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Energy and the Environment

Asit K. Biswas, Ph.D.

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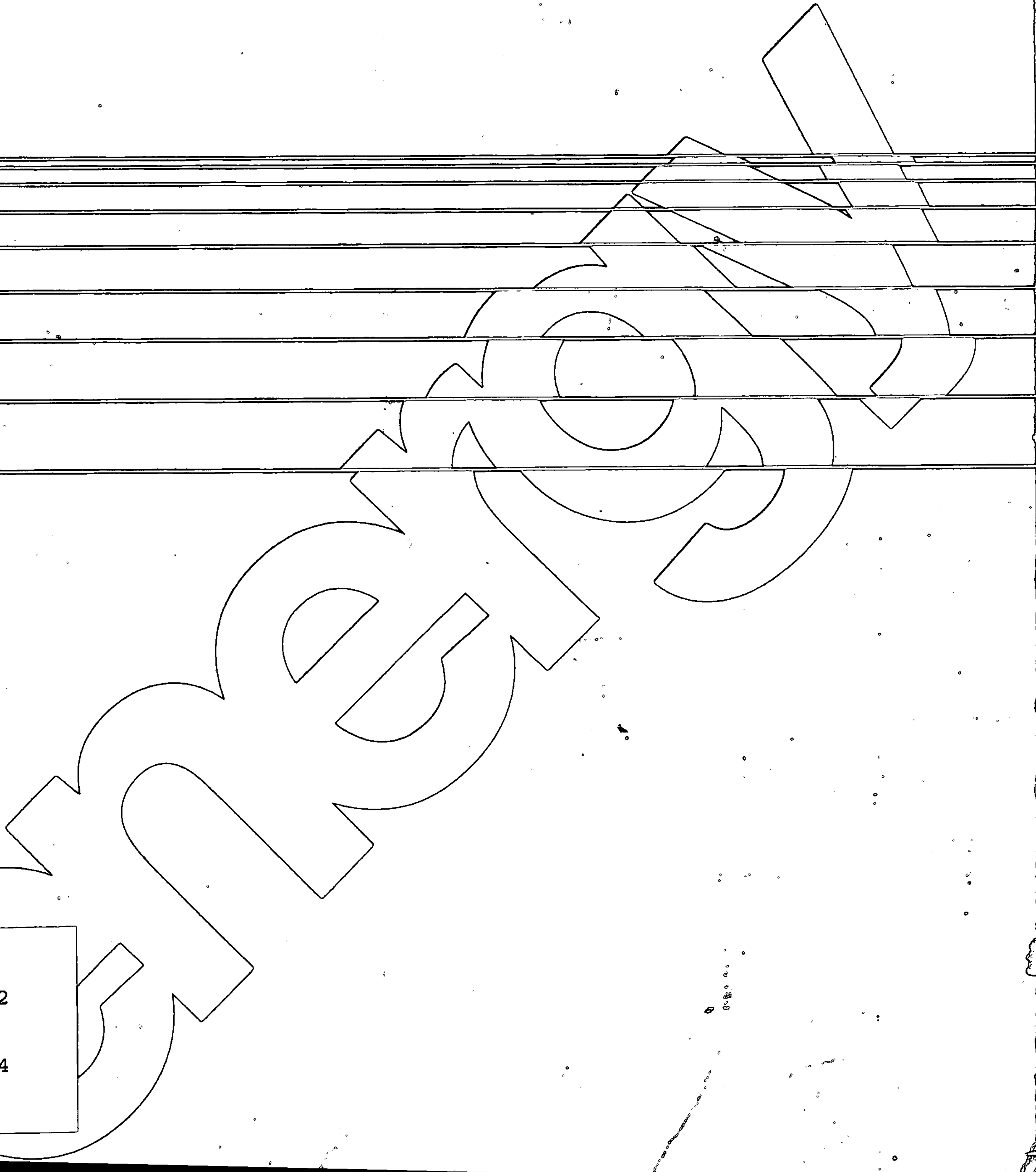

Energy and the Environment

By Asit K. Biswas Ph.D.
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Environment Canada
Planning and Finance Service
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Preface

This study was initiated by a request from the Science Council of Canada to prepare a report on the environmental consequences of energy development. Because of my personal interest in this area, I was given the task of preparing the report.

During the course of my research, I have had discussions with engineers, ecologists, economists, political scientists, sociologists, physicists, and environmentalists from both sides of the Atlantic. I have reviewed the extensive literature in this area, and only the most important ones have been referred to at the end of the report. Except for the diagrams and tables whose sources are explicitly noted in the text, the rest are based on my own analyses and computations. The report is primarily aimed at the scientific and university communities. However, a considerable portion of it should be of interest to anyone who wants further information on the subject.

This is the first of two reports on the subject in which I have attempted to define the problem. The second report will look to the future and discuss what steps are being taken and should be taken to alleviate environmental disruptions from energy development and use.

I have benefited much by my discussions with Dr. E. Roy Tinney and Dr. F. Kenneth Hare of the Planning and Finance Service of this Department, Dr. P. D. McTaggart-Cowan, Executive Director of the Science Council of Canada, and Mr. A. R. Scott of the Energy Department Sector of the Department of Energy, Mines and Resources, and for these I am grateful. I would also like to express my appreciation to my colleagues for their comments on an earlier version of this report: Dr. R. E. Munn and M. K. Thomas of the Atmospheric Environment Service, Dr. I. C. M. Place and J. H. Ross of the Environmental Management Service, Dr. T. Ingraham of the Environmental Protection Service, and Dr. H. F. Fletcher, T. de Fayer, B. Cook and D. R. MacKay of the Planning and Finance Service.

The opinions expressed herein, however, are my own and not necessarily those of my colleagues or the Department.

Asit K. Biswas
April 19, 1973

Contents

Introduction

The optimist proclaims that we live in the best of all possible worlds; and the pessimist fears this is true.

James Branch Cabell

Life as we know and understand it, without energy, would be unimaginable. Without energy, our entire civilization would come to a standstill, and would very quickly revert to a primitive stage. Without energy there would be no industrial or commercial activities or electricity, walking would be the only mode of transportation available, and our agricultural production would virtually stop. Buckminster Fuller has estimated that if we took away the whole industrial network of energy-consuming machinery in the world, half of humanity would die of starvation within six months.

Energy Requirements Through the Ages

Energy has long been viewed as an essential ingredient to stimulate and support economic growth and our standard living, so much so that often a nation identifies its well-being with its gargantuan and growing need for energy. As our civilization has advanced, so has the demand for energy, both cumulatively and on a per capita basis. For example, primitive man, some 1,000,000 years ago, used his muscles to provide him with the basic energy necessary, approximately 2,000 kilocalories per capita per day, to satisfy his limited wants and needs. As he devised some basic tools for hunting and discovered the use of fire, some 100,000 years ago, his energy requirements went up to about 4,000 to 5,000 kilocalories per capita per day. Around 5,000 B.C. he learned the rudiments of farming and the skills of harnessing the power of animals which increased his energy consumption to about 12,000 kilocalories per day. The advanced agricultural man, around 1,400 A.D., could harness the energy of falling water and wind, used animals for transportation and started to burn coal for heating. This increased per capita energy requirements to 26,000 kilocalories per day. With the advent of steam engines and the development of machines powered by them, energy requirements escalated to about 70,000 kilocalories per capita per day around 1870 A.D., for industrially advanced nations. With further developments of centralized power stations and internal combustion engines, energy consumption in North America, in 1970, has skyrocketed to about 230,000 kilocalories per capita per day (Cook, 1971). Energy consumptions of individual nations, however, differ greatly, and even within a same nation there are significant regional variations. Thus, industrially advanced nations of the world, representing only 30 percent of its population, currently consume approximately 80 percent of the world's energy. The United States alone consumes 30 percent but represents only 6 percent of the total population (Darmstadler, Teitelbaum & Polach, 1971).

Energy Flow Through Earth's Surface Environment

If we consider the flow of energy through the earth's surface environment, we have basically three main sources: solar radiation, terrestrial energy and tidal energy. The total solar radiation intercepted by the earth is approximately 1.73×10^{17} watts, of which 47 percent (8.1×10^{16} watts) is absorbed by the earth's surface and atmosphere and is converted into heat at the ambient surface temperature, 23 percent (4.0×10^{16} watts) is accounted for by the hydrologic cycle and the remaining 30 percent (5.2×10^{16} watts) is reflected back into space as short-wavelength radiation (Biswas, 1972).

The second source of energy is the flow of heat from the interior of the earth by conduction in rocks or by convection by hot springs and volcanoes. Conduction accounts for 3.2×10^{13} watts whereas convection produces only 1 percent of this amount (0.03×10^{13} watts).

The third source, tidal energy, is available to us due to the combined potential and kinetic energy of the earth, moon and the sun systems, and has been estimated at 3.0×10^{12} watts. Thus, the total power influx into the earth's surface environment is 17.3×10^{16} watts, of which the solar radiation alone accounts for 99.98 percent (Hubbert, 1969, 1971).

Energy contained in the fossil fuels is obtainable by oxidation whereas nuclear energy is released by the fissioning of certain isotopes at the upper end of scale of atomic masses, and by the fusion of others at the lower end. Conceptually, however, these two types of fuel are closely related. In contrast to fossil fuels which store the radiant energy initially produced by the nuclear reactions in the interior of the sun, nuclear fuels store energy from nuclear reactions in the interior of certain stars.[1]

Energy Cycle

Plants use solar energy to convert carbon dioxide and water into carbohydrates by the process of photosynthesis, and simultaneously release oxygen into the atmosphere. When they decay or are eaten by animals, the process is reversed. Over geologic period of time, extending back to the Cambrian period of some 500 million years ago, a fraction of these organisms became buried with great masses of sedimentary materials before complete oxidation. These materials underwent chemical changes and were transformed into fossil fuels: coal, oil, natural gas, lignite, etc.

The stored energy is released by oxidation. Only part of this energy, however, is available to us to perform useful work: most of it is returned to the atmosphere as heat and other by-products of combustion which are listed in Figure 1 in the relative order of their volumes. This energy cycle is shown diagrammatically in the Figure 1.

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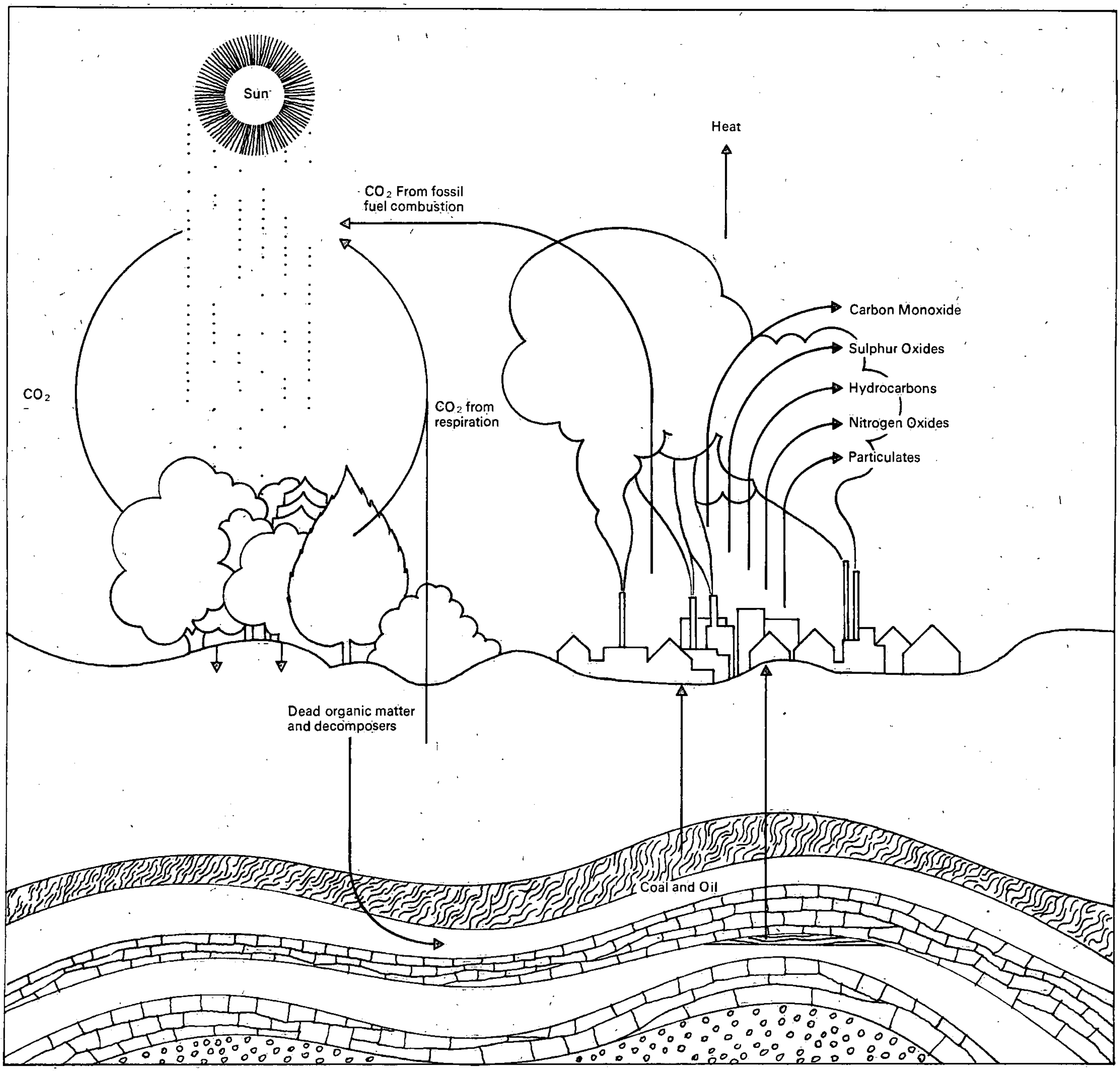
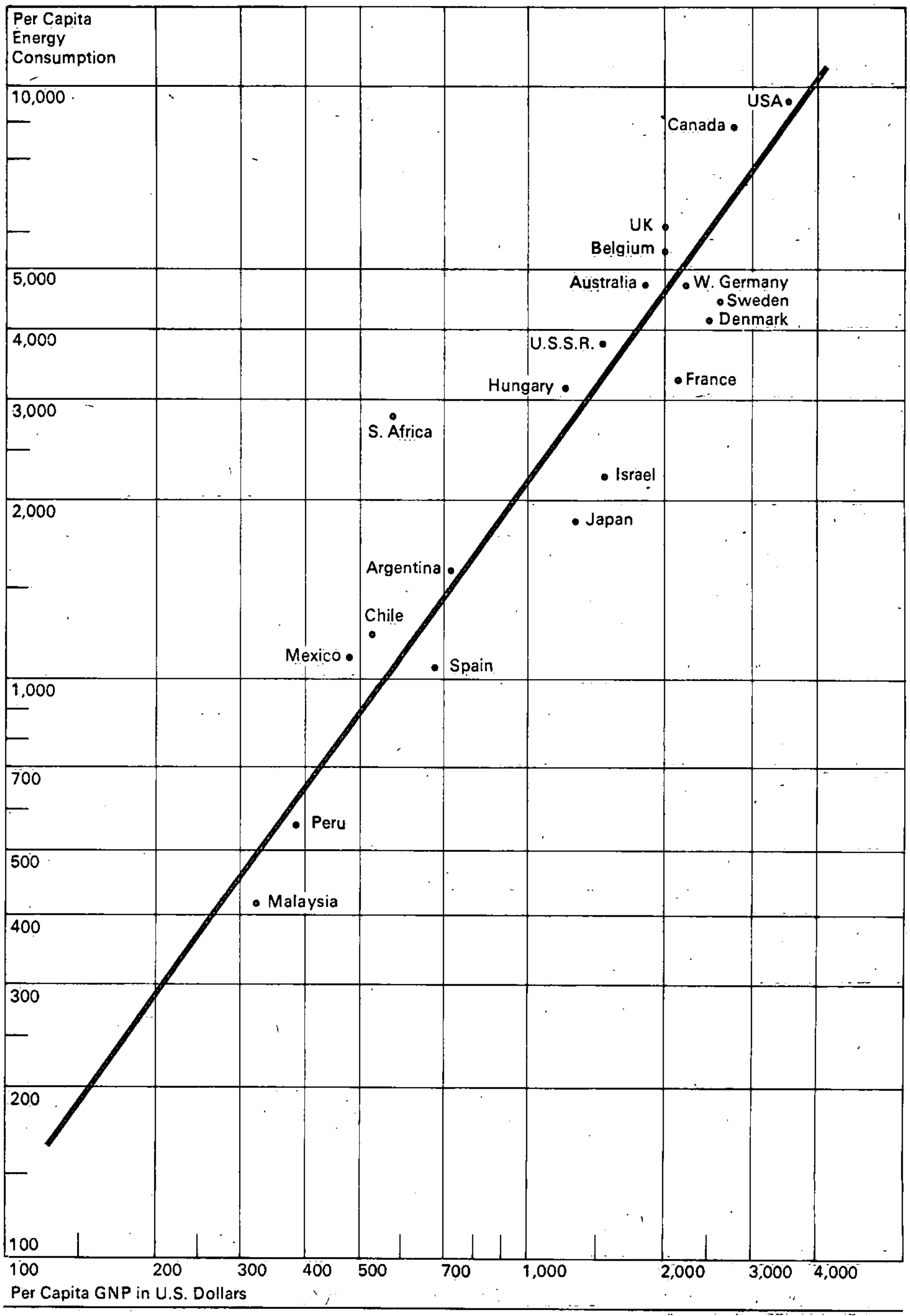
[1] As these stars exploded, they scattered into space the elements that had been synthesized within them. These elements went into the formation of younger stars such as the sun and its planets.

