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Environmental Implications of Energy Development

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Introduction

Energy and the environment are closely interrelated. In fact, the environment itself is an energy system, full of storages, conversions, transfers, and balanced budgets. We live in artificially controlled thermal climates, surrounded by clothes, houses, offices, and automobiles designed to control heat fluxes. We obtain energy by our intake of food, which is derived at one or two removes from the chemical miracle of photosynthesis in green plants, whereby photons of visible solar radiation bring about the synthesis of glucose from atmospheric carbon dioxide and soil water, ultimately from rain. We heat our homes, fuel our cars, and drive our industries with energy derived from the combustion of fossil fuels, from nuclear reactions, or from the gravitational potential in water power, derived from the sun-driven convection in the atmosphere. In addition, our ecosystems, among other things, are also energy systems. Thus, no one who wants to live in peace and harmony with his environment, whether natural or man-made, can afford to break the fundamental rules about energy.

However, when we speak of energy, we generally mean the human consumption of energy. We mean the deliberate harnessing of power sources to serve specific purposes. We are concerned with power to move industrial machinery, to transport people and goods, to heat, light, and air-condition buildings, and to support our present-day lifestyle, from frost-free refrigerators with butter-conditioners to electric toothbrushes and can-openers. Herein lies our major problem. We have begun to use energy on a scale out of all proportion to what earlier generations have done, and also out of kilter with natural processes. For example, the production of crude oil was negligible 100 yr ago, but by 1966, it amounted to 1.641 billion metric tonnes/yr. During the period 1936–1966, crude oil production increased sixfold, and the world production of motor vehicles increased

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from 5,000,000-19,000,000/yr. We expect to consume more energy during the next two decades than we have in the past century. We are consuming fossil fuels about 1,000,000 times as fast as they were created—burning up in less than 2 centuries the stored carbonaceous material that took at least 200,000,000 yr to synthesize. By natural standards, man is a revolutionary and catastrophic figure. He behaves as no other creature has ever dreamed of behaving.

Energy and Environment

The increase in energy consumption has precipitated concomitant environmental problems since every stage of energy production, transmission, and utilization has an impact on the natural environment. With ever-increasing production rates, the total discharge of waste materials to the environment has gone up as well. However, had all these energy activities been uniformly distributed over the entire country, the resulting environmental problems would not have been so bad. But ever since the Industrial Revolution, which started the great migration from rural to urban areas, human activities are being increasingly concentrated in a few urban regions which means that the environment in a few select areas has to assimilate a variety as well as high magnitudes of residuals. The natural environment in those areas cannot assimilate the waste products as fast as they are produced, creating environmental problems.

Even though the energy industry is one of the major and most broadly spread industries in North America, the environmental consequences of energy production, transportation, and use can be described as relative newcomers as areas 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. We wanted more highways, automobiles, planes, railroads, electricity and central heating and air conditioning of our houses and offices; we were comparatively indifferent to the concomitant increase in environmental disruptions. Consequently, if there was a conflict between increased energy production, or any other type of production for that matter, and the desirability of minimizing the pollution of our biosphere, it would have been resolved in favor of higher production in most cases as a routine procedure. To the extent that we considered this tradeoff within the decision-making framework, we tended to rationalize our decisions with regard to environmental deterioration as the price we had to pay for progress. Thus, in the main, society accepted secondary effects like environmental pollution in its stride.

Energy and Economic Growth

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, to some extent, our "environmental crisis" with relation to energy growth is due both to increasing levels of pollution and to our increasing perception of pollution resulting from the society's need or demand for a better quality of life. This in turn is a by-product of our increasing levels of education and affluence. This shift in value toward a better environment has gradually began to permeate the political process and is reflected in Energy Minister 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 totally environmentally-clean forms of energy sources available, our exponential growth in energy requirements has precipitated related pollution problems. Population growth has certainly been a major factor in this increase, but a more critical factor has been the per capita increase in energy use, so much so that a recent U.S. study attributes only 20% of the increase to population growth and the remainder, 80%, to increased use per individual (8).

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 inevitably 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% and the total energy requirement goes up by 10% during the same period, then the total cumulative effect on the environment will be reduced by a meagre 1%. In other words, to paraphase Lewis Carroll, it will take all the running to keep in the same place.

Environmental Implications

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

The potential pollution hazards from coal, at different stages of its energy conversion process, are shown in a matrix form in Table 1(a). 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. 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

TABLE 1.—Potential Environmental Damage by Type of Energy Source

Parameter (1)	Air (2)	Water (3)	Land (4)	Solid waste (5)	Radiation (6)	Other (7)
			(*a*) Coal			
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 Sulfur oxides Nitrogen oxides Particulates Coke oven Particulates Hydrogen sulfide Carbon monoxide Hydrocarbons	Thermal discharges	Esthetic pollution of landscape	Fly ash and slag Failure of slag heaps		
			(*b*) Oil			
Exploration and extraction	Fuel combustion products	Drilling accidents Brine disposal				
Upgrading	Sulfur 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			

