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ENVIRONMENTAL RESTRAINTS ON ENERGY CONVERSION

E.R. MITCHELL

FUELS RESEARCH CENTRE

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Environmental Restraints on Energy Conversion

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ABSTRACT

The physical magnitude of the Canadian air, land and water environments together with their natural scavenging mechanisms can assimilate more pollution than is produced in energy conversion. Nonetheless, concentrations of pollution at single sources and the proliferation of sources exceeds the capacity of the environment in some specific, but widely separated, areas. Thus, if our environments are to be given a reasonable opportunity to assimilate pollution, there is no choice but to ensure that stack emissions are minimized and, having done that, to make full use of the dispersion capacity of air sheds. However, neither fuel highgrading, i.e. the use of premium fuels as an expedient for the moment, nor pollution controls that waste energy are viable long-term solutions for protecting the environment.

The effect of winter conditions on scavenging mechanisms is described, adding emphasis to the need for proper plume dispersion. Otherwise, pollution may concentrate in snow only to run off in the spring to the water environment.

The limited dispersion capacity of the sub-arctic and arctic air sheds, under winter conditions, is mentioned, but the obstacle to energy conversion may not be too serious in large areas where bogs and wet lands are strongly acidic. However, lichens of the arctic tundra could be easily destroyed by sulphur dioxide emitted from heat processes so that the risk to the delicate arctic ecosystem seems grave unless special precautions are taken to continue using non-polluting fuels and to avoid ground-level fumigation.

Heat pollution and the possibility of large-scale nuclear power generation in the foreseeable future are also discussed.

E. R. MITCHELL, head of the Canadian Combustion Research Laboratory, graduated from Queen's University in 1940, completed the Canadian Westinghouse graduate training course and joined the Canadian Army in 1942. Upon discharge from the RCEME in 1946 with the rank of captain, he re-directed his professional career to what was then known as "smoke abatement".

Through employment with two large Canadian industries in responsible engineering positions he demonstrated a pre-occupation with the formation of pollutants in flames. Although he admittedly preferred industrial life, he joined the Department of Mines and Technical Surveys as a qualified combustion engineer because of the opportunity to pursue research in his chosen field of specialization.

In 1955 he was invited by Dr. John Convey, director of the Mines Branch, to plan a national program of combustion research that would assist the development of indigenous fuel resources. One phase of his program which is now highly developed is the characterizing of pollutants in relation to flame properties.

He and his research group have many patents and papers to their credit and are well known internationally on such subjects as fuel additives, flame aerodynamics, low NO_x flames, blue flames, the minimizing of pollutants at flame and process sources and, most recently, plume dispersion research.

Mr. Mitchell has served as chairman of an OECD Committee on Air Pollution from Fuel Combustion, is currently chairman of the Commonwealth Liaison Committee on Fuel Research, served many years as chairman of the ASME Fuels Research Committee, is a member of the board of directors of the British Flame Research Committee, is a founding member, past president and past secretary of the Institute of Combustion and Fuel Technology of Canada, and is active in many other technical-scientific societies.

For his contribution in establishing a meaningful Canadian Combustion Research Laboratory which gained international recognition, he was awarded a Public Service Merit Award in 1965, and was made a Fellow of both ASME, New York, and the Institute of Fuel, London, in 1968.

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INTRODUCTION

WHEN THE SUBJECT of environmental restraints was assigned to me it was realized that, as Members of The Canadian Institute of Mining and Metallurgy, you share the concern of many people about the challenge to growth which resulted from two computer studies in the United States — one entitled "World Dynamics" by Jay W. Forrester and the other "Limits to Growth" by Dennis L. Meadows. The world was also startled by another report entitled "A Blueprint for Survival", which was endorsed by 33 of the most prestigious scientists in the United Kingdom. These reports contain many assumptions, but warn that man may be so greatly out of balance in the ecosystem that the present concept of growth must be revised, at least, and possibly reversed. Then, Barry Commoner, in his book "The Closing Circle", illustrates the fallacy of increasing fuel consumption with no comparable increase in productivity but with a significant increase in pollution.

As geologists, mining engineers and mineral processors, you have a good basic training in the physical sciences. Many of you have travelled this great land by all manner of transportation, even on foot, and it is quite possible that the least of your problems has been pollution unless you are engaged in mineral extraction or energy conversion. Nonetheless, whether viewed from the ground or from the air, our Canadian environment (air, land and water) is of a magnitude that projects a very strong sense of security, especially below latitude 60°N.

Being resource oriented you have a certain intimacy with the environment; you have endured its idiosyncrasies; you have suffered its cruelties; but you have also enjoyed its indescribable beauty. Some have retaliated to its cruelties by striking back and leaving behind scars that will either long endure or will be corrected by environmental safeguards. However, most Canadians are impressed with, even have a passion for, the great beauty of our environment and give their support to those who assume responsibility for its preservation. At the same time they expect that technological support will be at their disposal whenever it is wanted for either essential services or unnecessary luxuries and seldom, if ever, will they stop to consider the impact of their personal energy use on the environment(1).

POLLUTION FROM ENERGY CONVERSION

Energy Consumption

The average Canadian used 214 x 10^6 Btu of energy during the year 1970, and in doing so was responsible for 17 tons of pollution, which includes CO$_2$(1, 2, 3). Energy sources as a percentage of total energy consumption are given in Table 1(4).

