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Science Council of Canada Report No. 23

March 1975

Canada's Energy Opportunities

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The Honourable Charles M. Drury, PC, MP,
Minister of State for Science and Technology,
House of Commons,
Ottawa, Ontario.

Dear Minister:

In accordance with sections eleven and thirteen of the Science Council of Canada Act, I take pleasure in forwarding to you the Council's Report No. 23, *Canada's Energy Opportunities*.

The study on which this report was based was commenced in September 1971 and the Council's Committee and contractors have been in contact with substantially all those who have knowledge or concern about Canada's energy opportunities. To the best of our ability, the report is based on a sound analysis of factual information.

The Report outlines the Council's views on action which should be commenced now and continued into the future if we as Canadians are to keep our energy options open so that the difficult political decisions in this field as they emerge can be based on the widest degree of choice. We would like to stress that it is our opinion that if action along these lines is not initiated, political choices will be narrowed to the point where second or third best choices are those which remain as political options when the time for decisions arises.

As quickly as possible, the Council will be placing the background information on which this report is based in the public domain.

Yours sincerely,

Roger Gaudry,
Chairman,
Science Council of Canada.

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I. An Initial Perspective

Canadians can be optimistic about their long-term energy opportunities. Our energy resource endowment is vast and varied, our options are many and our human potential for exploiting this position is adequate.

However, in sharp contrast to our growing understanding of the great extent of our energy resource base, we in Canada face real concerns about possible energy shortages, and particularly about possible oil shortages, in the years ahead. This paradox of potential scarcity in the midst of potential abundance is not difficult to explain.

First, in the immediate future, even though we are net exporters of oil, we will remain unable to deliver Canadian oil to markets in Eastern Canada, since there is no transportation system in place; in an unsettled world market for oil, this makes us vulnerable to threats to the security of our supplies.

Second, during the 1980s we are unlikely to be able to satisfy demands for oil from domestic production even though we have found the needed resources. We will become net importers of oil because we will not be able to install the necessary productive capacity and transportation systems in time. This may apply also, to a lesser extent, to other forms of energy. Again, to the extent that we have to be importers, we endanger the security of our supplies.

Third, the potential abundance beyond the eighties depends on our having, at that time, the technological capability to use energy resources which we are unable to utilize today. These presently untapped resources will have to replace the conventional supplies which we are currently depleting.

The paradox of scarcity in the midst of plenty is a consequence of the long lead times involved in introducing new patterns of supply and demand into energy markets. It takes time to develop new transportation systems and new productive capacity, it takes time to develop new types of energy supply technologies, it takes time to change demand patterns. To resolve the paradox, we must make a start today on all of the activities needed to turn our potential future abundance into a practical reality.

The solutions to the immediate problems facing us, and to many problems in the eighties, are dependent on political decisions much more than on anything which R & D might produce. They will require prompt actions by governments and by the energy industries to ensure that our conventional resources are found, developed and brought to market – they will also require sustained efforts by consumers to avoid waste. R & D, however, is the key to unlocking the potential of the resource base on which we will be dependent in the long term. A failure to mount technological initiatives now will ensure that our paradox remains unresolved and that we will face continuing "energy crises".

In this report we have set out to identify the energy options open to Canada, to argue the case for energy R & D to keep those options open, and to discuss its organization. Our concern is with the problems of both energy supply and energy demand. Moreover, we stress throughout the report that energy R & D should not operate in a vacuum, but instead should be closely integrated with Canada's long range energy policy, and we insist that this should be a national policy, embodying the interests of both federal and provincial levels of government.

To date all developed nations, in establishing their energy policies, have tended to place dominant emphasis on supply growth, to the exclusion of consideration of the possible curtailment of demand. Alternatives are now being considered and it is clearly recognized that, in the longer run, reducing the rate of growth of demand must receive much greater attention than it has in the past. In this report we discuss in some detail the actions the Science Council of Canada believes should be taken on both the demand and the supply fronts.

R & D is not a single entity but a complex web of government, industry and university efforts, of pure research and the application of results to social and technical problems. In brief, the main objective of energy R & D is to acquire and use the scientific and technical knowledge necessary for both the development of an energy policy and the achievement of its objectives. This, of course, assumes the availability of clearly stated goals of energy policy toward which to direct R & D. Currently, this is not the case. Instead, policy making is frequently a matter of implication; alternative scenarios are not systematically presented and their impacts not always assessed. Consequently, R & D thrusts are often guided by existing momenta, established organizations, vested interests and dominant personalities. While it is admittedly difficult to formulate the goals of energy policy explicitly, one of the most important goals relevant to R & D must be to reach a position in which there will be no technical restrictions barring Canadians from access to their natural resources. In this light, R & D funds can be considered payments for future security.

