1986, p. 14.

(9) Total Archives. 00AH001/142. Total, *Les cahiers de l'environnement*, 1992 (a cardboard folder distributed by Elf before and during the Rio 1992 conference).

(10) Historical Archives of the European Union. FXO-95. François-Xavier Ortoli, "Potential Global Climate Change - The Realities?" Speech at 15 th Congress of the World Energy Council, Madrid, 20–25 September 1992, p.2.

(11) Total Archives, 07AH0077/4. SNEA G/DPES, F. Girault, Note à l'attention de MM. les membres du comité de Direction Générale, "Effet de serre (proposition de plan d'action)", March 12, 1993.

(12) Id.

(13) Historical Archives of the European Union. JD-1669. Press conference held by Jacques Delors at the end of the United Nations Conference on Environment and Development, June 13, 1992.

(14) Total Archives, Elf Fund, 07AH0077/4. F. Girault, "Greenhouse effect and environmental tax. Proposals for action", Nov. 17, 1992.

(15) Id.

(16) Id.

(17) Total Archives, Elf Fund, 07AH0077/4. DRTE, "Environnement Énergie 1994. Bilan Perspectives", p. 16 and 5.

(18) Total Archives, Elf Fund, 07AH0077/4. Philippe Jaffré to Alain Juppé, Oct 14, 1994.

(19) Total Archives, Elf Fund, 07AH0077/4. B. Tramier to P. Castillon, "Effet de serre: actions à entreprendre", Nov. 30, 1992.

(20) *EnergieS*, n°10, July-August 1992, p. 6–7 and 8–11.

(21) Total Archives. 05AA594/14. Premier séminaire de développement durable (Sept. 30-Oct. 2, 2002). Compte-rendu, p.10.

(22) The relative unavailability of corporate archival material from after the year 2000 presents a challenge for reconstructing Total's strategic engagement with the negotiations surrounding the EU ETS

quota allocations.

(23) Id.

8. Authors statement

C.B. conducted archival research and interviews and drafted analysis in French from 1968–1997. P.-L.C. conducted research and interviews and drafted analysis in French from 1997–2020. B.F. provided the 1971 document and drafted the paper in English. All authors subsequently participated in revisions.

9. Disclosure statement

B.F. has served as a consulting expert for climate change litigation, and the findings reported in this article may be relevant to such litigation. P.-L.C. has conducted a 9-month post-doc at ESSEC which was funded through a research convention with Total (IRENE-Codev Research Program, May 2019 – January 2020).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gloenvcha.2021.102386>.

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Annex 566

J. Uri, “65 Years Ago: The International Geophysical Year Begins”, *The National Aeronautics and Space Administration (NASA)*, 5 July 2022



7 MIN READ

65 Years Ago: The International Geophysical Year Begins

John Uri

Johnson Space Center

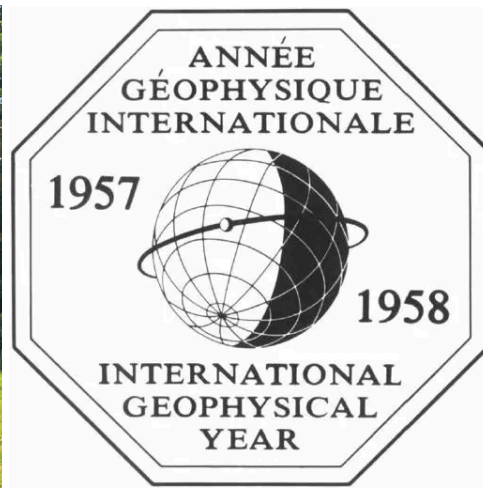
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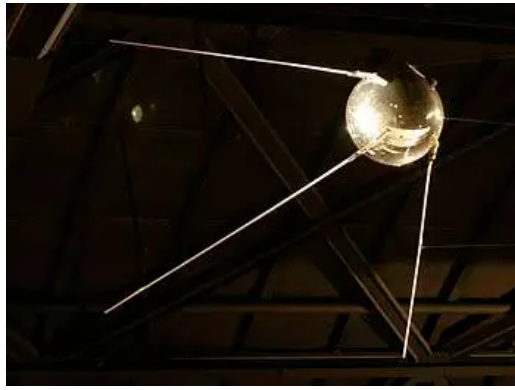