TABLE 1 — Energy Sources, 1970

Fuel	% of Total Energy Consumption on a Btu Basis
Petroleum Products	56.0
Natural Gas	21.6
Coal	12.9
Hydro and Nuclear	9.5

Pollution Potential of Fuel Combustion

The factors which influence fuel selection have been described elsewhere(4), but the pressures to "high-grade" (the use of premium low-pollution fuels) as an expedient for environmental protection are best understood by comparing the pollution potentials of commercial and industrial fuels shown in Table 2. It should be pointed out that the sulphur content of many Western Canadian coals is low and at the same time it is neutralized to different degrees by cations in the coal ash(5). Thus, the principle environmental problem is one of fly-ash removal, an area of research which has potential for significant environmental improvement.

Oil does not have the same advantage of a built-in sulphur neutralizing agent, so the Canadian Combustion Research Laboratory (CCRL) developed an additive which completely neutralizes SO$_3$ produced in flames, leaving SO$_2$ in a dilute phase (no more than 1200 ppm) to be dispersed(6).

Both Western Canadian coal and oil have physical and chemical properties which complement one another; therefore, coal-in-oil fuel was proposed as a means for extending petroleum resources. It is a relatively low-polluting fuel, especially with electrostatic precipitation of the small amount of ash involved(7). It could be substituted for natural gas in large industrial and utility boilers or processes which can tolerate a small amount of innocuous ash.

TABLE 3 — Diesel Exhaust Emission[1]

Pollutants lb/10^6 Btu	1200 rpm, ¼ load	1600 rpm, full load
CO$_2$	144.800	150.800
CO	1.086	3.439
NO	1.327	1.810
NO$_2$	0.331	0.072
SO$_2$	0.047	0.059
Particulates[2]	1.639	0.591
Total Pollutants	149.200	156.800
Harmful Pollutants	4.431	5.972

[1] After L. R. Rickner, W. E. Scott and W. F. Biller, "The Composition and Odour of Diesel Exhaust", API Meeting, Montreal, Quebec, May 1965. (Data are not necessarily typical, but are for an inter-urban bus engine and a commercial diesel fuel).

[2] Includes hydrocarbons calculated as hexane (C_6H_{14}), ethylene, acetylene, formaldehyde, acrolein, benzene-soluble and benzene-insoluble particulates.

Despite the magnitude of our great country we have, per capita, only 7.5 acres of farmland, of which 4.8 acres are food-producing. Clearly, if we are to have an adequate and balanced diet we must have highly mechanized farming and extensive transportation systems. Both are based on the internal combustion engine, the largest single source of air pollution from energy conversion.

Table 3 presents the pollution potential of an inter-urban bus engine burning a commercial diesel fuel; Table 4 presents the pollution potential of an automobile engine burning gasoline, liquified petroleum gas (LPG) or liquefied natural gas (LNG). None of the examples selected for Tables 3 and 4 are intended to be typical.

Energy Budget and Associated Pollution

The pollution from fuel energy conversion in Canada for the year 1970 is given in Table 5, together with that of the United States and the world to facilitate comparisons. This is not intended to justify our pollution, which is small in an over-all comparison but large on an individual personal basis. Instead, it is intended to show where we stand on both a North American and a global scale. However, it is not possible in Table 5 to illustrate the influence of geography on either the rate of energy consumption or the assimilation capacity of the environment. Table 6 shows the physical magnitude of our environment in comparison with the

TABLE 2 — Pollution Potential of Commercial-Industrial Fuels

Pollutants lb/10^6 Btu	Lignite (0.58%S)	Western Canadian Bit. Coal (0.7% S)	Residual Oil (2.5% S)	Canadian Crude Oil (0.44% S)	Natural Gas	Coal-in-Oil
CO$_2$	222.9	219.6	171.6	165.8	118.8	180.3
CO	.08866	.09231	.08355	.084	0.07132	.1314
NO	.4275	.4455	.4028	.1563	0.1719	.2343
SO$_2$	.6865[1]	.5385[1]	2.729	.5158	—	.5249
SO$_3$	.0172	.01346	.0682	.0132	—	.3626
Particulates[2]		(7.422)	.1364	.0526		(2.037)
95% Ash Removal	.5207	.3711	NA	NA	—	.1018
97% Ash Removal	.3124	.2228	NA	NA	—	.0611

[1] Assuming 50% S in coal is neutralized by cations in the ash.

[2] Particulates include C_xH_y, fly-ash and soot.

TABLE 4 — Comparative Emissions from Motor Vehicles Using Gasoline and Gaseous Fuels

Fuel	Miles per U.S. gal	Btu/lb	Emissions, g/mi			Evaporative Emissions g/test
			HC[1]	CO	NO_x	
Gasoline, pre 1968	16.5	18,500	8.05 (16.8)[2]	79.1 (125)[2]	3.83 (4.5)[2]	(60)[2]
Gasoline, 1969	16.5	18,500	2.83 (3.2)[3]	22.6 (33)[3]	5.5	—
LPG	14.5	19,900	1.38	9.03	5.5	NA
LNG	12.14	21,500	.373	1.75	0.5	NA
Gasoline, 1973-74	14.5 (est.)	18,500	(3.4)[3]	(3.9)[3]	(3.0)[3]	(2.0)[3]
Gasoline, 1975	13.2 (est.)	18,500	(.41)[4]	(3.4)[4]	(0.4)[4]	(2.0)[4]

[1] Calculated as hexane (C_6H_{14}).