Obviously Canada cannot fully develop all conceivable options. Moreover, it need not do so. Full development of any resource or technology is the final step beyond a number of stages ranging from exploratory research efforts to pilot plant design and operation. Financial and manpower commitments grow substantially as one moves from the early to the late stages of development. Thus, while an energy R & D program for Canada should be as broad as possible in the exploratory and low-cost stages, we should be very selective when it comes to pushing any technically promising option to full development. If Canada follows this strategy, we will be in a position to choose those alternatives that appear most suitable for the economic and social condition at any future time, rather than being forced into second or third preference choices through collective ignorance. In this process we will on occasion follow blind alleys in the exploratory stages. But the cost of these failures will be small compared to the cost of foregoing the development of important new energy sources.

It should be remembered that development within Canada is not the only option. One can often buy technology abroad and this may on occasion be preferable, particularly as an economical expedient in the case of those technologies we do not now consider vital to Canada's energy future. This of course implies that the technological and industrial community is in a position to understand what it is buying and is in a position to use it. When purchasing technology, it is important to retain the ability to continue further development within Canada, both to enable us to respond to particular domestic conditions and to avoid being excluded from future export opportunities.

Energy R & D does not exist in isolation, but rather in a matrix of social and economic opportunities and pressures that occur not only in Canada but in the world as a whole. Thus, we can approach a discussion of the relevance of energy R & D only through an examination of our resources and of the possible demands that may occur in the future. Furthermore, the process of examining energy supply and demand projections and of developing an R & D strategy will itself play a part in determining the future mixture of energy supply and the future level of demand. For example, emphasis on nuclear technology will inevitably mean a stimulus toward an electric society while emphasis on coal gasification and the synthesis of hydrocarbons would tend to prolong the petroleum era. Formulation of an R & D policy, as we will show, requires decisions on the long-term energy system in Canada, decisions which may be based on factors other than simply supplies and demands, and which may include employment patterns and other social and environmental considerations. In addition, the criteria which influence decisions may change over time and we may have to depart somewhat from any predetermined position. Reliance must be placed on a flexible mechanism to sense and respond to new situations.

There are difficult questions to face as we attempt to foresee the kind of energy system we should develop for the next century. While the Science Council does not advocate solutions depending on rigid planning, it is conscious of the fact that at present the stance of governments is too reactive. The BNA Act is in part responsible for the apparent lack of an active policy. The time appears ripe to modify our approach to formulating national energy policy; we devote some attention to this serious problem in the report and suggest at least the outline of a solution for the consideration of Federal and Provincial Governments.

The Science Council believes that the elements of a long-term national energy policy that relate most pertinently to research and development needs are the following. We should gradually move away from a dominant reliance on non-renewable energy resources toward inexhaustable* ones; from traditionally high rates of demand growth, and from environmentally harmful uses and processes toward less destructive ones. These trends should take place in a framework within

* The words "inexhaustable energy resources" as used in this report do not consist only of those in the conventional sense of the word (such as solar and hydro resources) but also include those for which a very long depletion time exist (uranium, thorium).

which flexibility for moving from one energy form to another is created. Moreover, energy for home and commercial use, transportation and industry must at all times be assured even though the form may be permitted to differ from the users' first choice. Regional differences will be an important consideration – for example, while nuclear energy may be a logical choice in Ontario, it may not be so in Alberta at the same time. Actions will be needed to ensure the security of energy supply: "do nothing" is not an acceptable stance. More freedom of action can be obtained, for example, by increasing the variety of available types of supply through R & D, by a strategy of importing some energy resources from diversified sources of supply without greatly lengthening the transportation routes, and by increasing our capability for competitive substitutions of one form of fuel for another.

There is one further consideration which will influence Canada's national energy policy, and hence our energy R & D program – that consideration is Canada's international role.

Canada is endowed with a quantity and variety of energy resources unique in the world. The very fact that one of the main concerns for Canada, identified in this report, is the need for determining the desirable nature of Canada's future energy system reflects the fortunate position in which the country finds itself. It is a position it shares with few other countries. Most countries do not have choices but instead will increasingly encounter difficulties in satisfying their very real energy needs. Canada's situation of having energy riches in the midst of a world of energy shortages creates both problems and opportunities.

The problems have been defined in their starkest terms by Maurice Strong when he said:

> "Canadians must face the prospect of having to defend before the world their continued right to exclusive sovereignty over a disproportionate share of the world's territory and its resources. Just as the needs and interests of the whole national community have in the past led to modification of our concepts of private property, to permit intervention, control and even expropriation of private property, in the public interest, the increasing pressures of population on scarce resources are bound to raise the same kind of issues internationally. Indeed such questions may be raised sooner than most Canadians think – and most likely by our best friends."*

We believe that, in this context, the principal concern is for the plight of energy-poor Third World countries, rather than for those developed nations which already consume a disproportionate share of our global resources.

*"Canada in a Planetary Society", Address by Maurice Strong to the Men's Canadian Club of Ottawa, 12 February 1974.