TABLE 1.—*Continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Effect on permafrost			
Utilization	Emissions from internal combustion engines Sulfur oxides Nitrogen oxides Particulates Particulates	Thermal discharge Used oil disposal				
(*c*) Gas						
Exploration and extraction						
Upgrading						
Transportation	Nitrogen oxides at compressor stations		Pipeline problems			
Utilization	Thermal discharge Nitrogen oxides					
(*d*) Nuclear Fuels						
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	
(*e*) Hydro						
Exploration and extraction						

TABLE 1.—*Continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Upgrading Transportation Utilization			Transmission lines			
	Microclimate	Changes in water quantity (level, discharge, velocity, ground water and losses) and quality (sediments, nutrients, turbidity, salinity and temperature)	Flooding Submerged land			Food chain repercussions
						Disease vectors
	Evaporation		Loss of animal habitat			Submerged vegetation
			Landslides Earthquakes			Benthos Aufwuchs
			Drawdown zone			Zooplankton Phytoplankton

disposal of fly ash and slag. Current data indicate that a modern 1,000-MWe power plant, burning 8,000 tonnes of coal per day, containing 3-1/3% sulfur, will produce 27,000 tonnes of carbon dioxide, 550 tonnes of sulfur dioxide, and 70 tonnes of nitrogen dioxide into the atmosphere during the same period (9).

Oil produces different types of waste products from coal, as shown in a comparable matrix form in Table 1(*b*). 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 in the Santa Barbara incident) is increasing all the time. The main pollutant, however, at the extraction phase is the brine that is brought to the surface along with crude oil. It is often reinjected into subsurface strata, which could seriously contaminate ground water. For example, 1 l of brine containing 1,000 ppm sodium chloride will render approx 400 l of freshwater 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 conducted before these by-products can be recycled.

From an environmental viewpoint, as evident from the pollution-matrix shown in Table 1(*c*) 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 sulfide is present, it is removed as well, and sold as elemental sulfur. It has been estimated that 15% of sulfur 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.

Nuclear Fuel Considerations

Mining of nuclear fuels as with coal, produces a large quantity of solid waste [Table 1(*d*)]. 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 sulfur. They do, however, create two 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 (5). A modern and efficient conventional fossil-fuelled power plant converts nearly 40% of the heat energy of combustion to electricity, and the remainder is released to the environment—45% to cooling water and 15% to the atmosphere through the smoke stack. By comparison, a nuclear power plant converts only 30% of the input energy to electricity and the remainder, 70%, is released to cooling water. Secondly, they create a number of radioactive pollutants like the Noble gases (Ar^{41}, fission Kriptons and Xenons), iodines, tritium oxide, Cesium 137, alkaline earths and particularly Strontium 89 and 90, and spent fuel rods that still contain a high percentage of potential nuclear fuel.

Management of highly radioactive wastes presents some unique problems. One of the waste products, plutonium, is the deadliest substance known to man, and it appears that inhalation of a millionth of a gram is sufficient to cause lung cancer. Thus, there are two major problems involved. Firstly, the question of the cost of waste disposal, a waste that has to be completely isolated from the biosphere for at least 200,000 yr (1,2). The costs of these types of hazards are difficult, if not impossible, to quantify under the format of benefit-cost analysis, and, consequently, the benefits may look more real since they could be quantified much more easily. In addition, the underlying premise of benefit-cost analysis necessitates that the redistributional effects of the action, for whatsoever reason, be inconsequential. Thus, when we consider hazards that may affect the society for 200,000 yr, the equity question can neither be neglected as inconsequential nor evaluated on any theoretical or empirical grounds (6). Secondly, we are making a social commitment with an implicit assurance that from now to perpetuity our social institutions will remain of sufficient stability to guarantee the continued existence of a cadre that will continually take care of these highly radioactive wastes. A glimpse at man's past history of only the last 3,000 yr will indicate that this may very well turn out to be an impossible

TABLE 2.—Environmental Implications of Hydro Dam

Physical System			Biological Ecosystem		Human System	
Hydrologic (1)	Atmospheric (2)	Crustal (3)	Aquatic (4)	Terrestrial (5)	Production (6)	Social (7)
Water quantity	Evaporation	Geology (soil, mineral content, structure)	Benthos	Submerged land and vegetation	Agriculture	Anthropological effects
Level	Microclimate	Earthquake	Aufwuchs	Drawdown zone	Fishing and hunting	Political implications
Discharge			Zooplankton	Zone above high water level	Recreation	Social costs
Velocity			Phytoplankton	Failure impacts	Energy	
Ground water			Fish and aquatic vertebrates	Loss of animal habitat	Transportation	
Losses			Plants	Food chain repercussions	Manufacturing	
			Disease vectors			
Water quality						
Sediments						
Nutrients						
Turbidity						
Salinity						
Temperature stratification						

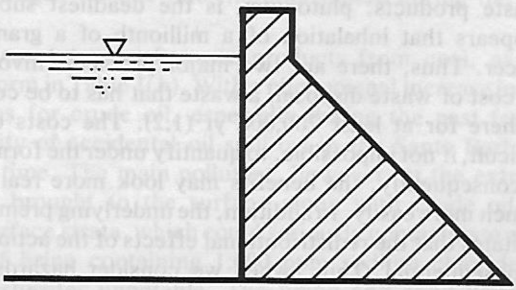

FIG. 1.—Environmental Implication of Hydro Dam

assumption. We know of no government, democratic or otherwise, whose life was more than an instant by comparison to the half-line of plutonium.