U.S. Vehicle Emission Standards — 1968-1976

[2] Using 1968 Federal Test Procedure (7 mode).

[3] Using 1972 Emission Test Procedure (CVS-72).

[4] Using 1975 Mass Emission Test Procedure (CVS-75).

TABLE 5 — Energy Budget and Pollution from Fuel Combustion — 1970

	World Total	Continental USA[1]		Canada		
		Total	% World	Total	% World	& USA
Fuel and Energy Consumption[1]						
Fuel Consumption ... Btu × 10^{15}	217	65.9	30.4	4.2	1.9	6.4
Per-Capita Fuel Consumption ... Btu × 10^6	60.3	319.0	529.0	193.5	320.9	60.6
Energy Consumption ... Btu × 10^{15} [2]	267	68.6	25.7	4.64	1.7	6.8
Per-Capita Energy Consumption ... Btu × 10^6 [2]	72.2	337	460	214	296	64.5
Heat Budget — Solar Energy and Energy Conversion — below Latitude 60°N						
Solar Energy Received ... Btu × 10^6/acre yr	63,450	24,078		13,339		
Fuel Energy Conversion ... Btu × 10^6/acre yr	2.1	29.2		2.5		
Ratio Solar: Man-Made Energy	30,214	824.6		5335.7		
* Total Solar (10^8 Btu) Q/yr	4,000	56.6		21.7		
Pollution from Fuel Energy Conversion (Combustion), Short Tons × 10^6 [3] [4]						
Total Products of Combustion	23,285	7803.3	33.5	505 6[5]	2.2	6.5
CO_2	15,900	4845.0	30.5	346.0	2.2	7.1
Water	6,620	2730.0	41.2	135.0	2.0	4.9
Total Harmful Pollutants	765.6	228.3	29.8	12.3	1.6	5.4
CO	274.0	125.3	45.7	6.8	2.5	5.4
NO_x	53.0	21.4	40.4	1.2	2.3	5.6
SO_x	220.0	33.0	5 0	2.0	0.9	6.0
Particulates	218.6	48.6	22.2	2.3	1.0	4.7
Air Shed Contamination (Troposphere) per Year, lb/lb Air × 10^{12}						
Total Products of Combustion	5.88	107.63	—	6.52	—	—
Harmful Pollution	0.19	3.15	—	0.16	—	—

[1] ASME Energy Crisis Forum, New York, November 1972 and Encyclopaedia Britannica.

[2] Includes electric power from hydro and nuclear sources.

[3] Eric G. Walther, "A Rating of the Major Pollutants and Their Sources by Effect", Jour. APCA, Vol. 22, N5, May 1972.

[4] E. Robinson and R. C. Robbins, "Sources, Abundance and Fate of Gaseous Atmospheric Pollutants", Stanford Research Institute Project PR-6755.

[5] E. R. Mitchell, "Fuel Combustion Trends and Resulting Air Pollution in Canada, 1965 to 1980", Proceedings Quebec Branch APCA Symposium, Ste. Adele, Quebec, May 28-30, 1972. (Does not include process pollutants such as SO_2 from sulphide ore roasting.)

TABLE 6 — Physical Magnitude of the Environment and Population[1]

	World Total	Continental USA[3]		Canada		
		Total	% World	Total	% World	% USA
Magnitude of the Environment						
Air Shed Capacity (Troposphere), lb × 10^{16}	790.8	14.5	1.8	15.5	2.0	106.8
Total Land, Water and Forest, Acres × 10^6	126,080	2348.6	1.9	2464.9	2.0	104.9
Land, less Forest ... Acres × 10^6	26,285	1508.9	5.7	1668.6	6.3	110.6
Forest ... Acres × 10^6	10,195	758.9	7.4	796.3	7.8	104.9
Farmland ... Acres × 10^6	—	1117.8	—	162.5	—	14.5
Water ... Acres × 10^6	89,600	81.4	—	200.8	—	256.3
Population × 10^6	3,700	203.2	5.6	21.7	0.6	10.5

[1] Encyclopaedia Britannica, 1970.

*Misprint - should read (10^{18} Btu) Q/yr.

United States and the world. One factor that stands out is that our sparse population in 1970 was only 0.6% of the world's population but produced 1.6% of the world's harmful pollution.

Having examined the pollution potential of fuel combustion it is important to understand the "effect factor" or "severity factor" of each of the major pollutants. A number of experts on the subject have developed effect factors which were compiled by Babcock and Nagda and are repeated in Table 7(8). The factors which seem most appropriate to Canada are those in Column 3 by Babcock (1970). The emphasis placed on hydrocarbons by Walther(9) may suit the California climate, but it seems excessive for Canada when it is realized that compounds of the terpene class $(C_5H_8)_n$ are produced in nature in such large quantities that they cast the bluish haze often seen over our large forest regions and cause no concern.