Figure 1 Energy Cycle



Energy, Economic Growth and Environment

Figure 2 Relation Between GNP and Energy Consumption per Capita, 1965



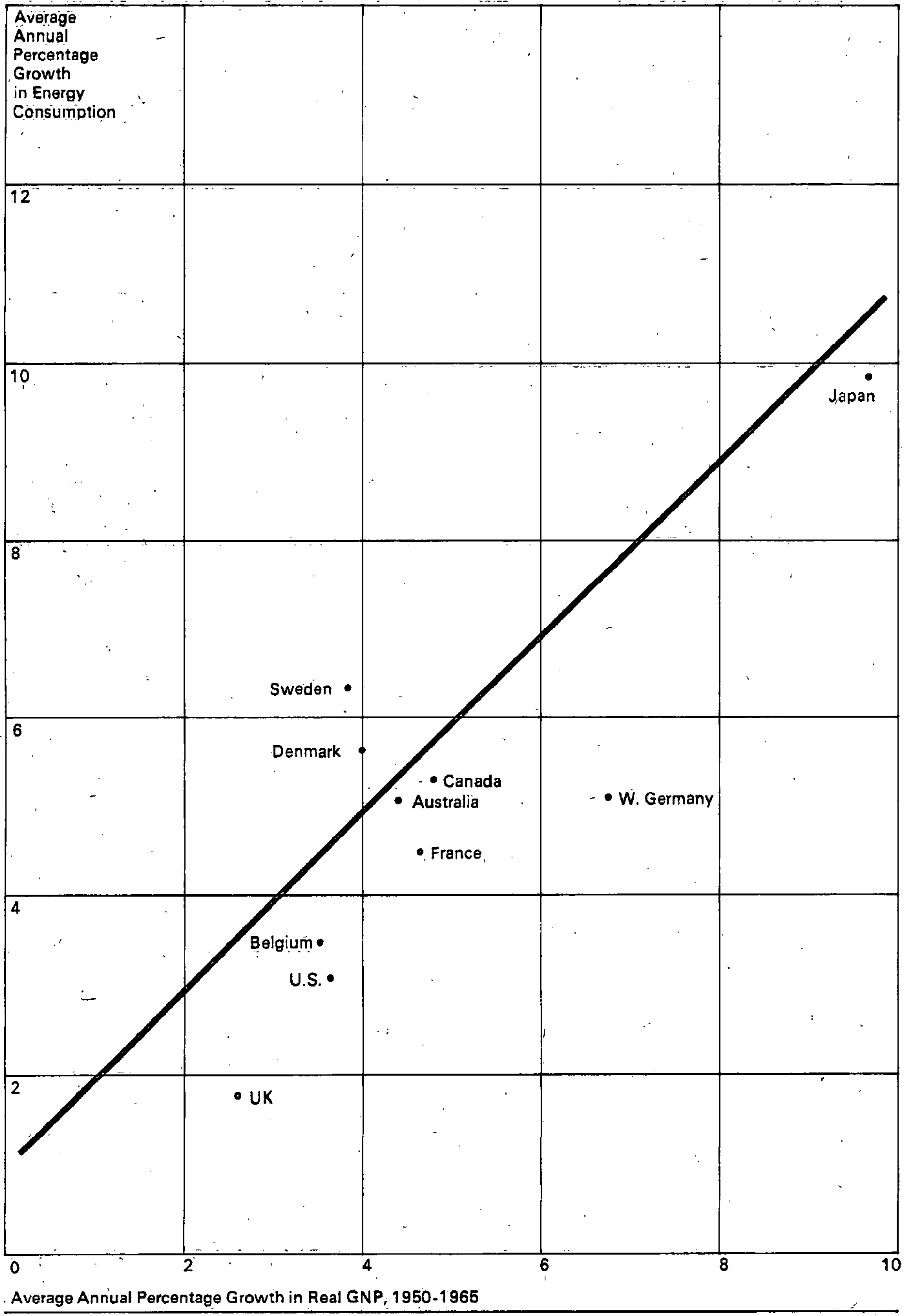
Energy and Economic Growth

Traditionally and historically, as countries have advanced economically, their energy consumptions and requirements have gone up as well, so much so that per capita energy consumption has often been taken as an index of wealth. If we compare the standard indicators of economic development, say for example, Gross National Product (GNP) which includes production of all goods and services within a region, and energy consumption, both in per capita terms, we find that they are closely interrelated. The close relationship has been valid historically, and analyses indicate that the correlation coefficients are uniformly and consistently high. Thus, as a country's GNP in real terms rises over time, its energy consumption has gone up as well, in close conformity, if not proportionately.

Even though there appears to be a close correlation between GNP and energy requirements, this relationship may be somewhat fortuitous rather than axiomatic due to several factors. Thus, the correlation between the two parameters should be interpreted with some caution. For example, the structure of the economy will affect the correlation between GNP and energy consumption, e.g., the rate of increase of GNP and energy use would be somewhat similar for energy intensive exports, but for non-energy intensive exports, GNP will increase at a much faster rate than energy use.

Figure 2 shows the relationship between per capita GNP and energy consumptions for 1965, for 20 different countries. At the top of the scale are the United States and Canada, both of which have high per capita GNP and equally high per capita energy consumption. If these

Figure 3 Relation Between Average Annual Percentage Growth in GNP and Energy Consumption, 1950-1965



statistics are presented in a somewhat different fashion, in terms of average annual percentage growths in real GNP and energy consumption, the relationships still remain remarkably similar. Figure 3 shows such relationships for the period 1950 to 1965 for 10 selected developed countries. In this case, Japan, which had a very high growth for these two indices for this period, is at the top of the scale, Canada occupies a somewhat middle position, and the United States and the United Kingdom are at the lower end of the spectrum.

The relationships between population, GNP, energy consumption and electricity consumption for different regions of the world are shown in Figure 4. Presented in a different fashion, Figure 5 shows the per capita GNP, energy and electricity consumption and energy per $1 of GNP, all in relation to the North American requirements, all of which have an index value of 100.[1] These two figures, however, should be interpreted with some caution. To cite one example, the mode of generating electricity could have a direct relationship on the primary energy requirements of a country. Thus, countries like East Germany and Czechoslovakia that use lignite, a thermally inefficent material for electricity generation, have rather high primary energy consumptions in relation to their GNP's.

From these two figures, it is evident that the North American shares of GNP, energy and electricity consumption are rather disproportionate to its percentage of the global population. In 1965, North America having less than 8.0 percentage of the global

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[1] Figures 2 to 5 and Tables 1 and 2 are based on data from Darmstadter, Teitelbaum and Polach (1971).

Figure 4

Regional Distribution of Population, GNP, Energy and Electricity Consumption, 1965

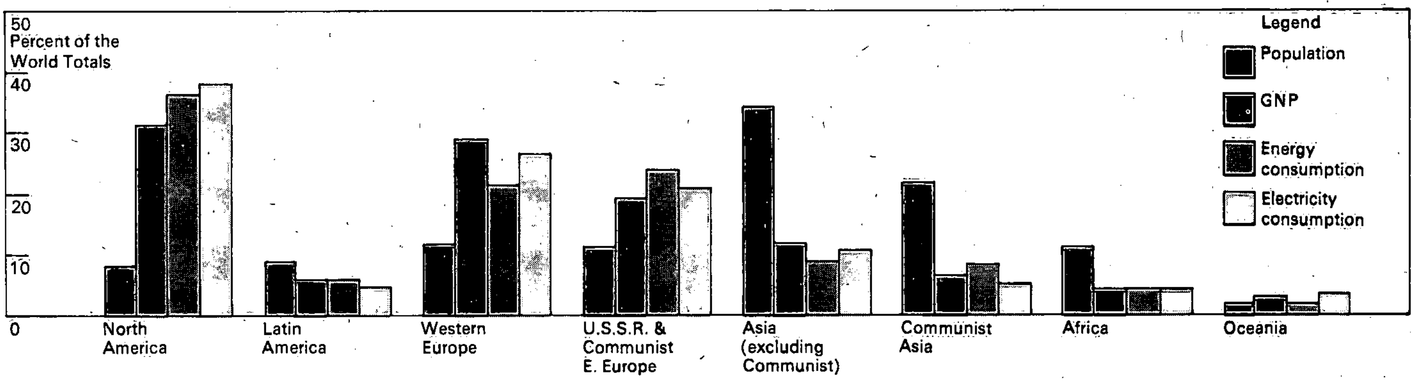

Figure 5

Per Capita GNP, Energy and Electricity, and Energy Consumption Relative to GNP, 1965

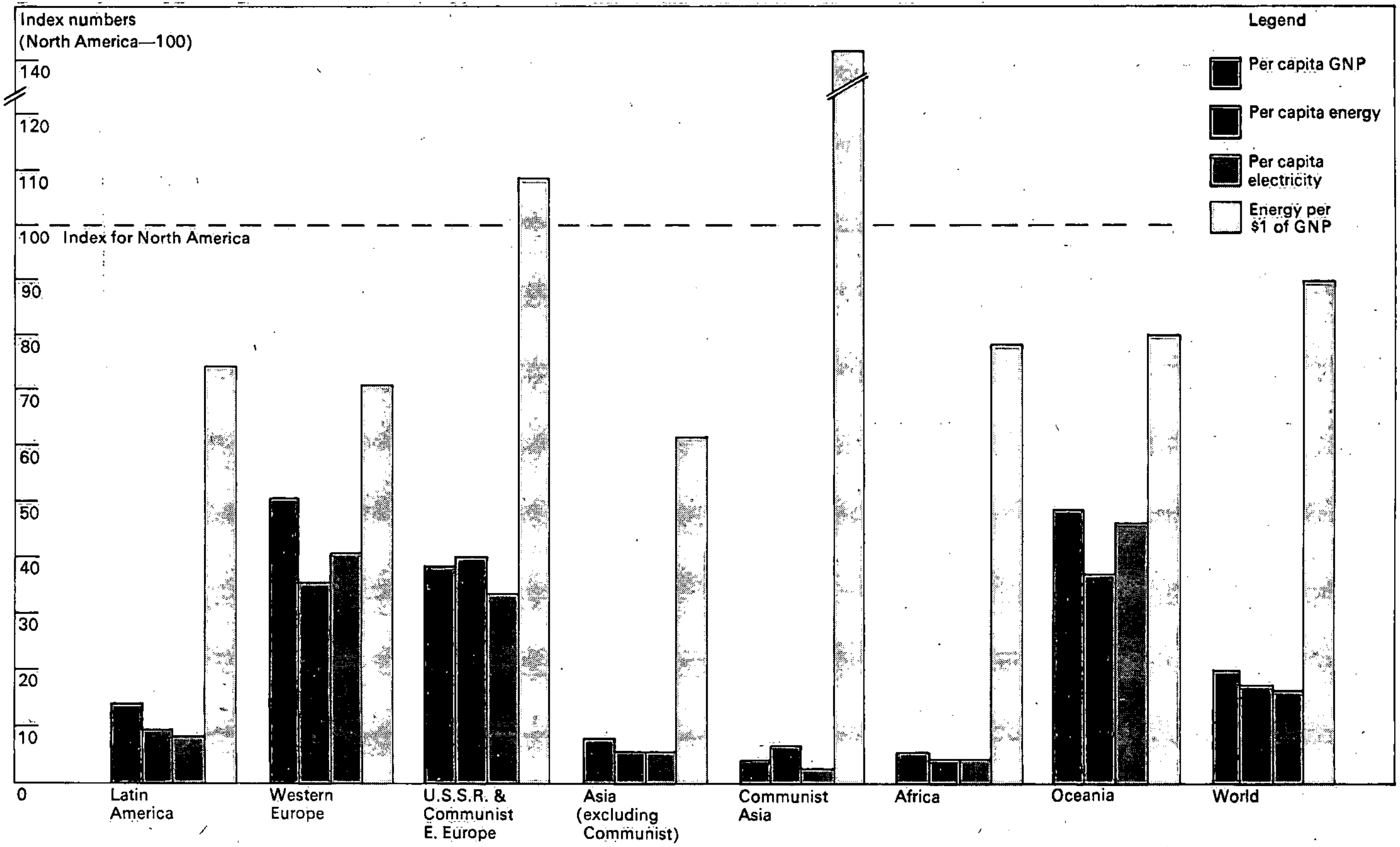

Table 1 Energy-GNP Relationship, 1925-1965

	Ratio: energy consumption per $1 of GNP (kilograms coal equivalent)						1925-1965			1950-1965		
							Average annual percentage rate of growth			Average annual percentage rate of growth		
Country	1925	1935	1950	1955	1960	1965	Energy consumption	GNP	Energy-GNP elasticity coefficient	Energy consumption	GNP	Energy-GNP elasticity coefficient
Canada	2.91	2.73	3.03	2.70	2.75	3.04	4.1	4.0	1.03	5.1	4.5	1.13
United States	3.62	3.13	3.05	2.82	2.87	2.75	2.4	3.1	0.77	3.0	3.7	0.81
Sweden	1.07	1.47	1.34	1.60	1.76	1.85	4.9	3.5	1.40	6.2	3.9	1.59
Denmark	1.38	1.49	1.42	1.77	1.55	1.78	3.7	3.0	1.23	5.5	4.0	1.38
Switzerland	0.76	0.84	0.75	0.81	0.97	1.16	4.0	2.9	1.38	7.7	4.7	1.64
West Germany	n/a	n/a	2.67	2.41	2.00	2.11	n/a	n/a	n/a	5.2	6.8	0.76
France	1.73	1.80	1.58	1.55	1.51	1.57	1.9	2.2	0.86	4.7	4.7	1.00
Norway	1.77	1.68	1.55	1.66	1.76	1.80	3.3	3.3	1.00	5.1	4.1	1.24
United Kingdom	3.89	3.33	3.17	3.23	2.78	2.66	1.2	2.1	0.57	1.8	2.9	0.62
Australia	n/a	n/a	2.16	2.29	2.32	2.46	3.6	n/a	n/a	5.1	4.2	1.21
East Germany	n/a	n/a	3.91	3.90	3.55	3.54	n/a	n/a	n/a	4.4	5.0	0.88
U.S.S.R.	0.56	1.80	2.32	2.56	2.67	2.85	9.3	4.9	1.90	7.4	5.9	1.25
Israel	n/a	n/a	1.40	1.67	1.34	1.70	n/a	n/a	n/a	12.1	10.7	1.13
Japan	1.32	1.58	1.57	1.47	1.54	1.58	4.7	4.2	1.12	9.9	9.9	1.00
South Africa	n/a	n/a	4.86	5.36	5.22	5.16	4.6	n/a	n/a	5.1	4.7	1.09
Mexico	n/a	n/a	2.06	2.15	2.48	2.33	4.8	n/a	n/a	6.9	6.1	1.13
World	n/a	n/a	2.38	2.36	2.40	2.47	3.3	n/a	n/a	5.1	4.8	1.06

n/a—not available.

population, accounted for 33 percent of the world GNP for which it needed 37 percent of the world's energy and 39 percent of electricity. By comparison, Africa's share of the world GNP and energy consumption is between 1.5 to 2.0 percent, and, if we consider the developing countries as a whole, their total share of the global energy and electricity is somewhat less than 10 percent—even though they account for half of the world's population. This can be partly explained by the agricultural-industrial mix of the developing countries which has a direct bearing on energy consumption. Generally, agriculturally-based countries require less energy than their more industrial counterparts. The fact, however, still remains that countries having high per capita income tend to use disproportionately high per capita energy.

These data, however, can be portrayed differently. Table 1 shows the energy-GNP relationship for 10 different countries as well as for the whole world for the period 1925 to 1965. It also shows the energy-GNP elasticity coefficients which may be defined as percentage growth in energy consumption over a predetermined time period for each percentage point increase in GNP. Table 2 indicates the energy-intensiveness of national economies. Obviously these two parameters, elasticity and energy-intensiveness, are interrelated. For example, if the rate of growth of energy consumption is higher than the GNP growth rate, the elasticity coefficient will be greater than 1.0 and the energy consumption rate per $1 of GNP will also rise.