At the height of the Cold War in the 1950s, scientists established the International Geophysical Year (IGY), a global effort for a comprehensive study of the Earth, its poles, its atmosphere, and its interactions with the Sun. Seven years of planning led to coordinated activities in 11 science disciplines by participating scientists in 67 nations during the 18-month effort that began on July 1, 1957, and ended on Dec. 31, 1958. The Soviet Union and the United States announced plans to place satellites into Earth orbit during the IGY. The launches of Sputnik and Explorer 1 began the Space Age and led to new scientific discoveries. The large volume of information gathered during the IGY required the establishment of World Data Centers to make the results widely accessible.



*Left: The house of physicist James A. and Abigail Van Allen in Silver Spring, Maryland. **Image credit: Courtesy Physics Today.** Right: Official emblem of the International Geophysical Year.*

As with many great plans, the idea for the IGY began in a humble setting. In April 1950, physicist James A. Van Allen of the Johns Hopkins University's Applied Physics Laboratory and his wife Abigail hosted a dinner party at their house in Silver Spring, Maryland, for several prominent geophysicists. They discussed an idea to hold a third International Polar Year (IPY), based on the model of the first (1882-3) and second (1932-3) IPYs, international collaborations that sought to increase our knowledge of the Earth's polar regions. As they talked with other scientists, a consensus emerged that this international endeavor should not limit itself to just studying the Earth's poles. In May 1952, the International Council of Scientific Unions (ICSU) endorsed the idea and established the Special Committee for the IGY, better known by its French acronym CSAGI. Over the course of several meetings, the CSAGI established the IGY for the 18-month period from July 1, 1957, to December 31, 1958, to encompass an entire year in both of Earth's hemispheres. The time period coincided with the next expected maximum activity phase of the Sun's 11-year cycle. The scope of the IGY encompassed 11 different Earth sciences: aurora and airglow, cosmic rays, geomagnetism, glaciology, gravity, ionospheric physics, precision mapping, meteorology and radiation, oceanography, seismology, and solar activity. Two additional disciplines dealt with the development of rockets and satellites and the establishment of regular and special World Days for synchronized global observations. The large volume of information from the collective activities led to the establishment of World Data Centers to make the results available to all participants.



Left: Launch of Sputnik, the world's first artificial satellite. Middle: A model of Sputnik. Right: Laika, the first animal in orbit aboard Sputnik 2, during preflight testing.

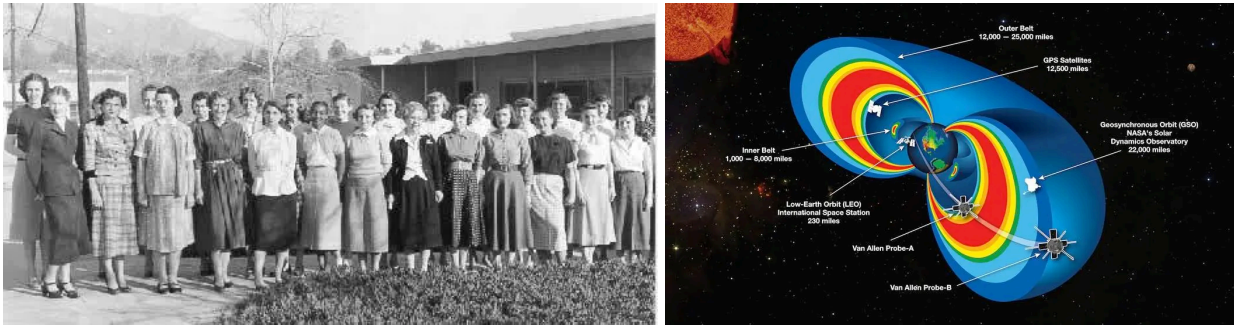
After the United States announced on July 29, 1955, that it planned to launch artificial Earth satellites during the IGY, the Soviet Union responded four days later that it would do the same. At the time, the U.S. had separate ongoing satellite development efforts managed by its military branches. The Soviet Union formally approved a single program on Jan. 30, 1956. America made its plans and progress public while the Soviets worked in secret and therefore had an edge in upstaging U.S. efforts. Sergei P. Korolev, the chief designer of the Soviet Union's early space program, envisioned a large scientific satellite code named Object D as his country's contribution to the IGY. When the project ran behind schedule, the Soviet government directed him to launch a much simpler satellite in order to beat the Americans into space. On Oct. 4, 1957, following a crash program to develop the simple satellite and several test flights of its R-7 booster rocket, the Soviet Union announced that it had placed Sputnik into orbit around the Earth. Although it carried no scientific instruments, Sputnik had a large impact on the United States' space program. Buoyed by the success of Sputnik, and its political impact, the Soviet government directed Korolev to develop a second satellite, this one carrying a living animal. On Nov. 3, the Soviets launched Sputnik 2, carrying a dog named Laika. The first U.S. attempt to launch a small satellite named Vanguard on Dec. 3 ended in failure when its rocket exploded a few seconds after liftoff.