IMPACT OF POLLUTION ON THE ENVIRONMENT

Air and Land Scavenging Mechanisms

The environment has built-in scavenging mechanisms, some of which are described in another paper by the present author(10). Some of the mechanisms that are understood or may be reasonably postulated are described briefly, but there are likely other mechanisms, yet unknown. In any event, it is clear that the total Canadian environment can scavenge much more pollution than is now produced in energy conversion while the climate is temperate. However, our severe winter climate restricts these scavenging mechanisms and introduces the possible risk, albeit highly localized, of pollution concentration in snow which runs off to the water in the spring. In this way we could be contributing to the global deterioration of the oceans.

The concentration of pollution sources and population, typical of highly industrialized areas of Canada, introduces problems specific to urban air sheds, to certain land areas and to the water environment, where possibly the greatest rate of deterioration is occurring.

Environmental Deterioration Dictates Restraints

A measure of the impact of pollution on the air environment is the first step toward an understanding of potential environmental deterioration, keeping in mind the previous discussion. There is no direct method of measuring this impact, but it helps to understand the extent to which pollution may accumulate in the atmosphere in relation to the concentration of both population and pollution sources. In such a model study, one should assume stagnating weather conditions during which there have been no ventilation and a persistent inversion for 24 hours. This is referred to here as a 24-hour static model in which there is no provision for atmospheric scavenging of pollutants; such conditions might occur in a severe winter climate.

Fortunately, high wind velocities and good ventilation occur periodically during our northern winters. However, the worst combination has been chosen for the 24-hour static model summarized in Table 8 in which a fairly liberal inversion height of 500 m has been chosen. Pollutant concentrations are given in $\mu g/m^3$ for convenient comparison with provincial regulations.

Dispersion Capacity of Air Sheds

Although our air and land environments are large, problems arise from the concentration of sources. People congregate in urban communities, and it is this concentration, illustrated in Table 8 and Figure 1 (a), that requires special attention. If the capacity of the air and land environment are to be used efficiently, there is no alternative to the proper dispersion of combustion-source pollution. This can be achieved through a knowledge of the dispersion capacity of air sheds and is the reason why CCRL undertook a plume dispersion research program. When dispersion capacities of air sheds are understood, stacks may be designed to avoid localized fumigation by CO, NO_x, SO_x and small particulates(11, 12). By dispersing the gases properly, concentrations are reduced everywhere, and maximum use is made of the total environment.

In Figure 1 (b), the highest ground-level concentrations of SO_2 from two thermal power stations — one in the U.K. and one in Toronto — are compared with the levels of concentration which may cause damage to sensitive plants. These high concentrations occur 2% of the time in the U.K. and less frequently in Toronto. It is a matter of judgment what frequency of fumigation incidents, if any, should be tolerated and whether stack heights should be selected on this basis. The alternative is to continue current fuel practices of using high-quality, low-sulphur fuels which will eventually lead to the kind of energy crisis now being experienced in the U.S.A. Although this may be expedient for the moment, it contributes to a crisis situation later unless alternate clean sources of electric power are available in sufficient time, and that is a debatable proposition at present.

TABLE 7 — Comparison of Pollution Tolerance and Severity Factors[1]

Pollutant	Apparent Tolerance Factors	Severity Factors				
		Babcock Nagda 1972	Babcock 1970	Caretto Sawyer	RECAT	Walther
Carbon Monoxide	7800	1	1	1	1	1
Hydrocarbons	788	10	2	62	60	124
Nitrogen Oxides	330	24	78	44	100	22
Sulphur Oxides	266	29	28	27	120	15-21[2]
Particulate Matter	150	52	107	38	133	21-37[2]

[1] After Babcock, Lyndon R., and Nagda, Niren L., "Cost Effectiveness of Emission Control", Jour. APCA, Vol. 23, N3, March 1973.

[2] Primary-Secondary Standards.

TABLE 8 — Air Shed Pollution Burden — 24-Hour Static Model at 500-Meter Mixing Height[1] — Fuel Combustion and Process Sources

	Canada Below Latitude 60°N	Industrial Area North of Great Lakes	Canadian City	Continental U.S.A. Below Latitude 60°N
Land Area, km^2	6,584,257	259,000	621.6	9,051,696
Population Density, people/km^2	3.3	50.2	3032	22.4
Air Pollution, $\mu g \times 10^{15}$				
Total, incl. CO_2	927.6	556.5	59.3	12301
Harmful, excl. CO_2	42.8	25.0[2]	2.9	566[3]
CO_2	884.0	530.9	56.4	11735
CO	16.9	9.8	1.077	312.0
Particulates	6.0	3.6	0.382	120.7
NO_x	3.0	1.8	0.191	53.1
SO_x	16.9	9.8	1.077	82.0
Pollution Burden, $\mu g/m^3$				
Total, incl. CO_2	281.76	4297.3	190,800	2717.94
Harmful, excl. CO_2	13.00	193.0	9,331	125.06
CO_2	268.76	4104.3	181,469	2592.88
CO	5.133	75.68	3,466	68.94
Particulates	1.823	27.80	1,231	26.67
NO_x	0.911	13.90	615	11.73
SO_x	5.133	75.68	3,466	18.12

[1] No allowance has been made in this model for either natural scavenging of the environment or dilution factor by normal ventilation, which has been measured in Ontario at 1600 at 14 km and in Alberta at 7000 at 3.1 km downwind from industrial sources.