An interesting aspect of Canada's energy consumption emerges from these two tables. Even though the per capita GNP in the United States is 32 percent above Canada, we use 10.5 percent more energy than United States to produce per $1 of GNP. The contrast is worse if we compare Canada and Denmark. Denmark's per capital GNP is only 12 percent less than Canada's, and yet their energy consumption per dollar of GNP is 41.5 percent less than ours. These anomalies can possibly be explained by three factors. To start with, climate plays an important part on the primary energy requirements of a country. For similar income levels, a colder region will consume more energy due to heating requirements than a more temperate region. However, it is unlikely to be a major factor in explaining the significant differences in

Table 2 Per Capita GNP and Energy Consumption, and Energy Consumption per Dollar of GNP, 1965

	GNP per capita		Energy Consumption			
			Per capita		Per dollar of GNP	
Country	U.S. Dollars	Rank	Kg coal equiv.	Rank	Kg coal equiv.	Rank
United States	3,515	1	9,671	1	2.75	5
Canada	2,658	2	8,077	2	3.04	3
Sweden	2,495	3	4,604	7	1.85	10
Denmark	2,333	4	4,149	8	1.78	12
Switzerland	2,331	5	2,699	13	1.16	16
West Germany	2,195	6	4,625	6	2.11	9
France	2,104	7	3,309	11	1.57	15
Norway	2,015	8	3,621	9	1.80	11
United Kingdom	1,992	9	5,307	4	2.66	6
Australia	1,910	10	4,697	5	2.46	7
East Germany	1,562	11	5,534	3	3.54	2
U.S.S.R.	1,340	12	3,819	10	2.85	4
Israel	1,325	13	2,248	14	1.70	13
Japan	1,222	14	1,926	15	1.58	14
South Africa	535	15	2,761	12	5.16	1
Mexico	475	16	1,104	16	2.33	8

energy consumption between the countries mentioned. Probably more likely causes are the difference between the industrial mixes of the countries or our inefficient energy generation and use practices or both. Canada, partly because of historic low-cost hydroelectric energy availability, has energy-intensive industries, i.e., pulp and paper, mining, metallurgy, and chemicals, which require high energy content per unit of output.[1] These industries account for nearly 30 percent of Canada's value added in manufacturing but their share within Denmark's manufacturing sector is substantially less. Finally, Canada's physical size and the distance between main population centres contribute considerably to her high per capita use of energy.

Table 1 also points out another interesting phenomenon. During the period 1925 to 1965, the energy-GNP elasticity coefficient for Canada is 1.03, i.e., the average annual percentage growths for GNP and energy consumption were very similar. However, if we consider a somewhat smaller time frame toward the end of this period, say 1950 to 1965, the elasticity coefficient is 1.13, full 10 percentage points higher than the overall period. The corresponding figures in the U.S. are 0.77 and 0.81 respectively, a 5.0 percent rise which is approximately half of the Canadian increase. If we consider a still smaller period, 1960 to 1965, our energy-GNP elasticity coefficient increases still further. This indicates that our average annual percentage rate of growth in energy consumption is increasing much more rapidly than our average annual growth in real GNP, and there is every indication that the divergence of the growth rates will continue to increase, at least in the near term. A similar trend can be discerned in the U.S., but our elasticity coefficient is increasing at a much faster rate than that of our southern neighbour.

Energy and Environment

Ever since the industrial revolution which was accomplished with the use of energy from fossil fuels–mainly coal–a comforting all-embracing panacea had been that economic growth is the key to most social problems. This widely-held concept has not only been somewhat discredited in the recent years, but also the medicine itself, growth, has been blamed for some of our environmental illness. In many instances the past is catching up with us, and considering the rate at which we have made economic and technologic progress, it should not come as a surprise to any of us.

[1] For example, in contrast to textile and food-processing industries which require 1.80 and 1.30 kg energy (coal equivalent) per $1.00 of value added, basic metals, chemicals and papers require 3.60, 3.90 and 6.30 kg energy respectively. (United Nations, 1967)

Even though the energy industry is one of the largest and most broadly spread industries in Canada, the environmental consequences of energy production, conversion and use can be described as a relative newcomer as an area of major national concern. Before the present era of environmental awareness, our society as a whole placed an overriding priority on the first-order effects of technology and economic growth. Consequently, if there was a conflict between increased energy production, or any other type of production, and the necessity of minimizing the pollution of our biosphere, it would have been resolved in favour of higher production in most cases almost as a routine procedure. The secondary effects like environmental pollution would have been taken in stride.

Times are changing, societal values and norms are shifting significantly from an automatic acceptance of economic growth for its own sake toward a deep concern and better understanding of environmental and social consequences. In the field of energy growth, within a short time span of a few years, societal concern with the protection of the quality of the environment has grown significantly in terms of public awareness, policy implications and the urgency and complexity of the research problems posed.

Thus, our "environmental crisis" with relation to energy growth is due partly to increasing levels of pollution and partly to our increasing perception of pollution resulting from the society's need or demand for a better quality of life, which, in turn, is a by-product of our increasing levels of affluence and education. This shift in value toward a better environment has gradually begun to permeate the political process, and is reflected in our Energy Minister, Donald Macdonald's statement that "one of the most important issues confronting us today in the energy and mineral policy field is that of environmental protection", or in President Nixon's suggestion that we need "the blessings of both a high-energy civilization and a beautiful and healthy environment".

Since there are no total environmentally-clean forms of energy sources available, our exponential growth in energy requirements has precipitated concomitant environmental pollution problems. Population growth has certainly been a factor in this increase, but a more critical factor has been the per capita increase in energy use, so much so that a U.S. study attributes only 20 percent of the increase to population growth and the remainder, a staggering 80 percent, to increased use per individual (Smith, 1971).

These developments have created a difficult dichotomy. On one hand, after decades of sustained growth, our current energy requirements are increasing at an even faster rate than in the past, and on the other we are intensely concerned with protecting the environment from the deterioration which the development, distribution and use of energy can create. Since we do not have an environmentally clean source of energy at present, increase in energy consumption will invariably create additional environmental degradation. The degree of this degradation, however, will be dependent on the steps taken to reduce environmental pollution. Another factor worth remembering is that if we reduce total pollution from energy sources by 10 percent and the total energy requirement goes up by 10 percent, then the total cumulative effect on the environment will reduce by a meagre 1.0 percent. In other words, to paraphrase Lewis Carroll, it will take all the running to keep in the same place.

It should also be noted that our current pollution control regulations will further increase the demand for energy. It has been estimated that the installation of electrostatic precipitators to eliminate up to 99 percent of the stack emissions of fly ash and solid particulates of thermal power plants can consume more than 5.0 percent of their capacity (Friedlander, 1970; White, 1971). Introduction of new emission control regulations for automobiles will increase gasoline consumption. Thus, energy can have a positive impact on the environment.

The basic philosophy that will be followed in the remainder of this report is that our energy policies and environmental concerns, in a very real sense, are cut out of the same cloth. We have to seriously consider energy conservation practices and increase the efficiency of energy production and utilization processes[1] to reduce our rapidly escalating energy requirements, at least in the near and medium terms, and until better and adequate sources of clean energy are available. This, in turn, will alleviate much environmental disruption.

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[1] It is important to distinguish between policies designed to conserve available resources of energy and policies designed to limit the growth of energy use for environmental reasons, since the policies may be quite different. For example, limited resources availability might lead to minimizing the use of natural gas. On the other hand, minimizing the environmental effects of energy use might well lead to maximizing the use of natural gas

Environmental Concerns

Every state of energy development and utilization has an impact on the environment. These impacts range from small and insignificant ones at the lower end of the spectrum to very large ones that are almost unmanageable or, at best, very costly to control. In general, the status of our technological development and the nature of our disposal practices define the level of impact. These inter-relationships become clear if we consider the elementary law of conservation of matter in an environmental sense, that is, in an ultimate sense we really do not consume any material: we simply change them from usables to residuals which are then discharged into the environment in some fashion.

In order to obtain a macro picture of the environmental impacts from our energy industries, we will have to consider the patterns of energy use in Canada, especially the types and quantities of fuels used for energy consumption at present and their possible composition in the future. We will also have to determine the environmental impacts of each type of energy conversion system, preferably in a matrix form. Such environmental impact analyses, however, are difficult to make, and are somewhat subjective in nature (Coomber and Biswas, 1973). Thus, a macro picture of the total environmental impact of any of our energy industries can be obtained, at least conceptually, by the multiplication of the market share of that industry with its environmental disruptions matrix.

Patterns of Energy Use in Canada

Figure 6 shows the current energy conversion systems available as well as certain systems that can be used under special situations and possible new systems which may be available by the year 2000 due to further technological developments and breakthroughs.

At present, in Canada, we use water, wood, coal, petroleum, natural gas and fissile fuels for energy generation. At the present state-of-the-art, there are also possibilities of using some special situation conversion systems, especially tidal power at the Bay of Fundy, wind and geothermal energy, and energy from solid wastes.[1] Their cumulative share of our total energy consumption is unlikely to be high in the near and medium terms. One salient point, however, is becoming self-evident, that is, increasingly more complex technological advancements are being introduced in practically all phases of energy conversion processes as our traditional fuel sources are being depleted or are becoming unacceptable because of environmental reasons.

The composition of our primary energy sources has steadily changed in the past and there is every reason to expect that they will do so again in the future. These changes are primarily due to technological developments, economic considerations, fuel availability and environmental and social constraints. Thus, if we consider the contribution of wood to primary energy consumption in Canada, it was nearly 12 percent in 1945. Since then, its share of the market has steadily declined (see Figure 7), both in absolute and percentage composition terms (only 2.0 percent in 1969). During the same period, the share of hydropower[2] has increased, in absolute (by 300 percent) as well as percentage (by 3.16) terms. Coal, which provided 58.1 percent of the primary energy in 1945, has steadily lost ground to oil, and, by 1969, their respective shares of the market were 13.6 percent and 52.7 percent. The use of oil almost doubled in absolute terms during 1945 to 1950.

Figure 6
Present and Future Energy Systems

Current Systems
Hydroelectricity
Fossil Fuels
  Coal
  Petroleum
  Natural gas
Fissile Fuels

Advanced Systems
Fissile Fuels–Breeder Reactors
Solar Energy

Developing Systems
Fusionable Fuels–Fusion Reactors
Magnetohydrodynamics
Hydrogen

Special Situation Systems
Tidal Energy
Geothermal Energy
Wind Energy
Energy from Solid Wastes–Oil, Heat and Electricity

The use of natural gas, during the same period, has also steadily increased. Originally gas was viewed only as a by-product of oil production, and was considered to be of little value. Sometimes it was used locally, and mostly it was flared into the atmosphere. Its tremendous potential as an excellent additional source of energy was realized after the Second World War (Winger *et al*, 1972). Its good combustion characteristics and exceptionally low price rapidly accelerated its acceptance

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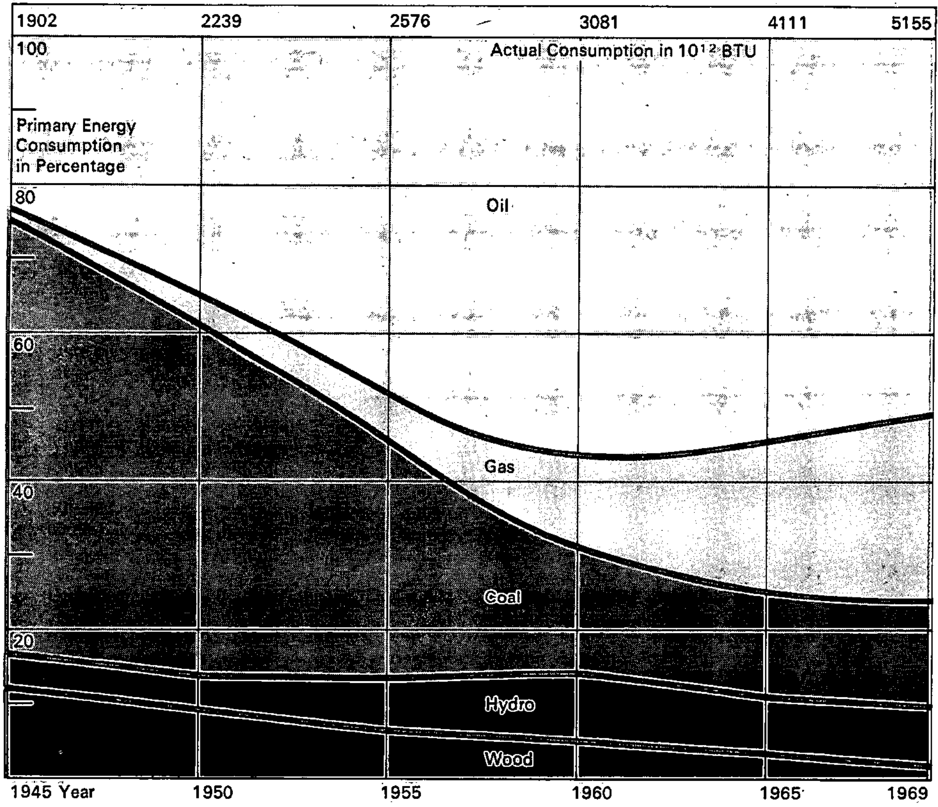
[1] For a detailed analysis of possible energy generation from solid wastes, in terms of heat, oil or electricity, see Biswas and Jacobs (1972).

[2] For the derivation of Figure 7, hydro's output equivalent is assumed to be 3,412 BTU's per kwh. This figure has come under some criticism lately.

Figure 7 Changing Pattern of Canada's Primary Energy Consumption



and use, and by 1963, it had replaced coal as the second largest source of energy in Canada. Current projections of our gas, oil and total energy requirements, as forecasted by the National Energy Board, for 1975 and 1990 are shown in Figure 8.

Nuclear power, our latest form of energy, has not made any impact on our energy market yet, its current share still being a fraction of 1.0 percent. However, our rapidly escalating energy requirements and significant advances in nuclear power technology, including environmental control, will ensure that nuclear energy will increasingly become a more important source in the future. The Economic Development Committee of the Canadian Nuclear Association forecasts that our nuclear generating capacity will increase from 1,200 MWe in 1971 to 2,500 MWe in 1975, 7,000 MWe in 1980, 16,000 MWe in 1985 and to 35,000 MWe in 1990. In other words, it is suggested that within a short period of 20 years there would be as much nuclear generating capacity in Canada as there is total generating capacity today.

Environmental Pollution by Types of Energy Conversion

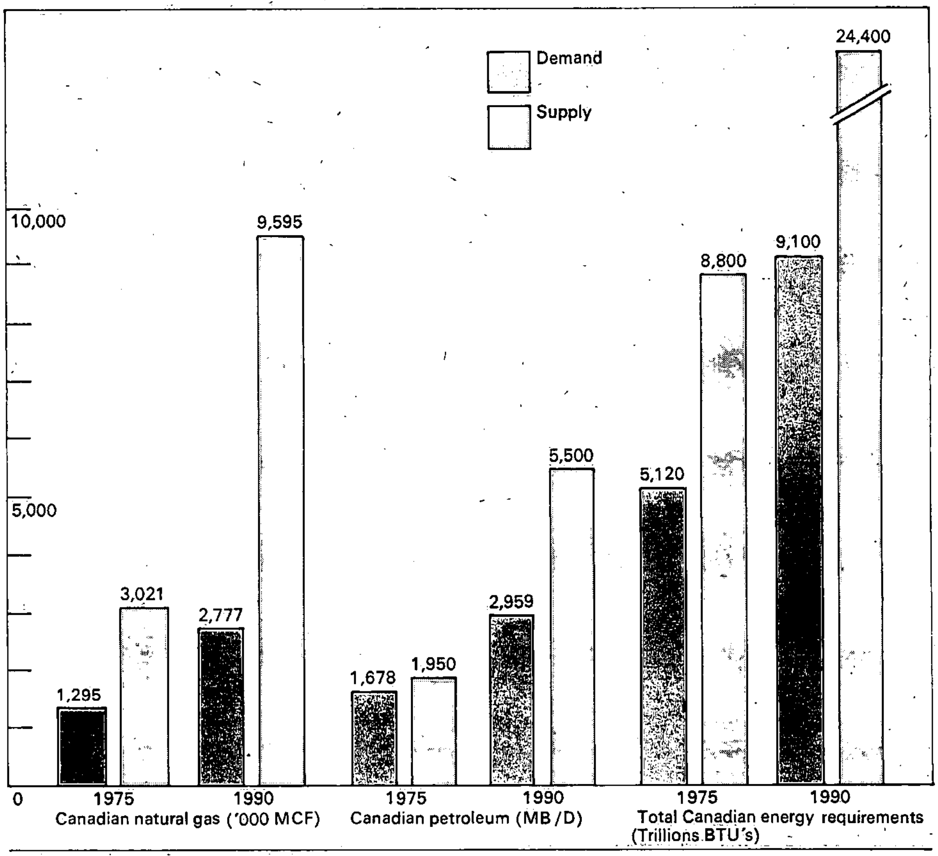
All primary fuels as well as hydroelectric power have definite characteristics associated with them, and, hence, their consumption presents different types of potential hazards to our environment. The potential pollution problems from coal, oil, gas, hydro and nuclear fuels will be examined herein.