Left: Launch of Explorer 1. Middle: Director of the Jet Propulsion Laboratory William H. Pickering, physicist James A. Van Allen, and rocket designer Wernher von Braun hold a model of Explorer 1 during a postlaunch press conference. Right: Sputnik 3 during assembly.

The U.S. finally met with success on Jan. 31, 1958, with the launch of Explorer 1. Developed at the Jet Propulsion Laboratory (JPL) in Pasadena, California, Explorer 1 rode into orbit atop a Jupiter C rocket designed by Wernher von Braun, who went on to design the Saturn family of rockets that sent Americans to the Moon. A team of women mathematicians at JPL computed Explorer's trajectory and confirmed that it had achieved orbit around the Earth. Unlike its Soviet predecessors, more than half of Explorer 1's mass consisted of scientific instruments developed under the direction of physicist Van Allen, by then at the University of Iowa. The instruments included a cosmic-ray detector, five temperature sensors, and two micrometeoroid detectors. The cosmic ray detector indicated a much lower cosmic ray count than expected. Van Allen postulated that the instrument gave those readings because energetic charged particles originating mainly in the Sun and trapped by Earth's magnetic field had saturated it. Explorer 1's discovery of these trapped radiation belts, subsequently named after Van Allen, is considered one of the outstanding scientific discoveries of the IGY. On May 15, 1958, Korolev's Object D scientific satellite finally made it into space as Sputnik 3, carrying 12 battery-powered instruments to study

the Earth's upper atmosphere, magnetic fields, radiation environment, and cosmic dust. The various instruments collected data for one week to one month, but the onboard tape recorder failed shortly after launch, precluding the recording of data during critical parts of the spacecraft's orbit when it passed through the Van Allen trapped radiation belts. Sputnik 3 carried experimental silicon solar batteries that powered its telemetry transmitter and scintillation counter until it reentered the Earth's atmosphere on April 6, 1960.



*Left: Group of women mathematicians at the Jet Propulsion Laboratory who calculated Explorer 1's trajectory by hand. Right: Schematic of the Van Allen Belts discovered by Explorer 1 (right). **Image credits: Courtesy NASA/JPL.***

The IGY had a far-reaching legacy beyond accelerating the start of the Space Age. It served as a shining example of international scientific cooperation, even during a time of heightened political tension. The sharing of scientific information through a global network of World Data Centers ensured that data collected by one nation remained accessible to all. The IGY served as a model for later international agreements, such as the Antarctic Treaty of 1959, the Outer Space Treaty of 1967, and the IPY of 2007-2008. In the United States, in response to the first Sputniks, Congressional hearings led to a consensus that a civilian agency should be established to run the American space program. President Dwight D. Eisenhower signed the bill creating the National Aeronautics and Space Administration. The new agency began operations on Oct. 1, 1958. Explorer 1 and Sputnik 3 led to a series of scientific satellites that over the coming decades vastly increased our understanding of the Earth and its environs. Derivatives of the Russian R-7 rocket that launched the Sputniks remain in use today to launch satellites and crews to the International Space Station.

To be continued...