[2] Add 15% — for miscellaneous pollution from incineration, forest fires, agricultural burning, coal and other waste-bank fires.

[3] Add 18% — for same

Also plotted in Figure 1 (b) is the mean concentration of SO_2 at 4 km downwind from the Toronto power station, as recorded by Environment Canada. This mean concentration is well below pollution control limits and is too low to be of any harm. Those who object to properly designed stacks usually refer to the "tall stack" concept with the intention of emphasizing that dispersion does not stop the total pollution emission. This is certainly true, but nature disperses its pollutants on a global scale. Furthermore, low concentrations of SO_2 from energy conversion are beneficial to the land environment(13, 14) and until we have either perfect non-polluting fuels, or processes which defy natural physical laws, we must use "tall stacks" to make full use of the assimilative capacity of our air and land environments. Chimneys designed to properly disperse SO_2 will permit the use of Western Canadian coal and oil, without sulphur removal in modern process equipment.

The pollution due to population concentrations in a city may eventually reach the limit of the capacity of its air shed. If this happens after all stacks in the community have been properly designed and the automobile has been adequately controlled, the final solution, after energy conservation, is to stop the population concentration.

The effect of concentrating population and industry is illustrated in Figure 1 (a). The curves plotted on this figure are maximum concentrations of SO_2 from all sources in Chicago, Inner London, Montreal and Toronto where population concentrations are 15,800, 424,000, 13,500 and 7,850 people/sq. mi. respectively. The data for Montreal and Toronto were calculated from the 1971 Monthly Summary Reports of National Air Pollution Surveillance by Environment Canada. These maxima occur infrequently and the Ontario Ministry of Environment, as an example, has instituted a system whereby warnings are issued to major industry to reduce operations until the normal ventilating conditions return.

If all first-line corrective measures will not protect the environment, it would be logical to limit the concentration of both pollution sources and population and make provision for new town sites. This has been done in the United Kingdom through the "Towns Act of 1946"(15, 16). By this Act, 30 new towns have been created to date. In France, there is a National Commission on Towns which is planning nine new towns, five of them in the Paris region and four in the provinces. The first such town is named Vaudreuil, near Paris, and will eventually have a population of 150,000 people. It will be the first urban community without noise and pollution. It will have underground smoke and refuse ducts and the controlled burning of refuse will be part of the future city's central heating system(15, 16). In Canada, we have a Canadian Council of Urban and Regional Research and it is hoped that this comprehensive urban information centre may contribute to systematic urban development in Canada.

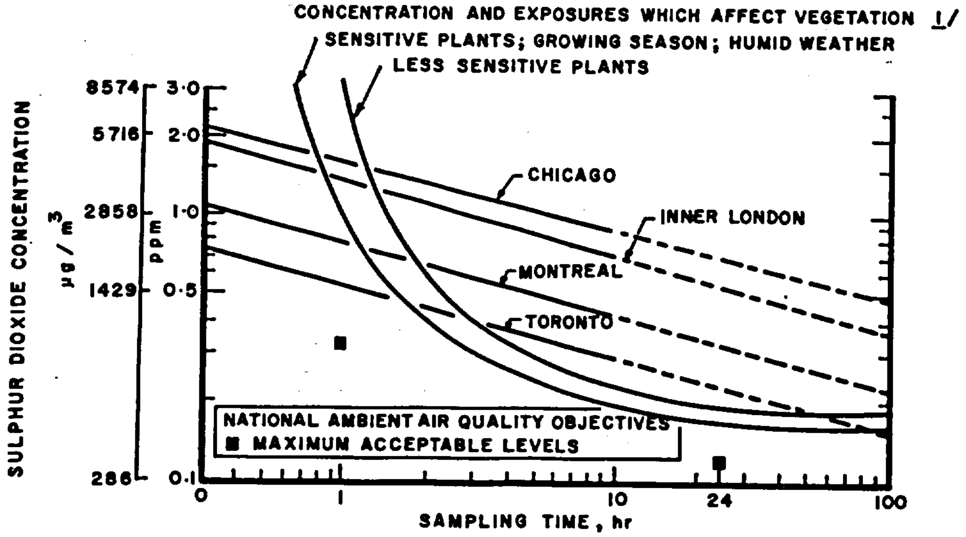
Quality of Life Dictates Environmental Restraints

Having examined the pollutant effect factors and scavenging mechanisms of the air and land environments it seems that quality of life, as well as environmental deterioration, dictates environmental restraints on all technology, of which energy conversion is a very large part.