The potential pollution hazards from coal, at different stages of its energy conversion process, are shown in a matrix form in Figure 9. It shows the impacts on air, water, land and solid wastes at each stage of the energy conversion process—exploration and extraction, upgrading, transportation and utilization. During the exploration and extraction phase, the worst environmental impacts are due to acid mine drainage, strip mining damage and production of large quantities of solid wastes[2]. In addition, the fine coal suspended in the slurries of the preparation plants is difficult to recover, and is often discharged to streams creating turbidity and sedimentation problems. In the actual utilization phase, the main problems arise from thermal pollution, gaseous emissions and disposal of fly ash and slag. Current data indicate that a modern 1000-MWe power plant, burning 9,000 tons of coal per day, containing 3.33 percent sulphur, will produce 3,000 tons of carbon dioxide, 600 tons of sulphur dioxide and 80 tons of nitrogen dioxide into the atmosphere during the same time period (Sporn, 1971).

Oil produces different types of waste products than coal as shown in a comparable matrix form in Figure 10.

[2] For a detailed analysis of environmental problems associated with coal mining, see Perry (1971).

Figure 8 Canadian Energy Supply and Demand, 1975-1990



With a phenomenal increase in our offshore exploration programs for crude oil, especially during the past few years, the cumulative probability of accidental oil spill (as the Santa Barbara incident) is increasing all the time. The main pollutant, however, at the extraction phase is the brine which is brought to the surface along with crude oil. It is often reinjected into subsurface strata which could seriously contaminate groundwater. For example, one barrel of brine containing 1,000 ppm sodium chloride will render approximately 400 barrels of fresh water unpotable. The liquid and solid wastes produced during the upgrading phase are difficult to dispose of in an environmentally acceptable manner, and considerable research has to be undertaken before these by-products can be recycled.

From an environmental viewpoint, as evident from the pollution-matrix shown in Figure 11, natural gas is one of the better forms of energy available. Not surprisingly, the gas industry probably has the best environmental practices among all energy industries. Usually hydrocarbons having higher molecular weight, i.e., ethane, propane and butane, have to be removed from natural gas and then processed and shipped separately. When hydrogen sulphide is present, it is removed as well, and sold as elemental sulphur. It has been estimated that 15 percent of sulphur marketed in the U.S. in 1970 came from this source. In addition, if natural gas contains commercial quantities of hydrogen and helium, they are also removed and marketed.

Mining of nuclear fuels, as in coal mining, produces a large quantity of solid waste (Figure 12). The uranium miners, in addition to the usual mining hazards, also face another major occupational hazard, i.e., a high incidence of carcinoma of the lung probably due to airborne radioactive radon daughters. The tailing dumps, unless cared for in perpetuity, can create problems because of their radium content. During the actual energy generation process, nuclear reactors do not produce any particulates, and since the combustion process is absent during heat release, there is no problem of environment pollution from the formation of oxides of carbon, nitrogen or sulphur. They do, however, create two rather unique environmental problems. Firstly, they contribute to significantly greater thermal pollution because of the low temperature at which light water reactors are forced to operate. A modern and efficient conventional fossil-fuelled power plant converts nearly 40 percent of the heat energy of combustion to electricity, and the remainder is released to the environment—45 percent to cooling water and 15 percent to the atmosphere through the smoke stack. By comparison, a nuclear power plant converts only 30 percent of the input energy to electricity and the remainder, 70 percent, is

Figure 9 Energy from Coal–Potential Environmental Damage

	Air	Water	Land	Solid Waste
Exploration and Extraction	Fuel combustion products Waste pile fire	Acid mine drainage Leaching of waste piles Erosion and silting of watercourses	Strip mining effects Land subsidence	Underground mining waste
Upgrading	Particulates from fine coal drying Waste bank fires	Plant effluents Leaching of waste piles		Coal cleaning waste Sulphur
Transportation				
Utilization	*Power Plant* Carbon dioxide Sulphur oxides Nitrogen oxides Particulates *Coke oven* Particulates Hydrogen Sulphide Carbon Monoxide Hydrocarbons	Thermal discharges	Aesthetic pollution of landscape	Fly ash and slag Failure of slag heaps

Figure 10 Energy from Oil–Potential Environmental Damage

	Air	Water	Land	Solid Waste
Exploration and Extraction	Fuel combustion products	Drilling accidents Brine disposal		
Upgrading	Sulphur oxides Nitrogen oxides Carbon monoxides Hydrocarbons	Thermal discharge Sulphuric acid Spent caustic		Spent phosphoric acid catalyst Spent clay
Transportation	Power sources	Oil Spills	Pipeline accidents Effect on permafrost	
Utilization	Emissions from internal combustion engines Sulphur oxides Nitrogen oxides Particulates	Thermal discharge Used oil disposal		

Figure 11 Energy from Gas–Potential Environmental Damage

	Air	Water	Land	Solid Waste
Exploration and Extraction				
Upgrading				
Transportation	Nitrogen oxides at compressor stations		Pipeline problems	
Utilization	Thermal discharge Nitrogen oxides			

Figure 12 Energy from Nuclear Fuels–Potential Environmental Damage

	Air	Water	Land	Solid Waste	Radiation
Exploration and Extraction		Waste banks leaching Uranium mine water	Strip mining effects	Underground mining wastes	Exposure to miners
Upgrading	Particulate emission	Waste banks leaching		Ore dressing waste	Exposure to plant workers
Transportation			Transmission lines		Possible accidents
Utilization	Radiation fallout	Thermal discharge		Waste disposal from fuel processing plants	Exposure during generation and disposal of wastes Possible accidents

Figure 13 Energy from Hydro–Potential Environmental Damage

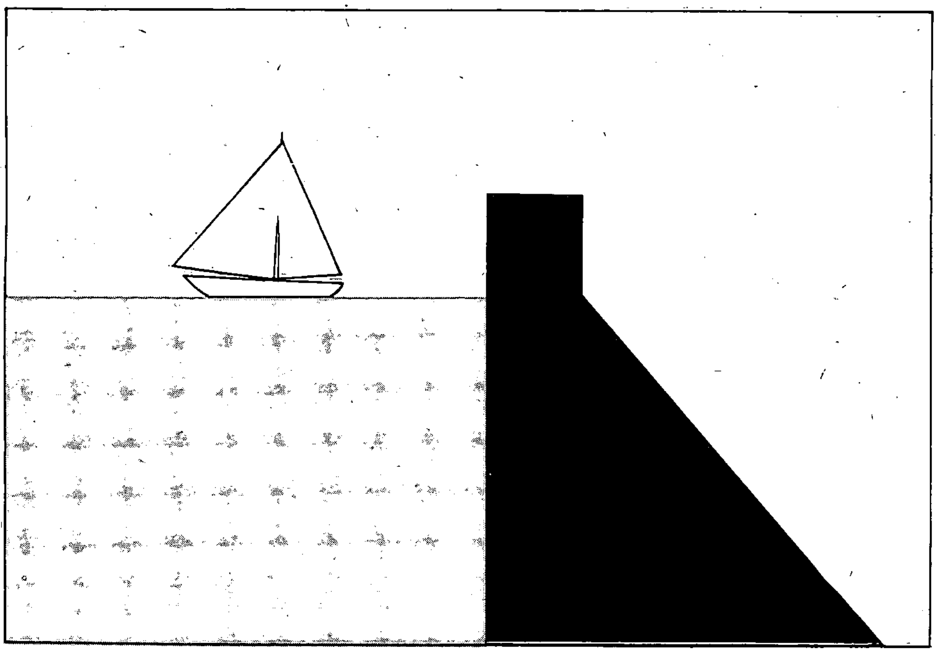
	Air	Water	Land	Other
Exploration and Extraction				
Upgrading				
Transportation			Transmission lines	
Utilization	Micro-climate Evaporation	Changes in water quantity (level, discharge, velocity, groundwater and losses) and quality (sediments, nutrients, turbidity, salinity and temperature)	Flooding Submerged Land Loss of Animal Habitat Landslides Earthquakes Drawdown Zone	Food Chain Repercussions Disease Vectors Submerged Vegetation Benthos Aufwuchs Zooplankton Phytoplankton

released to cooling water. Secondly, they create a number of radioactive pollutants like the Noble gases (Ar^{41}, fission Kryptons and Xenons), iodines, tritium oxide, Cesium 137, alkaline earths and particularly Strontium 89 and 90, and spent fuel rods which still contain over 90 percent of potential nuclear fuel. The impacts of these radioactive waste products will be discussed in a later sub-section.

The last but not least form of energy generation is hydroelectric power. In Canada, nearly 74 percent of our electricity is generated by hydro power, and, hence, our utilities are often known as "hydro" and the terms "hydro" and "electricity" are often used synonymously. Figure 13 shows the potential environmental problems associated with hydro power in a matrix form. Since with hydro power we do not really have exploration and extraction, upgrading and transportation phases like other types of energy conversion systems discussed before, the total environmental problems created are presented in a somewhat different but comprehensive format. Figure 14 shows the impact of hydroelectric developments on the physical, biological and human systems.

Environmental damages arising from the construction of hydroelectric dams are many and they have far-reaching effects. Their interactions are so complex and so little understood that ecologists and environmentalists cannot predict them with any degree of certainty. Our current knowledge of the ecology of man-made lakes leaves much to be desired, and unless planning precedes construction by 5 to 10 years, many things will go wrong and several unpredictable and unforeseen situations will develop, some beneficial and some adverse. With our present practices, ecologists often find it impossible to influence and convince engineers, economists and politicians against certain developments or of the necessity of incorporating remedial measures because of the lack of hard facts or solid scientific evidence. In addition to these difficulties, adequate environ-

Figure 14 Environmental Implications of a Hydro Dam



Physical System

Hydrologic System
- Water Quantity
  - Level
  - Discharge
  - Velocity
  - Groundwater
  - Losses
- Water Quality
  - Sediments
  - Nutrients
  - Turbidity
  - Salinity
  - Temperature stratification

Atmospheric System
- Evaporation
- Micro-climate

Crustal System
- Geology (soil, mineral content, structure)
- Earthquake

Biological System

Aquatic Ecosystem
- Benthos
- Aufwuchs
- Zooplankton
- Phytoplankton
- Fish and Aquatic Vertebrates
- Plants
- Disease Vectors

Terrestrial Ecosystem
- Submerged Land and Vegetation
- Drawdown Zone
- Zone Above High Water Level
- Failure Impacts
- Loss of Animal Habitat
- Food Chain Repercussions

Human System

Production System
- Agriculture
- Fishing and Hunting
- Recreation
- Energy
- Transportation
- Manufacturing

Social System
- Anthropological Effects
- Political Implications
- Social Costs

mental considerations have most often been lacking for some of our major water development projects[1]. An outstanding example is the near-disaster on the Peace-Athabasca Delta, where low water levels due to the construction of an upstream dam and a series of drought years resulted in serious consequences to the local flora and fauna.

Environmental Impacts

The environmental impacts of energy industries will be considered under five major headings: atmospheric emissions, thermal pollution, oil pollution, landscape aesthetics and radionuclear pollution. It should be noted that the five headings under which environmental impacts will be discussed is somewhat restricted in order to keep this report within bounds.

Atmospheric Emissions

For a modern industrial nation like Canada, energy production from fossil fuels represents an enormous amount of combustion with attendant effects on the environment. The substances that are injected into the atmosphere include carbon monoxide and dioxide, sulphur oxides, hydrocarbons, nitrogen oxides, particulates and heat. The major sources of production of these emissions are automobiles, industry, power plants, space heating and incinerators. These pollutants may be segregated roughly into two groups. The first group has a more or less direct toxic effect on the biological environment, the overall impact being dependent on the nature and amount of the emission and on the local dispersion characteristics of the

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[1] For a detailed analysis of this problem, see Biswas and Durie (1971).

Table 3 Emissions in 10^3 Tons/Years, Canada, 1970

Source	Particulates	Sulphur Oxides	Nitrogen Oxides	Hydrocarbon	Carbon Monoxide
Motor Vehicles					
Gasoline	31	19	622	1,970	12,854
Diesel	4	8	104	10	63
Aircraft	4	1	3	18	14
Railroads	9	34	22	13	18
Marine	11	108	19	6	8
Non-highway Use of Motor Fuels	4	2	68	214	1,397
Total (Transportation)	63	172	838	2,358*	14,354
Utilities/Power Generation	221	479	176	68	8

*Includes 127,000 tons for gasoline marketing.

atmosphere. In the second group are the emissions that when dispersed change the background concentration of some atmospheric constituent which enters into the determination of climate, the impact being dependent on not only the percentage change of the constituent, but also on its role in the complex mean behaviour of the atmosphere.

The first group is subject to local control of emissions under specific dispersion conditions although secondary effects downwind and through chemical chain reactions are increasingly becoming recognized. Carbon monoxide rates high among such pollutants associated with energy production. Current estimates indicate that motor vehicles produced some 12,917,000 tons in Canada in 1970 (Table 3, Environment Canada, 1973), a substantial portion of which was emitted in the populous provinces of Ontario and Quebec. This is a case of a pollutant which needs strict emission control in densely travelled areas having poor dispersion conditions but which creates no problem in the vast open areas with reasonable dispersion conditions.

The Canadian emission of hydrocarbons through the processing and combustion of petroleum in motor vehicles is also given in Table 3. Hydrocarbons react with nitrogen oxides in the presence of ultra-violet radiation to produce photochemical smog. Such productions take several hours and occur under special atmospheric conditions when stable lapse rates (inversions) can be maintained in the presence of strong sunlight which provides for the ultra-violet radiation but which tends to give rise to surface heating and convective mixing. The products of the reactions include ozone which in sufficient concentrations has highly detrimental effects on man and most biological systems.

Sulphur oxides present another environmental problem. Bates (1972) has pointed out that fine particulate matter, which often includes sulphur compounds, may have serious pulmonary and possibly carcinogenic effects. Successful removal of sulphur dioxide from the stacks of power stations has proven to be rather difficult, and is at best an expensive proposition. A distinguished panel of experts assembled by the National Academy of Sciences (1970) concluded that "contrary to widely held belief, commercially proven technology for control of sulphur oxides from combustion processes does not exist." Thus, increasing attention is being paid to remove sulphur from coal and oil, prior to the combustion process. This has precipitated the need for low sulphur fuels, and several techniques have been developed or are being developed for desulphurization of coal and oil[1]. It seems the target in our urban areas may become 0.3 to 0.5 percent sulphur content in heavy fuel oil. All these removal activities, however, have created a huge surplus in sulphur. In the past year alone, the price of sulphur in Canada has plummeted from $30 to $6 per ton (Times, 1972). Table 3 shows the distribution of sulphur oxides in Canada emitted from motor vehicles.

Nearly 24.5 percent of sulphur oxides emissions in Canada come from combustion of fuels (Environment Canada, 1973). Singer (1970), however, suggests that nearly 80 percent of sulphur oxide in the U.S. comes from the burning of fossil fuels containing sulphur. Its typical life-cycle in the atmosphere is approximately one week. It plays a role in low level photochemical smog processes and in the higher levels as a source for aerosols in the lower stratosphere. Some of this sulphur dioxide may become sulphuric acid or it may react further to form ammonium sulphate. When sulphur products are removed by rainfall, they increase the acidity of the precipitation. In some cases, especially in Sweden and the Netherlands, rainfalls having pH values of nearly 4.0 have been recorded. Rainfalls having low pH values have also been re-

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[1] For a review of desulphurization of coal and oil, see Squires (1971) and Alpert, Wold and Squires (1972).

corded in Canada. From an environmental point of view, sensitive species like salmon cannot survive at pH levels lower than 5.5.[1]

Another side-effect of energy development is the release of heat into the atmosphere either directly or through heated water. The heat island effect has been clearly identified in many cities where the average temperature in built-up urban areas differs significantly from the surrounding countryside. One recent study estimates that 56 million people will live in an area of 30,000 square kilometers in the Boston-to-Washington megalopolis by the year 2000. This would mean a heat injection rate of about 65 calories per square centimeter per day, a figure equivalent to 50 and 15 percent of the heat received by solar radiation on a horizontal surface in winter and summer respectively (Jaske, Fletcher and Wise, 1970). Coulomb (1970) has suggested that the possible impacts of doubling energy consumption in France every 10 years could lead to unbearable temperatures. Budyko (1961, 1969) has pointed out that if the existing trends in power consumption continue heat introduced into the atmosphere could become climatically significant.[2]

It should also be pointed out that the heat-island effect is not necessarily always detrimental. In northern cities such as Montreal, this may mean that a smaller percentage of the winter precipitation falls as snow in the urban area. The local heating also tends to produce deeper mixing and the overall effect will then depend on the vertical profile of emission concentrations. In addition, the heated area will tend to produce a local thermal circulation and is thus self-limiting.

The effects of the second group, since their consequences lie in the area of changing the climate–a subject which is itself not very well understood–are very difficult to assess. In general we are forced to consider whether the change is likely to be of detectable magnitude–whether or to whom the change will be detrimental poses a much more difficult question.

The most direct way that emissions affect the climate is through radiative fluxes. Not only is the mean temperature of the planet determined by the balance between incoming solar and outgoing terrestrial radiation but these are also the largest components in the heat-engine that maintains atmospheric circulations. Clouds and precipitation are important, but their main effect will also be felt in the radiation budgets. Even fractional changes in global hemispheric mean temperatures can have dramatic effects on human ecology. For example, the average temperature increase of 0.6°C between 1880 and 1940 was associated with northward movement of frost and ice boundaries, pronounced aridity in south central parts of Eurasia and North America leading to dust bowl conditions, and strong northern hemispheric zonal circulation (MacDonald, 1971). Since 1940, temperatures have dropped slightly–in the same epoch there have been higher wheat yields in India due to increased rainfall but substantial losses to Icelandic fishermen due to abnormal sea-ice coverage in the North Atlantic, especially in 1968 when conditions were the worst in over 60 years.