Hydroelectric Power

The last, but not least, form of energy generation is hydroelectric power. In Canada, nearly 74% of our electricity is generated by hydro power, and, thus, our utilities are often known as "hydro," and the terms "hydro" and "electricity" are often used synonymously. Table 1(*e*) shows the potential environmental problems associated with hydro power in a matrix form. Since in the case of 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 shown in somewhat different but comprehensive format in Table 2 and Fig. 1. It 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 complex, and at the present state-of-the-art, ecologists and environmentalists cannot predict them with any degree of certainty. Our current knowledge of the ecology of man-made lakes is not adequate enough, and thus several unpredictable and unforeseen situations could develop, some beneficial and some adverse. With this state-of-the-art, 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 environmental considerations have often been lacking for some of our major water development projects (4,7).

Environmental Limits

Energy has been remarkably cheap and readily available in Canada and elsewhere, in part because the environmental effects have been absorbed by a resilient environment and thus true environmental costs are not reflected in energy prices. However, as we move towards the 21st century, we have to consider the possible limits to the environment. Whatever these limits may be, we must test the full range of alternatives for development and final end use of energy to assure that energy development does not lead to environmental sacrifice.

To the general populace, reference to "limits" generally brings to mind traffic congestion—and the environmental impacts from a cheap and convenient energy source that has put one, two, or more automobiles in every garage. The automobile has shaped our cities and rural development for practically all of the 20th century. The average car will burn about 16,000 l (100 barrels) of gasoline before it goes to the scrap heap. There is also the energy used to run the refinery, and indeed the energy that was used to build the refinery. Consider also the energy that is needed to build a new car: To mine and transport the ore, smelt the steel, form the body moldings, even the energy to carry the workmen to the plant and back home after the day's work. Add to that the energy that goes into the building and maintaining our road networks, cleaning the streets, and so on. A tightly knit web of energy demands are woven around the role of the automobile as it has developed to become an integral part of our present lifestyle. It has greatly influenced urban and rural environments, as well illustrates the scope of environmental impacts from the interplay of technology and low-cost energy. Undoubtedly, shifts to new energy sources and higher cost of energy will contribute to adjustments to new ways of moving people, heating homes, and running our industry and agriculture (7).

The ways in which energy is used could be set aside as a separate issue from the direct effects of pollution and treated as simply an adjustment that will be made through economic forces, were it not the disturbing prospects that there are limits to growth. Rising world population, and aspirations for better opportunities and standard of living by the people in less developed nations will pose immense energy demands by the 21st century. In Canada we average more than one car per family. If we assume the Canadian lifestyle as the world norm of the future, can there be an automobile for every family when the global population goes up to 7 billions by the year 2000? If so, what effects will they have on the natural environment? If not, what other choices do we have?

The problem inherent in the limits to growth is fundamentally the problem we are discussing here; the environmental implications of energy alternatives. If the carrying capacity of the environment is finite, then the environmental effects from energy development and use may become the dominant factor in limiting energy use.

Conclusions

The environmental implications of energy alternatives can be dealt with in different ways. One approach is to reduce heat loss, particulate emission, nuclear wastes, and lands taken up by each unit of energy generation, as its use increases. This suggests careful forecasting of energy needs and technological developments. It suggests environmental impact assessment for each new energy project. It requires world-wide cooperation and joint action such as in the United Nations' Environmental Program. It necessitates social responsibility and concern for the environment at every stage of energy development and use.

A second approach, one which can proceed in parallel, is to minimize environmental demands by minimizing energy use, and increasing the efficiency of energy generation, transmission, and consumption. This suggests a change in attitudes towards energy. It would encourage everyone to use less energy. It would be supported by energy conserving technology, communications technology to replace business travel, architecture for heat conservation, and higher quality construction for longer life products. In essence, it suggests a thrust to growth in quality, not quantity, in the coming decades.

An entirely different scenario is possible, of course, i.e., to play down the environmental impacts from our growing prosperity. But if the environmental concern that the public now expresses continues, which it will, and if there is a continuing increase in pollution of the air, water and land resources of the world, then the potential of the energy industries to contribute in full to the growth of prosperity and welfare of mankind will be greatly constrained well before the 21st century.

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12681 ENVIRONMENT AND ENERGY DEVELOPMENT

KEY WORDS: Air pollution; Energy; **Energy consumption; Environmental effects; Environmental factors; Population growth;** Water pollution

ABSTRACT: Since no totally environmentally-clean forms of energy sources are available, our exponential growth in energy requirements has precipitated related pollution problems. Population growth has certainly been a major factor in this increase, but a more critical factor has been the per capita increase in energy use, so much so that a recent U.S. study attributes only 20% of the increase to population growth and the remainder, 80%, to increased use per individual. 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.

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