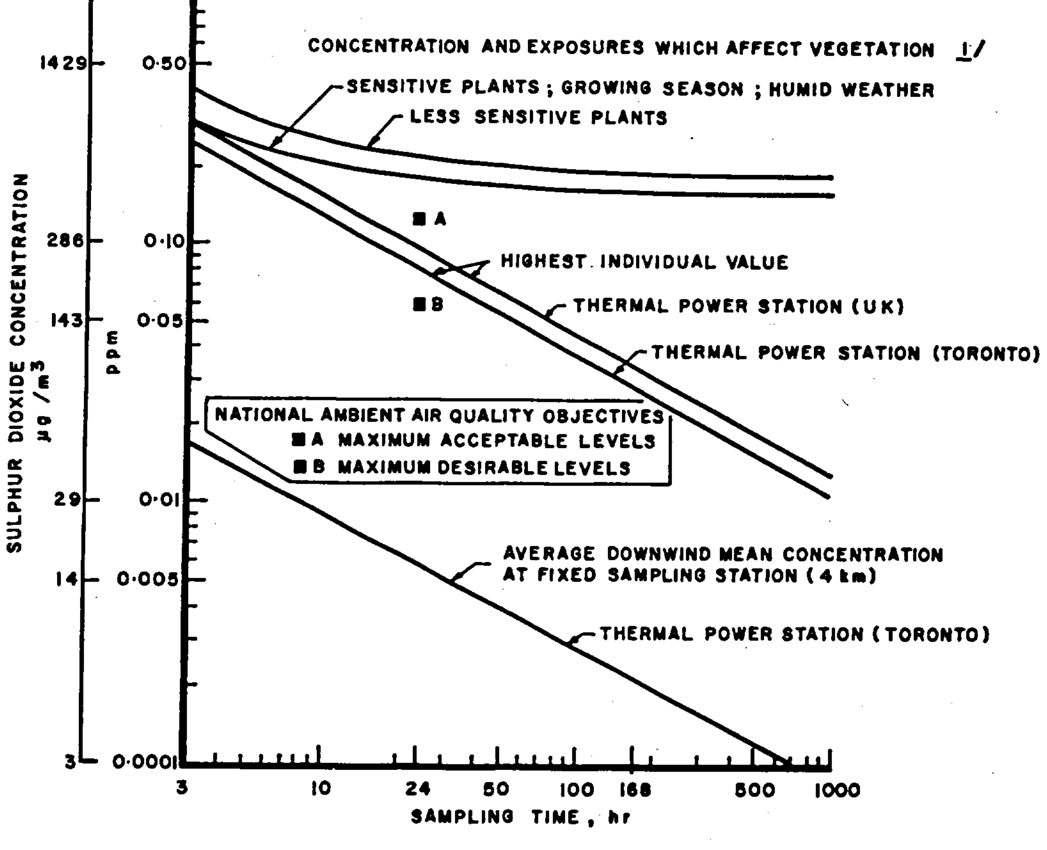
Considering the quality of life, it is well to remember that we have covered 9 x 10^6 acres of land with roads and town sites(17) in dedication to progress. Therefore, it may be argued that there is justification for using a certain amount of the environment to provide the basic ingredients of technology upon which we depend for survival. However, the warnings of ecologists have been heeded following incidents in industrialized areas of the country, and all agree that environmental deterioration should be avoided wherstart with conservation and, then, maximize productivity in relation to energy consumption.

Although we admit responsibility for a high rate of individual pollution, the energy placed at our disposal has helped to increase the Canadian (male) life expectancy from about 40 years in 1900 to 68 years today; i.e., for those who avoid obesity, are nonsmokers and are careful motorists(18). Dr. Bates conservatively estimated health costs for Canadians attributable to air pollution to be $50 million per year(19). By extrapolating experience in the United States, the health cost to Canadians could be escalated, theoretically, to the unlikely cost of $190 million ($2.30 to $8.75 per person per year average).

Comparing this with either 5,400 deaths and 200,000 injured in automobile accidents(20) that cost possibly **more than $1 billion per year or respiratory diseases**



(a) MAXIMUM URBAN SO_2 CONCENTRATIONS



(b) MAXIMUM AND AVERAGE SO_2 CONCENTRATIONS FROM SINGLE SOURCES

FIGURE 1 — Ground concentration of industrial-source pollution [¹Reference (13)].

from other causes, air pollution from energy conversion, although not condoned by anyone, is not very serious. Actually, of all the industrialized nations, Canada's air environment is the cleanest on average(21), although urban problems are recognized and are being corrected.

Water Environment Scavenging Mechanisms

The water environment is much larger than the land environment, occupying, as it does, 71% of the earth's surface. It is also a dynamic system and, unfortunately, the final repository of our pollution. The oceans are a major sink for CO_2, which becomes involved in both mineral and biological activity. Either way carbon ends up on the ocean floor both as calcium carbonate, for example, and as organisms.

The oceans, being alive with micro-organisms, plants and higher vertebrate life forms which are more abundant than any one class of land vertebrates, have always been an important source of food. For this reason, there should be concern over oil spills and heavy metals such as lead, arsenic, mercury and cadmium, not to mention man-made chemical formulations like DDT which do not exist in nature but all of which become lethal by accumulation.

Microbial biodegradation of pollutants is a complex scavenging mechanism which is being explored on a number of fronts. It is postulated that inorganic mercury may be converted to soluble methyl mercury, albeit at an extremely slow rate, by certain microbes(22); if true, it will add to the poisoning of fish. In the matter of oil spills, the scourge of the oceans, 62 species of bacteria which consume oil have been identified.