Changes in the distribution of incoming and outgoing radiation due to emissions arise principally through three factors: (a) variations in the concentrations of polyatomic gases, (b) increased turbidity (particulate matter) or cloudiness, and (c) surface effects.

Under the first category (a), is carbon dioxide, which has strong absorption bands in the infrared and is relatively uniformly mixed in the atmosphere. It has been the subject of much research because of its great importance in both atmospheric and biological cycles as well as the more recent measurements of global increases in carbon dioxide concentrations apparently associated with its production through combustion processes.

As our energy consumption has increased, so has the carbon dioxide emissions to the atmosphere[3]. Thus, its concentration in the atmosphere has increased from 290 ppm in 1860 to about 320 ppm at present, a total increase of more than 10 percent. MacDonald (1971) estimates that burning of fossil fuels currently releases about 1.5 x 10^{16} g of carbon dioxide per year. Measurements made by Charles D. Keeling of the Scripps Institute of Oceanography indicate that the carbon dioxide content increased by 6 ppm during the period 1958 to 1968 (Singer, 1970), which implies that its mass increased by 5 x 10^{15} g every year. If the current trend continues, the concentration of man-made carbon dioxide would double in the next 23 years. Fore-

[1] pH value of rainfall cannot be directly translated to pH value of the river water.

[2] It seems to be based on the assumption that the total energy consumption in the world will continue in the future for a century or more at an exponential rate. Budyko's main concern is with the melting of the Arctic Ocean which he thinks would be irreversible and would thus affect the general circulation, but many scientists disagree.

[3] For a summary of carbon dioxide exchange budget of the earth, see Hare (1971).

casts suggest that its concentration might increase to 375 to 400 ppm by the year 2000, and 500 to 540 by 2020.

Even though most scientists generally agree that the carbon dioxide concentration in the atmosphere has steadily increased[1] in the past (Singer, 1970; Eliassen 1971; MacDonald, 1971; Starr, 1971), mainly due to the combustion of fossil fuels for energy production, its climatic and environmental effects are somewhat uncertain. Since the net long-term flux leaving the earth must balance the incoming solar flux, one expects lower temperatures at upper levels and higher temperatures at low levels (increased surface temperatures). This simplistic approach, however, must be modified by a full consideration of the atmospheric circulations and the sources and sinks for carbon dioxide and so far estimates of temperature changes must be considered speculative and inadequate.

Water vapour is another gas which obviously plays a dominant role not only in radiative processes but in nearly all aspects of climate, atmospheric circulation and ecology. However, the influence of energy production in this area is likely to be limited to local effects because of the natural abundance and large variations, if we exclude such unresolved problems as the possible role of pollutants as nuclei for cloud and precipitation particles. The role of water vapour emissions in enhancing cloud formation in the normally dry stratosphere is also unresolved.

Another problem which requires resolution is the effect of high-altitude vehicle emission into the stratosphere on the ozone budget. The amount of ozone in the stratosphere controls not only the thermal structure of the layer by the heating due to its absorption of solar ultraviolet radiation but by the same process controls the amount of erythemogenic (sun burning) radiation reaching the surface of the earth. Thus, any significant change in the overall amount of ozone could have long term effects on not only climate but also the biological environment. The effect depends on secondary reactions involving the nitrogen oxides emitted through the combustion process. Here again detailed data on background concentrations, reaction rates and atmospheric processes are as yet inadequate to resolve the seriousness (or triviality) of this problem.

Under the second category (b) are the changes in the general turbidity or particulate concentrations in the atmosphere. Radiatively this is a scattering versus absorption problem. The solar beam scattering is effective at short wavelengths (like the blue-red sky effect) and leads to an increase of the overall albedo and lower mean temperatures, whereas absorption which can be effective at any wavelength depending on the composition of the particles leads to local heating. Since the scattering properties of most natural and man-made aerosols are still not well known, it cannot yet be stated with certainty whether changes in volcanic dust, smoke, etc., lead to net heating or cooling—although general opinion tends to favour the latter (Yamamoto and Tanaka, 1972).

Under the third category (c) fall the changes in surface conditions due to large projects which divert rivers, create water areas and change ice, snow and vegetation cover. One may note here the complex role of dust which as airborne aerosol tends to increase the albedo but when deposited on ice or snow has the opposite effect. All the foregoing factors affect the local climate but they must be integrated in some way to determine the net effect on large scale climate.

The atmosphere is thus seen as a complex system wherein the synergistic effects of different emissions are difficult to predict. One may postulate that carbon dioxide and energy production contributed to the temperature rises up to 1940 and that this was overtaken by the cooling effect as the increased dust content produced by man's and nature's activities reflected more and more of the incoming solar radiation, but one must await better and longer term data and the more sophisticated models now being developed before these questions can be resolved with any degree of confidence (Landsberg, 1970; Sawyer, 1971).

Thermal Pollution

The heat generated from combustion or nuclear reaction transforms water into high-pressure steam which turns the turbine motors. The motor is connected with a generator where mechanical energy is transformed into electrical energy. Typically, cooling water is necessary to remove the waste heat of vaporization of spent steam leaving the turbine exhaust. The steam then condenses into water and is pumped back under high pres-

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[1] Series of measurements taken at the summit of Mauna Loa, Hawaii and South Pole, two locations little affected by local sources, indicate remarkably steady secular increase of carbon dioxide concentration of about 0.7 ppm per year from the time observations were started in 1958 (Brown and Keeling, 1965; Pales and Keeling, 1965). Dr. Ingraham (1973) of Environment Canada, however, suggests that the "so-called evidence that there is an increase in the amount of carbon dioxide in the atmosphere is open to serious question. The analytical methods available indicate that the so-called trend is easily within experimental error."

Table 4

Potential Thermal Pollution from Generating Stations in Canada (Excluding Great Lakes)

Province	Heat rejected (BTU/HR X 10^{10})			Cooling Water requirements (cfs)		
	1970	2000	2000/1970	1970	2000	2000/1970
Alberta	0.626	12.150	19.4	1,752	34,400	19.6
British Columbia	0.264	11.250	42.6	718	31,850	44.4
Manitoba	0.152	2.185	14.4	402	6,160	15.3
New Brunswick	0.152	4.500	29.6	426	12,680	29.8
Newfoundland and Labrador	0.119	0.802	6.7	293	2,215	7.6
Nova Scotia	0.197	1.852	9.4	550	5,220	9.5
Prince Edward Island	0.024	0.339	14.1	48	928	19.3
Saskatchewan	0.376	4.870	13.0	1,056	13,550	12.8
Quebec	0.336	23.400	69.6	1,262	66,100	52.3
	2.246	61.348	27.3	6,507	173,103	26.6

sure to the boiler for the repetition of the steam cycle. The spent steam leaving the turbine has low grade energy, but since an enormous quantity of steam is involved, it needs correspondingly large amounts of water for cooling purposes. Thus, the purpose of the cooling water is to transport the waste heat from the steam condenser tubes into the environment.

Thermal efficiency of plants varies with the types of electricity generation. As a rule hydroelectric and gas turbine plants do not add significant amounts of heat to receiving bodies of water. The average heat rejection rate, in 1967, for fossil-fuelled steam plants was approximately 10,330 BTU per net kilowatt-hour generated. Coal-fired steam plants currently being installed have heat rejection rates of about 8,800 BTU per net kilowatt-hour. The worst offenders, the nuclear power plants, will discharge about 40 to 50 percent more heat into cooling waters than a modern fossil-fuel plant. With further technological developments, however, the nuclear plants are expected to be more efficient. Even now some of the modern nuclear plants that are replacing old and inefficient fossil-fuel plants are discharging less heat per kilowatt-hour into the environment than the stations replaced.

Most of the base-load type of hydroelectric plants have already been developed or are in the process of being developed, and, thus their share of the total electricity generated will substantially decrease in the future. The output from fossil-fired steam plants will increase, but their percentage of total market will gradually decline because of the increasing use of nuclear plants. Since from a heat rejection point of view, hydro is the cleanest form of energy and its total share of energy generated is going to be substantially reduced, and nuclear energy is the least desirable and its share of the market will increase substantially, the thermal pollution problem, if the present trends continue, can be expected to multiply manifold in the future.

Current studies indicate that heat rejected from generating stations to cooling waters in Canada (with the exception of the Great Lakes) will increase from 2.246 to 61.348 x 10^{10}BTU/hour during the period 1970 to 2000. This indicates a 26-fold increase in heat rejection rate during a 30-year period, equivalent to an annual growth rate of 11 percent, for which we would need a 25-fold increase in cooling water requirements, Table 4 (Montreal Engineering Co., 1970).

When compared to the solar heat received on a percentage basis, the thermal inputs would increase from 0.008% in 1970 to 0.2% in 2000 A.D. Notwithstanding such a phenomenal increase, it appears that there will not be a general shortage of cooling water in the country as a whole. Alberta and Saskatchewan, however, may experience difficulties in obtaining sufficient cooling water adjacent to fuel supplies or load centres.

Table 5 (Montreal Engineering Co., 1970) shows the development of the probable thermal pollution in Canada, from generating stations, industries and sewage disposal practices during the period 1970 to 2000. Approximately 80 percent of the total heat rejected can be attributed to the power plants. The table also shows the increase in total evaporation of water during this period due to the heat input: 20 times from fresh waters and 30 times from tidal waters. Thus, it is very obvious that the country faces a very serious and real problem in the future, if we have to dispose of all the residual heat in an environmentally acceptable fashion having the least possible deleterious effects on our ecological systems.

To a certain extent, the electricity-generating industry has itself to blame for the projected aggravating thermal pollution situation. Aided and stimulated by government policies, the industry committed itself heavily to nuclear power generation to provide for the future expansion necessary. The utility planners envisioned that

Table 5 Potential Total Thermal Pollution Problem in Canada

Year	Heat Rejection	Great Lakes	Remainder of Canada[c]			Canada		
		Fresh Water	Fresh Water	Tidal Waters[a]	Total	Fresh	Tidal	Total
1970	BTU/Hr x 10^{10}	3.165[b]	1.65	1.21	2.86	4.815	1.21	6.025
	Water Loss by Evaporation USgpd x 10^6	69	36	28	64	105	28	133
2000	BTU/Hr x 10^{10}	60	38.6	38.1	76.7.	98.6	38.1	136.7
	Water Loss by Evaporation USgpd x 10^6	1308	846	838	1684	2154	838	2992

[a] 100% of future thermal plant assumed to be Salt Water Cooled in Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick, British Columbia and 50% in Quebec.

[b] 1968 total x 1.3225, assuming 15% annual growth rate for region.

[c] Using ratio $\frac{\text{BTU/Hr}}{\text{USgpd}} = 21.8$ derived from figures for remainder of Canada.

nuclear power would be more economic than conventional sources and would contribute significantly less to air pollution. However, the investment and cost curves for the nuclear power have changed their shapes due to the ever-rising safety and quality control measures required, escalating wages of skilled labour and higher prices of basic materials. The result of such development policies has been the aggravation of the thermal pollution problem which the industry, for a while, insisted on characterizing as "thermal enrichment." Also, technology has failed to deliver the breeder reactor whose record of development so far has been rather inauspicious. At the very earliest, it will probably be at least 1990 before the breeder reactor will contribute to our power generation capability.

Temperature increases could have a number of effects on aquatic organisms (Abrahamson, 1972; Cairns, 1970; Sylvester, 1972), and among these are:

1. thermal death directly due to increased temperature;
2. internal functional aberrations, i.e. changes in growth, respiration, etc.;
3. interference with spawning or other critical activities in the life cycle;
4. disruption of normal biological rhythms, including migration patterns;
5. increased susceptibility to chemical toxins, and pathogenic organisms;
6. increased predation rate due to changes in avoidance reactions induced by temperature changes, decrease in swimming speed, stamina, etc.;
7. decreased spawning success and decrease in survival rate of young fry;
8. reduction in dissolved oxygen concentration due to higher BOD requirements;
9. disruption of food supply;
10. increased growth of taste- and odour-producing blue-green algae; and
11. competitive replacement by more thermally tolerant species.

The effect on aquatic organisms of prolonged exposures to small thermal increments is virtually unknown. One recent state-of-the-art study (Sylvester, 1972) concluded that:

" . . . slight increases in temperature can stimulate feeding, growth and overall general activity. It is also becoming clear, however, that increases of a few degrees can be lethal when combined synergistically with other forms of pollution. . . . Sudden temperature increases of a few degrees appear to have little effect on fish other than an increase in activity. Temperature increases of 10°C and above can cause sufficient stress in some fish, especially cold-water forms, so that activity is significantly affected and the fish are under stress."

It has often been argued that since fish tend to congregate in winter near thermal outfalls, it must be good for them. There is no doubt that the fishermen love this tendency. However, to suggest it is good for fish is somewhat analogous to arguing that since children love candy, it must be good for them. In fact, some of the current studies indicate that fish caught in the thermal effluents have body lesions (de Sylva, 1969). Thus, to summarize, thermal discharge pleases fishermen but not aquatic biologists.

Discharge of waste heat to the aquatic environment can be substantially reduced or eliminated if we consider other alternatives to the usual once-through cooling process. Waste heat can be dissipated to the atmosphere directly by using cooling ponds, spray ponds and natural or forced-draft evaporation or dry cooling towers. These alternatives, however, are more expensive and may create other additional environmental problems like visual pollution and change in the micro-climate of the area.

Several research projects are currently being undertaken to explore the possible beneficial uses of thermal discharges from power stations. Among these are: aquaculture, agriculture, space heating and cooling, and extension of navigating season. By controlling the temperature, especially in winter, it is possible to increase and control the growth rates of shrimps, prawns, catfish, oysters and other species. Use of heated irrigation water can extend the growing season and prevent damage from early and late frosts. These and other beneficial uses, however, do not need a vast quantity of heated water (Eliassen, 1971). In addition, their maximum needs are in winter, when the thermal pollution in Canada is not a major problem. Thus, the prospect of using thermal discharges for beneficial purposes to alleviate thermal pollution problems significantly, is not very promising. Cook and Biswas (1972) have reviewed the present state-of-the-art in this area.

Table 6
Estimate of Petroleum Oils Entering Oceans, 1969

	Metric tons/Year
Normal Operations	
Tankers	500,000
Other Ships	500,000
Offshore Oil Production	100,000
Accidental Spills	
Ships	100,000
Other	100,000
Refinery and Petrochemical	
Plant Operations	300,000
Industrial and Auto Wastes	
in Rivers	500,000
in Sewage Outfalls	100,000
Partial Total	2,200,000
Natural Seepage	100,000
Naturally Occurring Hydrocarbons in the Sea	large
Airborne Petroleum Hydrocarbons	large
Airborne Terpenes	large

Oil Pollution

The most conspicuously detrimental effects of oil pollution of our oceans are caused by accidents during the exploration and extraction phase, i.e., the Santa Barbara incident, or during transportation phase, i.e., *Arrow* or *Torrey Canyon* disasters.

Estimates of oil entering the world oceans are somewhat uncertain, but Table 6 (SPEC, 1970) shows an educated estimate. The 1969 partial estimate of 2.2 million metric tons is approximately 0.1 percent of total crude oil production for that year, 1.8 billion metric tons. With the increase of our production, transportation and consumption of oil, the quantity of oil entering the oceans is bound to increase. Nearly 90 percent of this estimate comes from normal operations of oil-carrying tankers, other ships, refineries, petrochemical plants, and submarine oil wells: from disposal of spent lubricants and other industrial and automotive oils; and by fallout of airborne hydrocarbons emitted by motor vehicles and industry. If we assume that the same percentage rate of oil will enter the world oceans in 1980, and consider the projected annual crude oil production of 4 billion tons per year, nearly 4 million tons of oil will be deposited in 1980.

The effects of oil spills are localized in character, and are primarily a surface or near-surface problem. For example, if the estimated 2.2 million tons of oil was uniformly distributed over all the oceans, the resulting mixture will have a concentration of 0.0015 parts per million. However, since the effects are localized their impact on our coastal zones could be catastrophic.

The effects of oil pollution on the ecology depend on the type, concentration of the oil and duration of the spill. Thus, the *Torrey Canyon* or the Santa Barbara incidents had much less effect on the aquatic ecology than smaller spills of refined petroleum products in shallow waters as in Baja, California, or West Falmouth, Massachusetts.

The most visible short-term effects of oil pollution are dead birds and fish, oily-smelling fish and polluted beaches. The long term effects may not be highly visible, but they could pose as large or even larger threats to the environment. The major ecological and environmental consequences of oil spills are the following:

1. death of oceanic birds due to the displacement of insulated air layer next to their skin as a result of which they freeze to death, drown or become unable to fly;
2. contact poisoning of marine life, such as invertebrates (clams, mussels, oysters, scallops, etc.), fish and marine birds, and especially the young which are more sensitive;
3. destruction of the food sources of higher species;
4. reduction of resistance of aquatic organisms to infection and other stresses;
5. suppression of evaporation due to changes in radiative properties of seawater;
6. degradation of the beach environment which reduces economic, recreational or aesthetic potentials; and,
7. contamination of marine equipment, piers, wharfs, buoys, etc., which may increase fire hazards.