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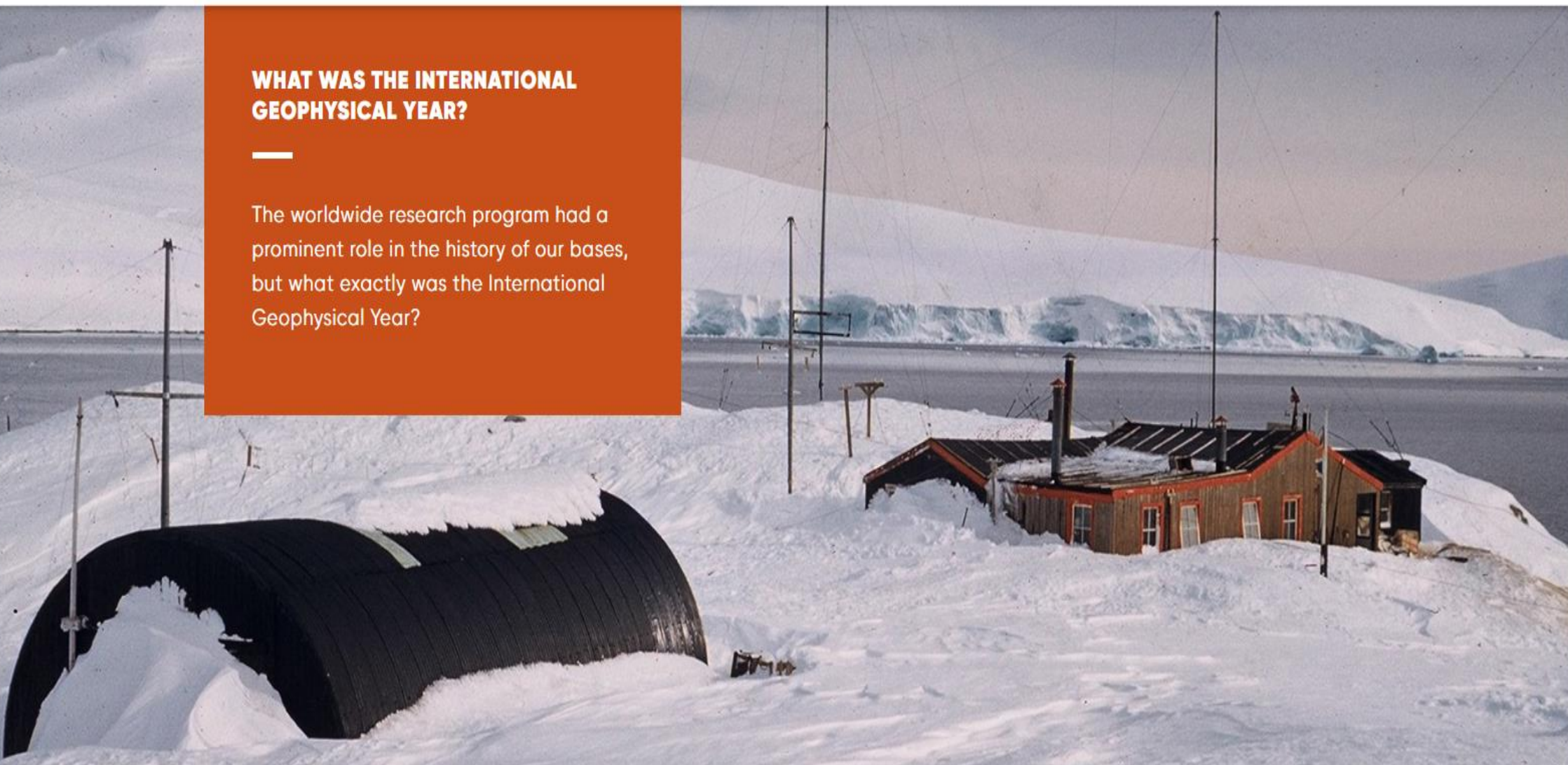
Responsible NASA Official: **Abigail Bowman**

Annex 567

“What was the International Geophysical Year?”, *UK Antarctic Heritage Trust*, 26
June 2023

WHAT WAS THE INTERNATIONAL GEOPHYSICAL YEAR?

The worldwide research program had a prominent role in the history of our bases, but what exactly was the International Geophysical Year?



WHAT WAS THE INTERNATIONAL GEOPHYSICAL YEAR?

26/06/2023

The worldwide research program had a prominent role in the history of our bases, but what exactly was the International Geophysical Year?