However, a new cause for concern is cadmium, which is the most lethal of all metals to man because it accumulates in the body, especially the kidneys, and it has been associated with hypertension and heart disease. It is a minor pollutant from energy conversion and associated functions such as vehicle tire wear, scrapped automobile radiators and combustion of motor oil. Its oxide and sulphide escape from smelters that refine lead, zinc and copper ores which contain cadmium. Other sources are cadmium plating of iron and steel, compounding of cadmium pigments, plastic stabilizers, fertilizers and pesticides(22).

Cadmium is converted to soluble form and migrates through soil to the roots of plants more rapidly than either mercury or lead. Having entered the food chain it is appearing in the solid residue of sewage treatment plants, and there is concern about its use in fertilizers.

Waste Heat

All of man's energy conversion, no matter how it is used in the first place, ends up as heat added to the environment. However, if the CO_2 greenhouse effect can be avoided(23) and if the ozone of the stratosphere remains unaltered, there is no need for concern at this time about man's addition of heat to the air environment, except for the waste of fuel that it represents in thermal power generation. In 1970, the total heat-energy produced in Canada from thermal, hydro and nuclear power generation amounted to 2.5×10^6 Btu/acre/yr below latitude 60°N. This compares with $13{,}339 \times 10^6$ Btu/acre/yr received from the sun giving a ratio of solar:man-made energy of 5335.6, as shown in Table 5.

Waste heat in Canada is now insignificant, but it should be put to use wherever possible both to conserve fuel and to minimize fuel combustion pollution(24). In thermal power generation, almost 70% of fuel input is lost to condenser cooling water, whereas it could be usefully applied either in district heating with no more than 30% loss or, possibly, for accelerating the growth of sea fish, as is being done at Hinkley Point Power Station in England and at another large station in San Diego, California.

The use of waste heat from power stations has been discussed for years and a World Energy Conference Committee examined the feasibility of long-distant transport of waste heat(25). It is a concept having many possibilities when it is considered that the waste heat of the Pickering nuclear power station, when in full operation, could heat 680,000 homes like that of the author's in the Ottawa climate.

The production of fish in ponds has been an industry in China for many years. With over-fishing of the oceans it would be convenient if we could have an inland fish industry using either fresh or salt water and waste heat from power stations to maximize fish growth rate. However, it is a complex subject where careful control of maximum water temperature would be necessary to maintain microscopic phytoplankton and algae which are the food source of higher organisms(26, 27).

This is only one phase of the broad subject of energy conservation which needs innovation more urgently than any other phase of technology.

Nuclear Energy

The dilemma of the world's imbalance between energy consumption and clean conventional fuel resources can only serve to place greater emphasis on the generation of electric power by nuclear means(28). Indeed, it promises to be an endless source of energy(29). However, some environmentalists have already impeded the nuclear program in the United States and have made the message very clear that they fear fission reactors as the greatest threat to the environment of all of man's technology.

It is reassuring to speak with experts who can show that the Canadian CANDU process is the cleanest of all nuclear power plants because the small amount of plutonium produced in its fuel cell can be processed without any problems(30). As yet, there is no known way of preventing the build-up of radiation in the secondary power-generating hardware.

Other light-water reactors (LWR's), in which less than 1% of the energy in naturally occurring uranium is used, consume the fissionable U^{235} isotope while converting only small amounts of the more plentiful U^{238} into fissionable plutonium. For this reason, LWR's were never considered more than a stop-gap by early proponents of nuclear power. On the other hand, fast breeder reactors, which seem to be the direction of development in the U.S.A. and the U.K., produce more fissionable plutonium than they consume. However, their great advantage is that they can theoretically utilize between 50 and 80% of the uranium and thorium resources(31). Plutonium does not exist in nature and for this reason we call it the DDT of the energy system. It is a permanent pollutant with a half-life of 24,400 years(31). Another environmental consideration is the disposal of large amounts of waste heat, as previously discussed, but it will be a long time before there are serious environmental thermal restraints in Canada.

The electric utility industry in the United States faces a grave decision because of the present embarrassing energy situation. It must decide whether (a) to back the fast breeder reactor (which may be 15 years in development) in the face of both its pollution potential and problems of plutonium security or (b) to wait as long as 60 years for the fusion reactor, which does not produce persistent radioactive wastes, but still has the problem of build-up of radioactivity in structural materials. There is a problem of confining the reacting fuel (deuterium — tritium) at temperatures ranging from 100,000,000°C to 1,000,000,000°C. The most recent development is laser-induced fusion in which small pellets of fuel are so rapidly heated with a laser pulse that fusion conditions are reached before the heat is dissipated(32, 33).

Regardless of the merits of the several fission reactors and the yet undeveloped fusion reactor, it seems evident that to meet the world's energy demand after the year 2000, only 27 years in the future, a 1,000-MWe nuclear power station will be erected every day somewhere in the world until a steady-state situation is achieved(31). Judging by today's power use, the predominance of these stations will be in the northern hemisphere, although several countries in the southern hemisphere could benefit most from nuclear power.

No other field of science and technology in all of human endeavour has applied such intensive voluntary restraints as nuclear power engineering to ensure safety. Nonetheless, there remain nagging doubts in the minds of the public about the safety of the fission reactor. Actually, man's susceptibility to radiation places him in the position of being the early warning system of potential damage to the biosphere by radiation.