When the Liberian tanker *Arrow*, carrying 3.8 million imperial gallons of fuel, sank at Chedabucto Bay, Nova Scotia, in 1970, it was responsible for fouling 169 miles of coastline, including 30 miles of some of the finest tourist and community beaches, and killed some 4,800 birds between Chedabucto Bay and Sable Island. The most extensive damage seems to have been to birds and aquatic mammals. In 1972, the tanker *World Bond* discharged nearly 12,000 gallons of crude oil during unloading operations at Cherry Point, just south of the Canada-United States boundary in the state of Washington. Some of the oil soon spread into Canadian waters. This incident, fortunately, was a relatively minor one, but it is a stark reminder of the inevitability of far more serious spills in the highly vulnerable Strait of Juan de Fuca. In addition, as exploration programs in off-shore regions proliferate, the cumulative probability of accidental oil spills will increase, and it is only a question of time before one is witnessed.

Landscape Aesthetics

There are three major aspects to landscape aesthetics from the energy viewpoint that should be considered in a Canadian context. These are the effects on the landscape due to strip mining, solid wastes disposal, transportation of oil and gas by pipelines, and power transmission.

Strip mining could cause irreparable damage to unique features of the environment. Besides being a visible and conspicuous eyesore, the effects of strip mining could well permeate to related ecosystems well beyond the actual mining operation. Flora and fauna may be affected by the destruction of the habitat, interruption of seasonal migration patterns and behavioural disturbance which could even result from the prevention of the use of undeveloped neighbouring habitats. Fish population may be affected due to the changes in water quality directly attributable to the mining operations or through effects on invertebrates which could disrupt their food chain. Effects on fish and wildlife, in turn, could have direct consequences on the recreation potential of the area in terms of loss of fishing, hunting or the aesthetic beauty inherent in undisturbed land.

The main reason for many areas being callously abandoned after strip mining is the lack of legislation which will force the mining industry to restore the area or to create acceptable alternative features, i.e., lakes, or compensate society in terms of financial assessment made payable to the government for the irreparable loss of the feature. In addition, the current legislation appears to place the public or the society in the unfortunate position of proving the nature and extent of the actual damages before the developer can be held liable. A far more acceptable approach would be to place the responsibility on the resource user to identify the nature and extent of environment disruptions, and to prove to the satisfaction of an agency that the development would not result in significant damages or that necessary corrective actions would be taken to overcome them.

The second aspect, transportation of natural gas and oil, by pipeline[1] from the Arctic, across the permafrost areas to the population and load centres in the south, needs careful investigation. We do not have enough scientific information available yet to assess, with a high degree of certainty, the ecological and environmental effects on the north of such large-scale transportation of fuel as well as on the native people. It seems logical, however, to expect that movement of hot oil will have far more deleterious consequences than natural gas. In addition, oil spills due to possible pipeline accidents should also be considered.

Finally, overhead electrical transmission and distribution lines are a possible source of environmental pollution. There are two major aspects to this problem. The first is the physical infringement on the landscape. The structures and the guys occupy land which prevents, or at least hinders, its possible alternative uses. As electricity consumption increases, so will the need for additional land for transmission facilities. The second factor is the visual pollution of the landscape. There is no doubt that a considerable amount of our landscape is now subject to this form of aesthetic pollution. It seems that the power industry neither paid enough attention in the past to design and build structures that could be graceful in form or blend in with the surrounding environment but still perform their technological function. Nor did they carefully scrutinize the route selection process which would have the least impact on the environment, subject to the usual economic, social and technologic constraints. The current controversy with the route selection process of the Ontario Hydro is an example.

One solution would be to provide underground transmission of electricity which has long been a common practice for relatively low power distribution in metropolitan areas. This, however, presents serious technological and economic problems. If high voltage transmission cables are to be

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[1] It now appears that we are getting fairly close to an understanding concerning a natural gas pipeline and its environmental effects whereas we are not at this stage for an oil pipeline.

buried underground, the conductors have to be carefully insulated from the earth, heat has to be removed from the cable and corrosion must be prevented. Because of these constraints, it has been estimated that a 48 km, 345-KV underground line in a built-up area would have approximately half the capacity of an overhead line of equal voltage but would cost six times as much (Avila and Corry, 1970).

Radionuclear Pollution

Environmental pollution from our nuclear industry can be due to waste disposal practices and possible accidents. The magnitude of the potential environmental hazards from radionuclides obviously depends on the forms in which they are released, the quantity of the released products, their radioactive half-lives and decay patterns, and their biological impacts on the ecosystems.

Nuclear power plants, under normal operating conditions, release minor radioactive effluents to the environment (Spinard, 1971). Careful research investigations have indicated that there is no threshold exposure level to radiation below which there could be "absolutely no harm" to biological organisms (Parsegian, 1971).[1] Radiation could pose two major problems: cancer and gene mutation (Lederberg, 1971). Unfortunately very little is definitively known about the effects of low level radiation on individuals. The reason is the smallness of the effect. If a population is exposed to one rad, one may expect one to three additional leukemia victims per year per million people (Lindop and Rotblat, 1971). Since the natural incidence of leukemia is 60 per million per year, a very large population would have to be exposed to obtain reliable data. With regard to genetic effects of radiation, it could cause gene mutations or chromosome aberrations. Genetic effects, however, could appear in the first generation born to individuals exposed or could remain latent for several generations.

When heavy water is used in a power reactor, tritium, an isotope of hydrogen, is generated in small amounts as a fission product. This is beta-active and can be harmful if absorbed by the skin or ingested. Most of the tritium is retained in the heavy water, but some of it could escape in the chemical form of water in which one hydrogen atom is replaced by a tritium atom, and in this form it is inseparable from water by any practical process. Additional tritium could come from chemicals which may be added to reactor cooling systems. Some could enter the reactor atmosphere in which case air discharged from the reactor building would be radioactive.

Radioactive isotopes of noble gases like argon, krypton and xenon escape from the fuel elements. Generally these gases are chemically inert, and have short half-lives, with the exception of krypton-85 which has a half-life of 10.75 years. Although considerable amount of radioactivity is involved in these processes, the magnitude of the problem is currently mitigated because of the dilution effect of the pollutants in air and water, which brings their levels to below permissible concentrations. With the increase in the number of nuclear reactors, however, the problem could become much more serious. For example, it has been estimated that the annual release of krypton-85 will be nearly 250 million curies by the year 2000 (Lindop and Rotblat, 1971). In addition, the concentration effects of these radionuclides as they pass through the food-chain cannot be discounted.

The argon in air becomes active if exposed to neutron radiation and has a half-life of less than two hours. Krypton is produced in the largest amounts, and current research investigations indicate that the technique of its possible cryogenic absorption holds considerable promise. However, from a long-term point of view, release of tritium to the environment may prove to be more damaging—especially if fission reactors are supplanted by fusion reactors. This is due to the fact that tritium production rate is over 100,000 times greater in fusion reactors than in the fission reactors.

The most significant potential environmental problem in the nuclear power area is the safe transportation, storage and disposal practices of highly radio-active materials. Currently, mined uranium is concentrated in various parts of Canada and is chemically refined at Port Hope, Ontario. It is then transformed into fuel elements in either of two manufacturing plants and delivered to the power plants. The problem then arises on how to dispose of spent fuel after it is discharged from the reactor. Since it contains almost all of the radioactive material generated by the nuclear reaction, as well as the depleted uranium and significant quantities of plutonium, it is highly radioactive and dangerous. The present practice is to store this highly toxic waste at the plant site.

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[1] Nearly all of our "conventional" pollutants also do not appear to have a threshold for biological effects. It should also be noted that the Canadian safety standards would permit approximately 100 times more radiation to escape from our nuclear reactors than the proposed U.S. regulations.

There are four major aspects to this type of waste disposal practice which should be carefully considered. Firstly, plutonium has a half-life of 24,000 years which means that if it escapes to the biosphere, it will be a serious life-hazard for some 200,000 to 240,000 years, a period much longer than the recorded history of modern man (Gofman and Tamplin, 1971). Plutonium was first produced and isolated only some 30 years ago, and yet one study suggests that by the year 1980, the commercial plutonium production in the U.S. will be 30 tons annually, and in excess of 100 tons by the year 2000 (Geesaman, 1971). In contrast, the Canadian estimate of plutonium production is 650 kg by 1976 (Zeller, Saunders and Angino, 1973). Plutonium is an alpha emitter, and is inherently carcinogenic in extremely small quantities. Current studies indicate that one-millionth of a gram injected intradermally in mice or injected into the blood systems of dogs will induce substantial incidence of cancer.

Secondly, as more and more nuclear reactors come on stream, there is going to be a tremendous stockpile of nuclear wastes at different geographical locations which we will have to leave to several of our future generations as a dubious legacy, and which would need very careful monitoring for several thousands of years. Thus, we are making a social commitment with an implicit assurance that from now to perpetuity our social institutions will retain sufficient stability to guarantee the continued existence of a cadre that will continually take care of these highly toxic radioactive wastes. A glimpse at man's past history over only the last three thousand years will indicate that this may very well turn out to be an impossible assumption.

Thirdly, as the quantity of long-lived radioactive wastes requiring perpetual isolation from the entire biological environment builds up, fail-safe management systems would have to be devised (Cook, 1972). Since the nuclear industry is only a few decades old, its capability to design an almost eternal fail-safe system has to be highly suspect.

Finally, the current Canadian practice is to store the spent fuel: fuel reprocessing or transportation of used fuel is not a part of the program (Gray, 1971). From a long-term economic view, however, it is unlikely that we will continue storing an enormous quantity of spent fuel rods in perpetuity, when their potential nuclear fuel contents, which could be as high as 99 percent, are considered. Thus, it is likely that the economics of the situation will dictate that we should reprocess the spent fuel, which means transportation and disposal of highly radioactive waste products in an environmentally acceptable manner[1]. Alternately, we will have to consider the possibility of selling the spent fuel rods to the U.S., Japan or some European countries.[2]

Even then, however, we will not, at least in the long run, escape from the radionuclear build up in our environment when the finiteness of the earth is considered. Thus, on a rather short-term basis, say within the next 10 to 20 years, our nuclear waste disposal practice is not harmful, but on a long-term basis it certainly falls far short of good environmental housekeeping.

Another aspect of nuclear power is the question of safety.[3] There is an enormous divergence of opinion on nuclear safety. The proponents suggest that the likelihood of an accident in a reactor is not "credible" (Seaborg, 1971). The opponents, on the other hand, point out that accidents will happen since every human activity is subject to human error and, eventually, economic analyses will override safety considerations. In spite of the small number of reactors currently in existence, there had already been 12 accidents throughout the world by early 1971 (Lindop and Rotblat, 1971). A major report (Science, 1973) on safety which has just been prepared by the U.S. Atomic Energy Commission states that:

> "The number of defects, equipment malfunctions, or failure events that have been encountered during construction, pre-operational testing and routine nuclear power operations to date has been large, attesting to the fact that there is considerable room for improvement in practice, if not in philosophy."

The possibility of loss-of-coolant accident merits serious discussions since the emergency cooling system is one of the major factors that allows nuclear plants to be built near major population centres. The emergency cooling system is designed on the basis of computer modelling and projections, and has not been tested in an operational reactor in Canada.

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[1] It has recently been suggested that high-level radioactive wastes can be disposed of in properly designed containers under the Antarctic ice cap. "The polar climate and the low temperature of the ice would furnish a sink for the heat given off by the radioactive waste canisters, and the large subsurface area of the ice would provide adequate space so that the canisters would not be in close contact with each other" (Zeller, Saunders and Angino, 1972).

[2] Already there is some talk of selling spent fuel rods to France (Gray, 1971).

[3] This discussion is mainly oriented toward the USA system.

Thus, we are depending on an unproven system to prevent a possible major accident.

The situation is no better with the U.S. nuclear program either. After claiming for years that the emergency system will effectively cool the core under any conceivable accident, the U.S. Atomic Energy Commission (AEC) tested the system in 1972 on a small mock-up reactor in Idaho. In six out of six trials, the system failed, and almost no water reached the core. Later AEC claimed that the Idaho tests are not fully representative of full-scale commercial reactors, but promptly issued tighter regulations for reactor operation. Currently AEC does not have any plan to test the emergency system under operating conditions till the 1974-75 season, and yet the unproven system is counted upon to prevent catastrophic accidents (Wall Street Journal, 1972).

The fact that the Canadian system has not been tested in a prototype, certainly merits further investigation and discussion. This is all the more important since the whole question of nuclear safety has become controversial partly because of a "growing mistrust of technology and partly because government and industry efforts at disseminating public information have been insufficient" (Gillette, 1973).

If the nuclear generating capacity increases in Canada from 1,200 MWe in 1971 to 35,000 MWe in 1990, as estimated by the Canadian Nuclear Association (Foster and Stewart, 1971), we would also have to develop a fool-proof system to prevent the diversion of plutonium and enriched uranium into the illicit manufacture of atomic weapons. The Canadian system produces more plutonium per ton than anyone else (Gray, 1971). This fact, plus the proliferation of nuclear stations in the future, will make it increasingly difficult to keep plutonium out of the hands of irresponsible persons who might decide to hold society at ransom. This is no longer an unrealistic proposition. In November 1972, the hijacker of a Southern Airways airplane threatened to crash it deliberately on the Oak Ridge nuclear plant if his ransom demands were not met. Another aircraft that was hijacked to Cuba, carried on board, unknown to hijackers, fissionable material from which a nuclear explosive could have been made (Ingram, 1973). Thus, like the aircraft, it is possible that nuclear power plants could also be held hostage for financial gain or political purposes (Novick, 1973.) These types of safety problems have to be seriously considered in any environmental protection scheme.

From an environmental viewpoint, and to ensure low level radiation exposure, it is essential that the following four criteria should be fulfilled (NAS-NRC, 1972):

1. attainment and long-term maintenance and of anticipated engineering performance;
2. adequate management of radioactive wastes;
3. control of sabotage and diversion of fissionable materials; and
4. complete avoidance of catastrophic accidents.

Policy Considerations and Implications

Since energy embraces all phases of life, any policy in this area will have implications on many sectors of our economy and environment. Thus, even if a policy is primarily designed to mitigate environmental consequences of energy development and consumption, its repercussions cannot be confined only to the environmental area: they will transcend to other sectors, like the country's economy, transportation, housing, etc.

Is Energy Different?

Since there has been considerable discussion on the whole question of energy growth, both past and future, any discussion on policy implications has to consider the question whether energy is different than any other commodity. Many have claimed that it is essential to stabilize or even reduce our use of energy if we are to protect our environment and leave some of our non-renewable natural resources for use by future generations. This may be a valid objective, but if we follow this type of reasoning for the energy industry, it should be extended to all other types of non-renewable resources industry, some of which have equally bad, if not worse, environmental and depletion problems. Ideally and logically, the environmental impact of all commodity and service uses should be treated on the same basis. It may be argued that energy is unique since it is essential for all manufacturing processes. This, however, is not correct. For example, we need steel for practically all manufacturing processes, including all stages of energy manufacture. Thus, to contend energy is more important than steel or vice versa, is like arguing which came first, the chicken or the egg.

The question then naturally arises why the energy industry is singled out for this type attack? There are several reasons. Firstly, energy is the new "in-thing" at present, having approximately the same glamour status as environment had in its hey-days of the late 1960's. Thus, it is fashionable to talk about the problems of energy growth and development. Secondly, there is no doubt about the high visibility and the shock value of some of the very serious environmental damages which have stemmed from the energy industry in the past. Certain power plants in populous centres provided some of the worst examples of environmental pollution. Accidents like the *Torrey Canyon, Arrow* or the Santa Barbara blow-out provided graphic examples of possible massive ecological disasters. Thirdly, energy has become a symbol of our entire system of industrial development and economic growth which concerns many people. Finally, the utility industry must share some of the blame due to their glowing forecasts of energy growth with the mistaken belief that such growth-rates would benefit their territory, their customers and their enterprise without having a serious impact on the environment. Forecasts of doubling time of 6 years are not exactly uncommon, which a simple calculation will point out means a phenomenal 250-fold rise in 48 years, 1,000-fold in 60 years and 33,000-fold in 90 years (Sporn, 1971).

It has been argued that energy should not be exported to the United States since it means all the adverse environmental effects associated with its production will stay in Canada while the "clean" finished product will be used in the U.S. without having any of the ill-effects. Whatever may be the merit or demerit of energy export from other considerations, the same argument can be extended to all other commodities. In all cases of export of finished products, the environmental problems will remain in the country of manufacture, while the importing countries will enjoy a relatively 'clean' product. What is necessary is that the cost of the exported finished product should reflect the environmental disruptions cost. Estimation of this cost, however, is not an easy task.

Cost and Demand for Energy

There is increasing evidence that one of the major factors contributing to the rapid growth of energy demand in recent years is that its costs, historically, have fallen relative to the overall price level. In fact, there are few, if any, types of industry that can match the price stability or even the price reductions of the electrical industry.