As UKAHT approaches our 30th anniversary, we're using the opportunity to share some stories of adventure, discovery and hope from our archives. For a long period during the Cold War, scientific cooperation between the East and the West was virtually non-existent. The two blocs were entrenched in a [nuclear arms race](#) which devoured much of their concentration in terms of reserve and development. The International Geophysical Year (IGY) from 1957 to 1958, marked the end of that discord – in science terms at least – and the beginning of a new period of global cooperation in Earth sciences.

BACKGROUND

The origins of the IGY can be traced to two intensive periods of research conducted in the polar regions known as the International Polar Years (IPY). The first was held in 1882-1883 and the second in 1932-1933. Recently, a third was conducted from March 2007 to March 2009.

In 1950, a group of geophysicists led by the American scientist Lloyd V Berkner proposed a third International Polar Year, that would build on the advances made in instrumentation and rocketry since the second IPY.



A sledge party near Detaille during the IGY (Credit: BAS Archive)

However, these proposals soon broadened from the field of polar studies to a wider array of geophysical research. The parent body of international scientific organisations – the [International Council of Scientific Unions](#) – sanctioned the broader study of proposals for what became known as the International Geophysical Year.

WHO WAS INVOLVED IN THE INTERNATIONAL GEOPHYSICAL YEAR?

National IGY committees were established by scientific organisations in many countries with around 70 nations cooperating in the IGY. One notable exception was mainland China which withdrew in protest against Taiwan's participation.

Argentina	Cuba	Greece	Malaya	Poland	Uganda
Australia	Czechoslovakia	Guatemala	Mexico	Portugal	UK
Austria	Denmark	Hungary	Mongolia	Zimbabwe	USA
Belgium	Dominican Rep	Iceland	Morocco	Romania	Uruguay
Bolivia	Ecuador	India	Netherlands	South Africa	USSR
Brazil	Egypt	Indonesia	New Zealand	Spain	Venezuela
Bulgaria	Ethiopia	Iran	Norway	Sweden	North Vietnam
Myanmar	Finland	Ireland	North Korea	Switzerland	South Vietnam
Canada	France	Israel	Pakistan	Taiwan	Yugoslavia
Sri Lanka	East Germany	Italy	Panama	Tanzania	
Chile	West Germany	Japan	Peru	Thailand	
Colombia	Ghana	Kenya	Philippines	Tunisia	

WHAT WAS INTERNATIONAL GEOPHYSICAL YEAR?

Running from 1 July 1957 to 31 December 1958, the IGY was a cooperative scientific program conducted to study the earth and its environment. The research was conducted in 11 fields of geophysics:

1. Aurora and airglow
2. Cosmic rays
3. Geomagnetism
4. Glaciology
5. Gravity
6. Ionospheric physics
7. Longitude and latitude determinations
8. Meteorology
9. Oceanography
10. Seismology
11. Solar activity

The timing of the IGY was chosen to coincide with the maximum sunspot cycle – a period when solar flares and other disturbances are at their most prevalent. As such, research on the sun was particularly significant.



US and USSR scientists in Antarctica (Credit: Alexander Maksimov)

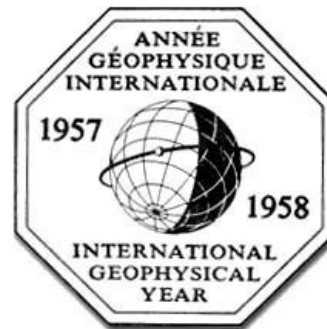
The IGY established the World Data Center system that is still in place today. The USA hosted World Data Center A and the USSR hosted World Data Center B while the World Data Center C was divided among countries in Western Europe, Australia and Japan.

Each data centre was equipped to manage myriad data formats. Additionally, each host country agreed to abide by the organising committee's resolution of free and open exchange of data among nations. In total, the IGY involved nearly 30,000 scientists.

The IGY pioneered the use of rockets to conduct studies of high-altitude and upper atmospheric phenomena. Several of the earliest artificial satellites launched by the USSR and the USA in the late 1950s were used to gather data for the IGY.

WHAT HAPPENED IN ANTARCTICA?

A significant focus of the IGY was to further the advancement of research in the polar regions, particularly Antarctica – the planet's least studied region. In fact, the official emblem of the IGY depicted the Earth's globe belted with a satellite's orbit and tilted to show the South Pole.