If present safety standards can be maintained without detrimental effect on the ecosystem, Canada has the unique possibility of a nation-wide energy corridor comprising nuclear in conjunction with thermal and hydro (with pumped storage) electrical generating systems, but a way must be found to control the build-up of radioactivity in nuclear station hardware.

It is often forgotten that we are all exposed continuously to natural sources of alpha, beta and gamma radiation. Some is normally contained in body tissue, most of which originates as gamma rays from the earth and cosmic radiation from outer space. The total natural background radiation, at sea level, which amounts to 0.125 roentgen per year (r/yr), increases with altitude. By comparison, an ordinary X-ray gives 0.2 rem (rem is the amount of radiation which will have the same biological effect on man as the exposure to one roentgen of ordinary X-ray). Lethal radiation dosage is about 450 rems and the recommended average annual exposure for radiation workers is 5 rems. The recommended limit for the general public is 0.5 rems per year, although the genetic dose for a total population should not exceed 0.17 rems(34).

ARCTIC INDUSTRIAL ACTIVITY

With the discovery of oil and natural gas in the Arctic North Slope there was a strong incentive to apply, by direct extrapolation, southern technology and to hope that the ecosystem possesses sufficient flexibility to adjust to it. The developers saw, primarily, a solution to the energy crisis in the U.S.A. and the only obstacles were thought to be those of distance and an inhospitable environment.

Others had learned from experience during World War II that the ecosystem of the north is extremely fragile because of its unique simplicity; i.e., there are few species but large numbers of each. Its vulnerability to damage became evident by the scars left on the landscape by tracked vehicles, by accumulation of waste, by fuel and oil that drained into lakes, and by the accumulation of the Alaska Flower (oil drums). It has been reported that the odour of oil has been detected 15 years after a spill on the permafrost(34).

In past years, vehicular traffic in arctic regions has destroyed thin vegetation to expose the permafrost to solar radiation. These vehicle tracks have, in many cases, been transformed into deep gullies, causing some drainage of lakes and changes in the landscape. The reason is that migration of water in the arctic silt results in the growth of ice lenses which lose volume on melting and cause gullies that fill with water or unmanageable mud.

Resource companies, in an awareness of the fragility of the north, have initiated conservation measures and research in an effort to protect the environment.

Conservationists have made known their concern about the construction of pipelines and roads, so much so that they are impeding the spread of technology in the arctic. CCRL measurements of plume dispersion under arctic-like winter conditions have revealed the existence of a thick and persistent inversion layer through which plumes cannot penetrate. Therefore, pollutants will remain intact and concentrate in a thin layer above the ground, and they can be expected to accumulate on snow-covered land most of the year and then drain into the myriad of bogs and small lakes with little or no assimilation in the soil. The products of energy conversion, therefore, will likely add somewhat to the acidity of already acidic water and land on which the subarctic black spruce and cedar thrive. On the other hand, lichens of the arctic tundra, which are essential in the fragile ecosystem, could be easily destroyed by SO_2 emissions from fuel combustion.

One cannot generalize about environmental restraints of a physical and chemical nature in the far north and each district must be separately evaluated to minimize damage that could be irreparable. Despite all precautions it seems evident that all technological activity in the north (as well as the south) will result in an alteration of the environment; so, it is really a question of how much alteration can be accepted. Careful design is required to ensure that a downward spiral of productivity of the land and water is not brought about.

PROSPECTS FOR THE FUTURE

The magnitude of the Canadian environments and their natural scavenging mechanisms can accommodate more pollution than is produced, despite our lavish use of energy. The only exceptions arise in specific locations where less than the best energy conversion processes are used, where the dispersion capacity of air sheds is not utilized to full advantage and where population concentration is excessive.

Severe winter and arctic conditions likely affect scavenging mechanisms of the environments and may result in the concentration of pollution in the waters during the spring run-off. The significance of this depends on the natural setting and will have the least negative effect where waters are naturally acidic and where plant life and trees, like the black spruce, thrive on acidic waters, as happens in some southern regions of the sub-arctic. The negative effects of pollution from energy conversion in Canada are currently less significant than other man-made and natural disasters.

The world needs either more technology or better distribution of existing technology to support its present population, but there are danger signs in specific areas where the biosphere and its capacity to support naturally occurring abundant and diverse forms of life seem to be deteriorating. Somehow this situation must be corrected, so the first logical step seems to be conservation, which might require more use of solar energy(35), because technology based on fuel combustion will likely be needed for another 60 years. By that time, conventional fuels will be in short supply and too valuable as feedstock for chemical production to be used as a source of energy as we now use it.

Whether it be 60 or 100 years from now, it seems obvious that a new way of life will be based on electricity from clean nuclear power generation. However, there will still remain a need for fuel in transportation and similar special applications. This has raised discussion on the hydrogen energy cycle in which hydrogen will serve as an energy carrier. The postulated cycle starts with large nuclear power sources that provide the energy to break water down into its basic components: hydrogen and oxygen. The hydrogen would be distributed in pipelines to major urban centers as a portable energy carrier(36). It is not a primary energy source because large amounts of energy are used to produce it, but this energy is recovered when the hydrogen is burned. If it is burned in air, the only pollutants are oxides of nitrogen, but their concentrations in the products of combustion are lower than from burning other fuels. When hydrogen is burned in oxygen, the only product is water and there are no pollutants at all.

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