If we consider the case of Ontario Hydro, it is currently selling a product at a lower price than it did 50 years ago. During 1938 to 1971, the Consumer Price Index rose by 170.6 percent, but the average cost per kilowatt-hour for a residential customer rose by only 2.3 percent. If we consider the Food Price Index, it rose by 31.4 percent during 1961 to 1971, but the average cost per kilowatt-hour to rural customers, including farmers, during the same period declined by 14.3 percent. Toward the end of the Second World War, a man with an average wage had to work three hours to pay an average monthly electricity bill. It still takes him three hours of work to pay the bill, but his consumption has increased three-fold during this period. In addition, the current per kilowatt-hour cost to industry is half the average cost of all municipal residential customers. Figure 15 shows the relative price changes in different energy commodities in Canada, from 1961 to 1971, with the 1961 base as 100.[1]

Historically, energy costs have come down for two reasons: increase in efficiency of power production, and hidden subsidies. The costs of building one kilowatt of fossil-fuelled generating capacity in the U.S. came down from $130 in 1950 to $118 in 1968, mainly due to efficiency reasons. The trend, however, has already reversed. Today, in the USA, the cost is $235 for fossil-fuelled plants and $330 for nuclear plants (Forbes, 1972).

Electricity prices are at an artificially low level due to hidden subsidies. To start with, our utilities can borrow money at 10 to 30 percent less interest than other industrial concerns in similar financial situations since the provinces guarantee their loans. Secondly, power companies often put an unrealistically long life-span on utility equipment for book and rate-making purposes which is almost unheard of in other industries. Thus, average depreciation rates of 2.4 percent are not exactly uncommon (Business Week, 1972). Finally the rate of return on their investment is rather low, as will be evident from the following comparison of gross operating returns, for 1965-1970, for selected utilities, both investor- and government-controlled:

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[1] Figure 15 is based on information from Statistics Canada, Prices and Price Indexes, Cat. No. 62-002

Government-controlled	
Ontario Hydro	7.4%
Quebec Hydro	8.6%
B.C. Hydro	8.9%
Investor-controlled	
Calgary Power	10.0%
Consumers Gas	10.5%
Union Gas	11.9%

Generally, the energy industry has tended to ignore price-demand relationships. Thus, estimates of future energy use have really been forecasts of "requirements" derived without explicit consideration of the effect of price. In a sense, the energy industry has the same basic philosophy as the highway planners. They forecast higher highway requirements which generate more traffic which, in turn, needs more highways. To a certain extent, the energy industry is caught in a vicious never-ending cycle, without seriously looking into other possible alternatives.

One of the methods used for preparing future energy requirements is by projecting total service area population increases and multiplying them by an average per capita use figure. In almost every case, the possible effects of changes in energy price are not considered in the analysis, although some do consider, in varying degrees, changes in life styles or industrial activity. The basic deficiency in this form of requirements approach analysis is not that it has failed to forecast needs to date, but that it fosters an approach to energy management which carries other heavier disabilities. By concentrating projection of past trends, attention is drawn away from other variables of the system. There is also a strong inclination to ignore further improvements due to better conservation and public education programs or an increase in efficiency of existing uses.

What is needed is an adjustment of approach, i.e., demand management rather than supply management through the use of responsive prices. This is at variance with the current practices of the energy industry and, if instituted, will represent a rather radical departure from the current conventional practice.

Pricing Policy

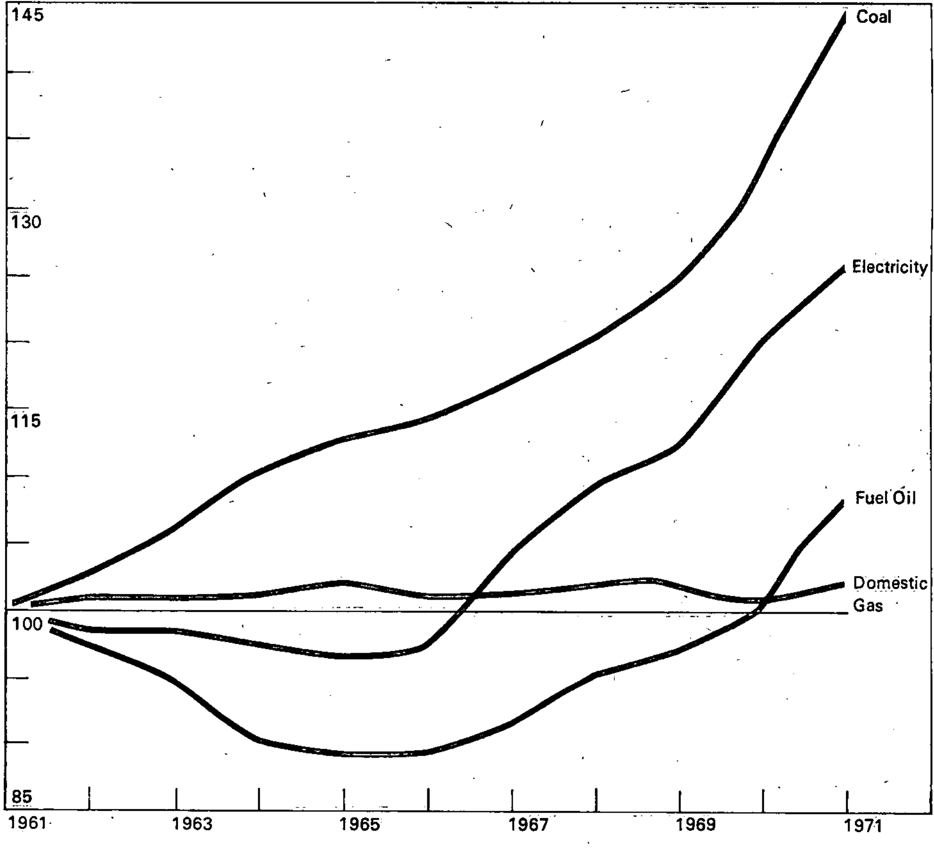
There has been considerable controversy over the energy industry's practice of inverted power rates, i.e., volume discount offered on price per kilowatt-hour to large users. Explained simply, it means that as the consumption increases, rates decline. The rationale, it seems, is that it reflects economies of scale in electricity generation and distribution. The cost criterion, however, is not really valid since the price differential between peak and off-peak power rates is absent.

The opponents of inverted rate structure argue that it will reduce energy demands by penalizing large users by higher costs, and it will have favourable income distribution effects because smaller (and, thus presumably poorer) users will pay less than larger (richer) users. The proponents suggest that energy consumption will not be reduced significantly by moderate price changes. Since, for most industries, power costs constitute a small part of the total cost of doing business, rate increases will be slow to reduce demand. Also, it is unlikely that householders will reduce their demands at peak periods because of the high cost of energy. It is highly improbable that people will turn off their air-conditioners during the hottest days. In fact, the chances are that they will cut back during off-peak hours, which means it will reduce the system's load factor which, in turn, would increase costs. Thus, the feasibility of interruptible electric service to a greater number of industries should be explored.

It is difficult to predict the real effects of an inverted price structure. If the price becomes too high, industrial users may decide to generate their own power, which may well prove to be less efficient, more difficult to control, and thus, potentially increase the total environmental pollution. Also, it may be possible that if the electricity consumption is reduced, the suppressed demand may opt out for other forms of energy, which would have different environmental consequences. The trade-offs may not be necessarily favourable. From an economic viewpoint, large scale production and distribution of electricity does have cost advantages which should be reflected in the pricing structure. Thus, it seems to be more logical to assess the environmental impact of energy generation, distribution and consumption, and impose charges accordingly, rather than relying totally on an inverted rate to accomplish the objective indirectly.

The conventional solution to the peak-load problem by the electric industry, which does not function under the usual market mechanism, is handled as one of supply management. Thus, maximum-day demands are accepted at face value (they are not related to price), and supplies are adjusted to meet the requirements regardless of the marginal benefits and costs associated with them. Solution to the peak-load problem from economic efficiency considerations necessitates the following rules:

Figure 15 Energy Price Changes in Canada, 1961-1971



Index 1961 = 100

1. if the capacity is not fully utilized, the price should reflect operating costs with no contribution to capacity costs; and
2. if demand exceeds capacity at this price, the price should be adjusted upward to restrain demand to the capacity level.

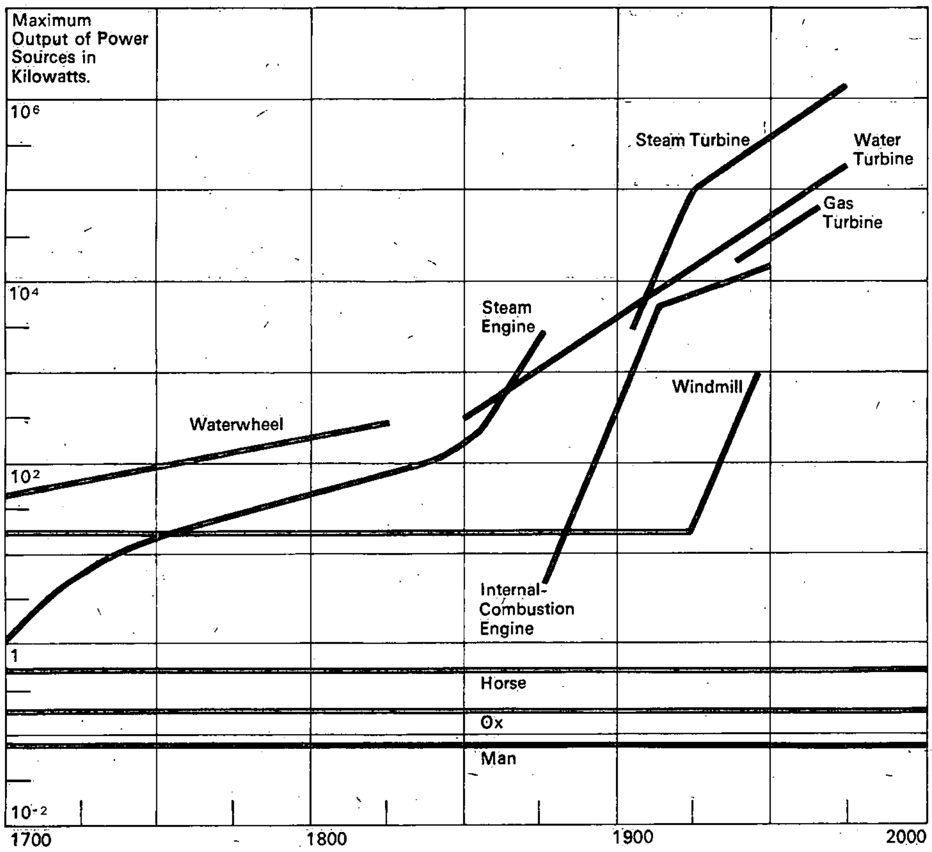
In other words, if the same type of capacity serves all users, capacity charges should be levied only when capacity is fully utilized, so that these peak users bear the responsibility for defraying capacity costs. The failure of the utilities to take into account the higher real cost of peak power is not defensible.

Demand and Promotional Practices

Environmentalists have often suggested that if the power industry changes its promotional practices, ranging from advertising to pricing, it would reduce the total energy requirements, which in turn, would alleviate the adverse environmental effects of energy production and distribution (Freeman, 1971). While some of these propositions may be partly valid, they are rather deceptive over-simplifications of a highly complex situation.

On the promotional side, some utilities claim that advertising has a minor effect on peak demands and is primarily oriented to fill slow periods of the year when there is excess generating capacity. Electrical utilities further claim that without heavy promotion they will lose part of their market, especially home-heating, to other sectors of energy like oil or gas, which will reduce their base load consumption and will lead to higher prices. The counter argument has been that these slow periods should be used to take things off the line for repair and maintenance work. Whatever may be the case, the attitudes of the utilities and their regulatory agencies are gradually changing, especially in the United States. Some have already voluntarily dropped their promotional efforts to boost energy use, and a few, being plagued by brownouts, have already started advertisement campaigns to conserve electricity. In some cases, regulatory agencies have forced the utilities to take different actions. For example, in 1971, Vermont outlawed all promotional advertising, except for such things as public events or efforts to protect the environment. Oregon has outlawed tie-in deals which encouraged the construction of all-electric homes. Michigan has forced one of its utilities to make its stockholders and not its customers pay for some advertisements explaining why the company applied for higher rates. New York has announced an almost unprecedented investigation for possible regulations which might reduce energy consumption. One of the possible regulations that is being considered is to restrict the amount of electricity that can be sold for heating

Figure 16 Power Output of Basic Sources



or cooling or limiting the supply of power for such uses only to properly insulated buildings (Wall Street Journal, 1972b).

With our current concern for energy and environment, the attitude of our energy industries is gradually changing. More and more are starting to stress energy conservation. This is a most welcome and encouraging trend.

Efficiency of Energy Production and Utilization

The power output of our basic machines has climbed steadily since about 1770, and is shown diagrammatically in Figure 16 (Starr, 1971). The efficiency of energy converters, during the same period, has also gone up. It may prove to be increasingly more difficult in the future to continue such increases.

In general, the efficiency with which fuels have been consumed for all purposes improved by some 400 percent during 1900 to 1970. If wood or coal is burnt in an open fire-place nearly 80 percent of the energy is lost through the chimney, and only 20 percent is available to the room. In contrast, a rather well-designed home furnace can utilize 75 percent of energy of the fuel, but the average efficiency is around 50 to 55 percent. In the case of electricity generation, somewhat less than 5.0 percent of the energy available in fuels was converted into electricity around the turn of the century. Today, the corresponding average efficiency of conversion is nearly 33 percent. Under existing conditions, the maximum theoretical efficiency is 60 percent. Our most modern steam turbines can have an efficiency of 47 percent which compares favourably with the current maximum overall efficiency of a steam power plant which is around 41 percent. Thus, in the future, the efficiency of energy conversion is not going to improve at the same rate as in the past; we may expect the efficiency to be around 50 percent by the year 2000.

The structure of the electrical utilities, to a certain extent, is responsible for inhibiting incentives for achieving better efficiencies or conservation practices. The whole basis of the rate of return in rate-making of the utilities can be questioned. Since the rate of return is basically cost-plus, there is no real incentive to conserve power, reduce peaks and meet demands as efficiently as possible. If an utility cuts costs, it still gets the same rate of return, and if costs increase, it gets higher rates. Hence, there is little, if any, reward for efficiency.

Even though considerable research is being conducted to improve the efficiency of energy production, the efficiency of energy utilization, however, has not received much attention in the past. A cursory examination will point out that we can increase the efficiency of energy utilization (and thereby reduce the total energy demand) in practically all areas: space heating and cooling, manufacturing, and transportation. Current studies indicate that better insulation practices in homes and buildings can reduce heating fuel requirements by 20 percent or more. In addition, it may be argued that the use of electricity for home heating is an inefficient use of energy, since a good oil or gas home furnace is nearly twice as efficient as the average power generating station.

Products can also be better designed to utilize less energy. For example, most of the energy consumed by a light bulb actually produces heat and not light. Refrigerators can be designed to run on less energy. Better recycling practices will also reduce energy demand because it requires a smaller fraction of energy to reclaim metals like aluminium, iron or lead than is necessary in their production from raw materials.

Changes in our existing modes of transportation will also have a significant impact on energy use efficiency. Currently, often we use a two-ton vehicle that is less than 10 percent efficient in energy use to transport only one person. Only one-sixth of this energy will be necessary in a mass transit system per passenger-mile. In addition, mass transit will reduce the congestion in our road systems, and will substantially alleviate our air pollution problems. Use of railroads, rather than highways, to transport more freight would achieve net savings in energy use.

There are many examples of inefficient use of energy. One wasteful use of energy that has practically received no attention in Canada is the illumination of our buildings. There is little doubt that most modern-day buildings in North America have far more light than necessary—in some cases 10 to 20 times too much. The lighting standards are suggested by the Illuminating Engineering Society (IES), primarily an industry association and it is widely followed by architects and electrical contractors. The lighting intensity requirements are being constantly upgraded, and consequently, the average level of light in commercial buildings has risen from 35 footcandles in 1940 to 85 in 1958 and to 125 at present. This is a 357 percent increase in 30 years, and IES predicts that this level will double by the year 2000!

If we compare the European and North American practices, the differences in lighting levels are unbelievable. For example, British schools have the minimum recommended lighting level of 10 footcandles compared to 70 in the U.S. and Canada. And yet, after a certain level, more light does not aid eye health or spur productivity. The current IES recommended level for libraries is 70 footcandles, but studies have indicated that as lighting levels increase above 25 footcandles, the improvement in distinguishing details accurately is very small, and what slight improvement there is "has practically no significance for reading".

It has been estimated that lighting levels could be reduced, on an average, by 50 percent without reduction in efficiency, and this would reduce the total U.S. light bills by at least $3.5 billion per annum. From an energy conservation point of view, it will have two significant benefits; it will reduce the total electricity consumption, since lighting consumes nearly 25 percent of all electrical energy, and it will also reduce air-conditioning needs, as the main function of office air-cooling is to remove the heat from interior lighting, except on the very hottest days. Currently some new buildings have so much light that there is still a need for cooling the inside air even when it is snowing outside.