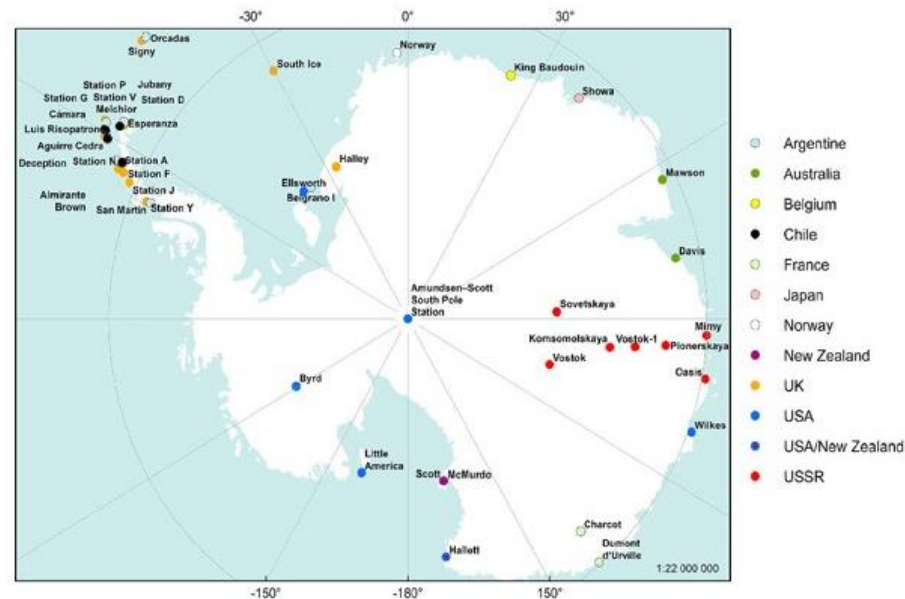


The IGY emblem (Credit: Public Domain)

Meteorological observations were one of the leading research areas in the IGY program. The global network of meteorological outposts established during the IGY consisted of over 4,000 scientific stations. Unsurprisingly, the polar regions were among the most important locations for IGY research due to their significant influence on the Earth's climate and weather.

The main goals of the research were to determine the circulation of the atmosphere and the study of the weather at high latitudes. Among other studies were the movements of drifting ice and geomagnetic and aurora phenomena and how radio interference was affected in the far north and far south by the auroras (northern and southern lights).

The countries that deployed IGY stations in Antarctica were Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, the UK, the US and the USSR. A total of 50 stations were organized on the Antarctic continent and sub-Antarctic waters.



IGY Antarctic research stations (Credit: Copernicus/CC 4.0)

Several UKAHT bases, including [Port Lockroy](#), [Horseshoe](#) and [Detaille](#), were key monitoring sites during the IGY. Port Lockroy acted as the communications centre for the 11 British bases during the IGY as well as undertaking atmospheric research.

Detaille Island was one of only two British bases that contributed meteorological data to the geophysical programmes of the IGY (the other being Port Lockroy). The remaining British bases mostly contributed to topographical surveying and geology.



Dennis Goldring uses a surveying instrument at Detaile (Credit: BAS Archives)

The IGY was also instrumental in establishing the first permanent structure at the South Pole, the [Amundsen-Scott Station](#). Constructed in 1956, the station has been continuously occupied since it was built with the original structure surviving for over 53 years until it was demolished in 2010.

WHAT DID WE LEARN?

A number of huge advancements – too many to list here – were made across several fields but key IGY discoveries included the confirmation of the existence of a continuous system of submarine mid-oceanic ridges that encircled the globe. The verification of this mountain chain, the largest on Earth, would later form the foundations of the recognition of plate tectonics in the 1970s.

The discovery of the Van Allen radiation belts – two radiation belts filled with electrons and charged particles that surround Earth [like giant doughnuts](#) at altitudes of hundreds and thousands of kilometres – was another major achievement of IGY.

THE ANTARCTIC TREATY

The IGY also paved the way for the 1959 foundation of the [Antarctic Treaty](#) which came into force in 1961. The Antarctic Treaty called for the use of Antarctica for peaceful purposes and cooperative scientific research which in turn led to the Antarctic Treaty System, putting several international agreements in place to [protect Antarctic wildlife](#).



The flags of the signatories at the Ceremonial South Pole (Credit: Public Domain)

The original 12 signatories to the Antarctic Treaty were Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the UK, the USA and the USSR – all of whom had been active in Antarctica during the International Geophysical Year of 1957-58, It has since been acceded to by many other nations taking the total number of parties to 56 today.

In a 1957 address, US President Eisenhower stated:

"The most important result of the International Geophysical Year is that demonstration of the ability of peoples of all nations to work together harmoniously for the common good. I hope this can become common practice in other fields of human endeavour."

Lead image: Port Lockroy during the IGY, 1957 (Credit: Peter Gale/BAS Archives)

Annex 567 bis

“International Geophysical Year (IGY)”, *Dwight D. Eisenhower Presidential Library,
Museum, and Boyhood Home*



International Geophysical Year (IGY)

★ ★ ★ ★ ★

Online Documents (/research/online-documents) / International Geophysical Year (IGY)

From July 1957 to December 1958 an international cooperative scientific program was conducted to study the earth and its environment. This program was called the International Geophysical Year. More than 70 countries participated in the project which led to the discovery of the Van Allen radiation belts, the theory of plate tectonics, exploration of outer space, construction of earth satellites, and increased research in the Arctic and Antarctic polar regions. IGY was sponsored by the International Council of Scientific Unions and involved nearly 30,000 scientists. In a radio and television address on June 30, 1957, President Eisenhower expressed his belief that "the most important result of the International Geophysical Year is that demonstration of the ability of peoples of all nations to work together harmoniously for the common good. I hope this can become common practice in other fields of human endeavor."

Article, "News Report of the National Academy of Sciences and the National Research Council, Volume IV, March-April 1954, Number 2 - The United States Program for the International Geophysical Year" by Joseph Kaplan, Chairman, United States National Committee, International Geophysical Year, March-April 1954 (/sites/default/files/research/online-documents/igy/1954-news-report.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16645342]

Letter, Asst. Secretary of Defense to Joseph Dodge regarding DoD's interest in the IGY program, March 19, 1954 (/sites/default/files/research/online-documents/igy/1954-3-19.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16645513]

Letter, Sinclair Weeks, Secretary of Commerce, to Detlev Bronk, President of the National Academy of Sciences, concerning U.S. program in geophysical research, March 23, 1954 (/sites/default/files/research/online-documents/igy/1954-3-23.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16645565]

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National Science Foundation report on the International Geophysical Year, June 2, 1954 (/sites/default/files/research/online-documents/igy/1954-6-2.pdf) [DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16645825]

List of 29 nations participating in International Geophysical Year, June 7, 1954 (/sites/default/files/research/online-documents/igy/1954-6-7.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16645860]

Letter, Chester I. Barnard, Chairman, National Science Board to the President, June 22, 1954 (/sites/default/files/research/online-documents/igy/1954-6-22.pdf) concerning IGY and President's response, June 24, 1954 (/sites/default/files/research/online-documents/igy/1954-6-24.pdf) [DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16646042 and 16646119]

"Outline of International Geophysical Year Program" by the U.S. National Committee, International Geophysical Year 1957-58, July 26, 1955 (/sites/default/files/research/online-documents/igy/1955-7-26.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16646133]

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Press Release by the National Science Foundation and the National Academy of Science, "Plans for Construction of Earth Satellite Vehicle Announced," July 29, 1955 (/sites/default/files/research/online-documents/igy/1955-7-29-nsf-release.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (1); NAID #16646897]

Statement by President Eisenhower concerning the Amundsen-Scott IGY South Pole station, January 11, 1957 (/sites/default/files/research/online-documents/igy/1957-1-11.pdf)[DDE's Records as President, Official File, Box 624, OF 146-E International Geophysical Year (2); NAID #16646930]

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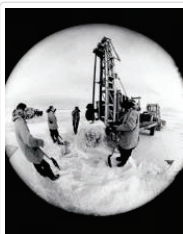
Additional Information:

International Geophysical Year Subject Guide (/sites/default/files/research/subject-guides/pdf/international-geophysical-year.pdf)

Photographs:



(https://www.eisenhowerlibrary.gov/sites/default/files/research/audiovisual/images/igy/75_92_30.jpg)



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