Policy Implications

Since all phases of energy generation have significant impacts on the environment almost all energy policies have environmental implications. Similarly most of our policies to clean up the environment will have impact on energy development and consumption. For example, federal and provincial pollution control regulations are likely to result in additional use of energy. A car, of 1976, or later, fully-equipped with emission control mechanisms, will experience a 15 to 25 percent fuel penalty over a comparable 1967 model. Thus, it seems highly desirable that alternative policies be developed for the twin objectives of both energy conservation and pollution control. These policies should be directed toward more efficient energy development and conservation practices which will reduce energy consumption and pollution and also toward developing more energy-efficient pollution control systems.

In terms of long-term energy environment policies, it is desirable to consider the relatively short life-span of fossil fuels, especially oil and natural gas. Figure 17 (Folinsbee, 1970), shows the period of use of fossil fuels in a historical perspective: plus and minus 5,000 years from the present. In terms of human history, it certainly looks like an ephemeral phenomenon. Figure 18 (Folinsbee, 1970) shows a

Figure 17

Time Perspective of Fossil Fuels and Nuclear Energy Consumption

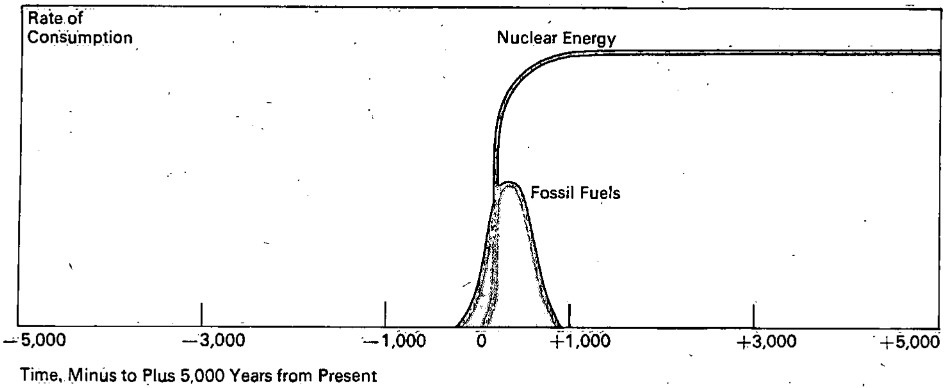
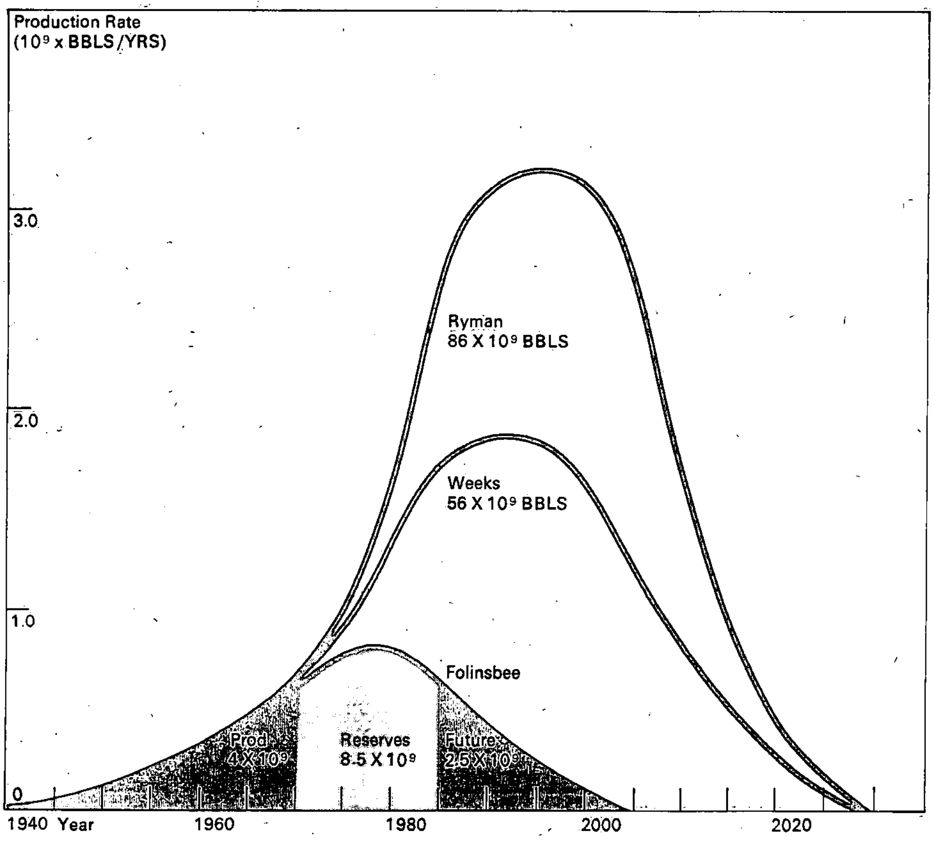


Figure 18

Complete Cycle of Crude Oil Production in Canada



similar diagram for the Canadian crude oil production. It shows three estimates of our current reserves and possible future discoveries. Even the most optimistic forecasts tend to tail off by 2020, less than 50 years away. It is totally immaterial whether this period occurs by the year 2010 or 2050; what is more important is the inevitability of its occurrence and the short-time period available to us to develop meaningful alternative policies, and have them accepted through the political process and implemented.

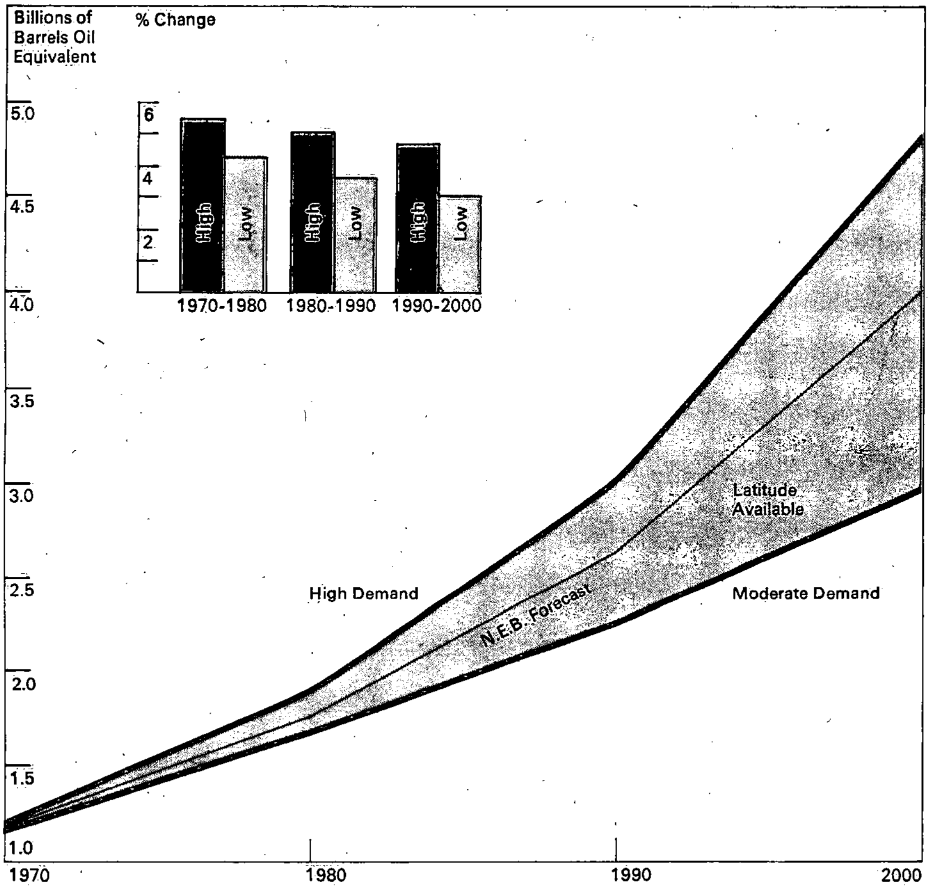
With this framework in mind, several policy alternatives have been suggested in Table 7. It should be realized that each of these policies or sub-policies would need careful intensive investigations to determine their benefits and costs. They may improve some parameters but could aggravate others, and thus trade-off studies are essential. To cite one example, there is no doubt that increased insulation of buildings will reduce energy consumption. At a certain point, however, the benefits accruing from energy saved will equal the cost of increased insulation. If all the environmental costs could be included in such benefit-cost analyses, the trade-off point could be easily determined. Since we cannot, it is imperative to do a comparative study of the environmental problems associated with energy and insulating-materials production. To automatically assume energy is the villain and that such a study is unnecessary, would be, to say the least, rather naïve.

Table 7 also shows the possible impacts of the policies on the environment, economic and social sectors. The impacts have been graded from very high to high, medium, low and very low. In the economic and social sectors, 'high' denotes a heavy impact

Table 7 Some Selected Policy Options in Energy-Environment Conservation

Policy Options	Impact			Public	Implementation
	Environmental	Economic	Social- Political	Acceptability	Possibility
More emphasis on mass transit –Improve and expand service –Reduce fares or no fares –Improve arterial mass transit –Better feeder services, i.e., dial-a-bus –Exclusive bus lanes –Provide fringe parking –Controlled entry to downtown cores –Make parking expensive in downtown cores –Pedestrians only oriented clusters –Develop better and more convenient forms of mass transit	High	Medium to High	High	Medium	Medium
Improve intercity passenger and freight services –Improve and expand service and network –Provide fringe parking –Ban subsidy on short flights by long flights –Encourage containerization and piggy-backing –Develop new and better passenger and freight handling systems	Medium to High	Medium to High	Low to High	Medium to High	Medium
Improve transportation efficiency –Improve automobile efficiency, i.e., better engines and drive trains, low loss tires, improved engine tuning –Improve urban design –Selective registration taxes on size, power, ancillary equipment, attachments –Develop energy efficiency standards for transportation –Encourage research to develop non-petroleum engines, advanced propulsion systems, advanced traffic control systems, etc.	High	High	Medium	Medium	Medium
Improve insulation of buildings to reduce heat loss in winter and heat gain in summer –Make improved and increased insulation mandatory under CMHC regulations –Make arrangements for better caulking and double glazing windows –Reduce excessive window areas –Provide tax incentives for adding insulation	High	Medium	Medium	Medium	Medium
Increase energy prices to reduce demand and achieve better efficiency –Initiate inverse rate structure –Ensure 'normal' investment return –Borrow money for capital investment at the market rate –Include environmental and social costs in the price of energy –Impose taxes and regulations	High	Low	Medium	Low	Medium
Shift heavy load to off-peak hours –Restructure rates –Ban or restrict heavy use of energy during peak hours	Medium	Low	Medium	Low	Low
Provide centralized and efficient heating and air conditioning system to serve a number of buildings	High	Low	Medium	High	Medium
Limit energy which can be consumed by each household and commercial building annually	Medium	Low	Low	Low	Low
Establish minimum efficiencies for air-conditioners, furnaces and other appliances	Medium	Medium	Medium	High	High
Establish more rational lighting standards for homes and offices	Medium	Medium	Medium	High	High
Increase recycling and reuse of materials and products	High	Medium	Medium	Very High	High
Provide economic incentive to upgrade inefficient processes and equipment	Medium	Medium	Low	Medium	Medium
Impose fuel and/or energy tax to generate revenue for research to develop environmentally clean sources of energy, and to improve efficiencies in generation and utilization of energy	Very High	Medium	High	Low (tax increase) Very High (R&D)	Medium
Develop public information and education program to promote efficient utilization of energy	High	Low	High	Very High	High

Figure 19 Possible Range of Energy Demand, 1970-2000



on them, whereas in the environmental sector, 'high' means the policy will have a substantial impact by reducing the total pollution problems. Similarly the public acceptability and implementation possibility for all the policies are graded.

The main advantage of studying these types of policies will be to practice conservation of both energy and environment. These policies could contribute to better efficiency of energy production and consumption, and, hence, would reduce energy growth and environmental disruptions. By considering these policies individually and collectively, at the same or different time horizons, one can determine the total benefits and costs of such policies and also the latitudes available to decision-makers due to alternate policies (Figure 19). This type of information is vitally necessary to the decision-makers to develop rational long- and short-term policies in the energy-environment area.

Conclusions

The attainment of a sensible trade-off between energy growth and environmental conservation is seriously hampered at present at every stage of analysis and decision-making by ignorance; by lack of physical and chemical knowledge of the effects of various emissions and discharges on our air, water and land systems; by our ignorance of the biological effects on flora and fauna due to different levels and types of pollution; by the unavailability of economic methodologies to test the market mechanisms, to internalize the externalities, to determine the value society puts on incremental improvement or worsening of the environmental parameters due to different levels of pollution or to determine how regulations to curb pollution would affect prices, employment or location of different industries; and by the absence of a proper institutional structure under which these factors can be considered and appropriate actions taken. These factors, individually or cumulatively, may cause decisions to be taken which may create irreversible environmental damages or to sacrifice acceptable development due to unreasonable and unnecessary environmental regulations.

What is badly needed is sober and unbiased appraisal of what is known and not known on the environmental effects of different pollution discharges by a reputable authority. This appraisal must have credibility in environmental-ecologic, engineering-economic, and political camps as well as with concerned general public groups. Virtually nothing is known about the long-term effects on ecology due to sustained low level of pollution discharges, be it carbon dioxide or hydrocarbons to the atmosphere, thermal discharges to the water, solid wastes to the land or nuclear waste products to the entire environment. A very high and intensive discharge will probably produce dramatic shock-effects which will assure quick clean-ups and formulation and implementation of policies to prevent such occurrences in the future. And yet, low level sustained pollution discharges to the environment may go unnoticed, and eventually could have far more adverse effects on the environment. The added danger is that man will adjust more and more to gradually increasing levels of pollution, and thus slowly lose much of his humanness. Research on the effects of these types of low level of pollution are vitally necessary to develop effective standards and guidelines. It would need several base line studies and careful continuous monitoring, which would probably prove to be expensive and time consuming.

On the economic side, it is more desirable to develop alternative types of analysis than marginal cost-benefit ratios. Irreparable damage to the environment, whether to human health from radioactive waste products, or to aquatic organisms from thermal discharges, or to the atmosphere from gaseous and particulate emissions, or to the beauty of a canyon and countryside by a hydro dam, or to the permafrost from hot oil transmission, cannot be analyzed by the fine tuning of marginalism. Neither can this approach be successfully used where benefits are short-run and quantifiable while the costs are long-run and mostly unknown and unquantifiable. Then, there is the question on nonlinearity of the cost curves of waste disposal with increase in production: low cost when pollution discharges are within the assimilative capacity of the environment, increasingly higher cost when this capacity is exceeded, and exponential increase in cost when the environment is saturated. From an economic viewpoint, it is difficult to handle the middle zone where, unfortunately, most of our problems fall. Also, there is the question of choice or value judgement. The cost of upgrading the quality of air or water is measurable, but the benefit of an additional unit of air or water quality is unmeasurable, and, hence in the realm of values. This, however, is not unique. Like many other social choices, it has to be made through our political process. As Mason (1972) suggests:

> " This is not a problem for science and technology, though the contributions of scientists and technicians can be important; it is not a problem of economics, though economists could be useful; nor is it a problem for administrators, though their assistance is necessary. It is ultimately a question of finding out what the people want and if what they want is feasible within technological, economic and administrative limits. And the ultimate answers can be found in only the political arena."

Finally, almost without exception, the best environmental solutions are to turn wastes into useful resources, and restrict harmful discharges to the environment. Costs are reduced as the amount of waste to be disposed of is reduced; and, if in addition, wastes can be converted into useful products, there may even be positive income. With the increase in waste disposal costs, and increasingly more stringent environmental regulations, the biases in the cost and pricing system that currently make pollution profitable will be diminished or even eliminated. If pollution abatement is made mandatory by regulation or by making it extremely costly, it will give a great impetus to the development of further pollution-abatement technology. In such cases, pollution control will no longer be on a corrective, band-aid and an after-thought basis, an approach which is not only inefficient but also expensive. Instead, it will be done on a preventive, built-in, and advanced planning basis, an approach that is both efficient and economic.

On the basis of current available information on the economic consequences of environmental protection due to energy growth, we can make two predictions. One is environmental protection will not be cheap, and the other is the costs will not be prohibitive[1]. Thus, the question is not whether Canada can afford environmental protection, but whether she wants to.

The era of cheap energy and the illusions about its unlimited abundance is ending. We have to seriously rethink the whole philosophy of uncontrolled industrial and energy growths, and their effect on the environment. As Earl Cook (1971) points out:

> " '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 mold our economic and social institutions to be dependent on the application of power and the consumption of energy."

If we do not rethink and change this type of growth-oriented philosophy, we will be caught in this vicious circle which will have very serious effects on our environment.

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[1] A recent U.S. study suggests that the average residential consumer will find his annual electricity bill in 1976 from $4.50 to $17.50 higher than it would be without any environmental regulation of the electric power industry (Quarles, 1972).

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