The opportunities, on the other hand, are usually more clearly perceived. Canada's resource endowment may be likened to the inherited capital of the millionaire's son. He may fritter the money away in idle complacency, protect it against the onslaught of the tax collector, or employ the capital to his own and his society's benefit. It is, of course, the latter course Canada must follow with its energy resources.

The world will not tolerate Canada's hoarding: equally, Canada should not accept a policy that results in the loss of its resources to the rest of the world without greater benefits to the country than has been the case in the past. Petrochemical exports instead of gas, agricultural products for world needs instead of oil, electricity exports and nuclear stations instead of uranium are just a few examples of the kind of changes in our traditional stance that can benefit both Canada and the world.

In short, the crux of our argument is that it is essential that Canada have a national energy policy for the long term, that an R & D policy be a vital component, and that steps be taken now to set the necessary R & D in motion on a wide variety of fronts. Lead times for introducing new technologies can be a decade or more in length, and it is longer still before these technologies have a significant impact on the overall energy supply and demand picture. Considerable change will take place in the way in which we fuel our society over the next fifty years. If we act now, we, in Canada, can look forward to these transitions with assurance.

II. Present Trends

Too often we Canadians allow our perspective on our energy resources to be confused by other countries' problems. Canada's position in relation to any of the Western market countries is one of almost embarrassing riches. Not only does this country have enough of all the basic energy resources, but it has, of some, quantities well beyond foreseeable needs. However, these resources are often only potential, not proven, or are not easily recoverable with present technology under current economic conditions.

In spite of the remarkable resource base Canada possesses, we could still make tragic mistakes. Instead of husbanding our resources wisely, we could exhaust them recklessly and rapidly. For a few generations, we could live a comfortable life depleting resources without improving the lives of the underprivileged at home or abroad. Similarly, we could develop our resources for the benefit of other nations without using them as a base for building a more diversified economy at home. All of these possibilities are conceivable consequences of our present lack of a clearly articulated energy policy.

To the extent it exists, energy policy in Canada, as elsewhere, has been concentrated on the short and medium term. This is understandable. Present day needs must be satisfied, and decisions must be taken now to assure readiness for the 1980s and the period immediately beyond. One of the dangers of having only a short-term perspective, however, is the prospect of a lack of manoeuvrability in the longer term, the future too often being seen as a direct extension of the present. Where oil, gas, coal or hydro-electricity are used now, it is assumed that they will be used in the future as well. But for the longer term this mode of thinking contains many pitfalls. While it is true that the country as a whole has an enormous investment in utilities, industrial plants, appliances, transportation, space heating facilities, and the like, which will require quite specific fuels or particular forms of energy, it is probable that the mix of both the primary sources and the secondary forms will change substantially in the longer-term future.

The primary emphasis in this report will be on the long-term future. We stress the point that this perspective is by no means a mere academic exercise. On the contrary, our future energy economy is going to be quite different from the present one and we in Canada must start consciously to establish the bases of future options today in order to maintain our freedom of choice tomorrow. We must begin now to determine what options are attractive, and do all the R & D work necessary to put us in a position to choose when a decision is required. We must emphasize that new technology based on today's science will not be fully incorporated into the energy system overnight because of the long lead times involved. If nothing else does, the reality of lead times measured in decades should shake Canada out of the complacency caused by the vastness of its potential resources.

Before discussing future prospects, however, we will briefly consider in this chapter the present situation and show some of the aggregate trends in both the supply and the demand areas.

The Energy of Today

During the last few decades, demand for primary energy in Canada has increased at an average annual rate of 4.3 per cent. Since the early 1950s, a marked shift from coal to oil and gas has occurred, with hydro-electricity's share remaining constant. At present, approximately two-thirds of the primary energy demand is satisfied by oil and gas, one-quarter by hydro-electric generation and one-tenth by coal, with wood and nuclear – while accounting for 1 per cent each – moving at unlike rates in opposite directions.

Oil

In the recent past, western society has been run mainly on oil and natural gas, non-renewable resources that will become scarcer and more expensive with time.

Canada's proven oil reserves and our ability to deliver them to market have been evaluated by a wide variety of industry and government experts. The picture they provide is that production from Canada's proven conventional crude oil reserves will diminish within the next few years. Even assuming a linear growth in demand (rather than the customary exponential growth rate projections) we can predict that Canada will be producing much less oil than it uses and by the mid-eighties, the short-fall could reach as much as one million barrels a day. Assuming an import price of $10/barrel this would result in an oil trade deficit of almost $4 billion per year, a sum which would increase annually.

Our perceptions of the coming problems are as follows:

First, we are currently using more energy than is being found. Forecasts point to increasing rates of energy consumption. The oil industry's investment in exploration is inadequate to meet the country's growing energy needs. Moreover, government-owned operational companies are not equipped to conduct enough exploration and development on a short time scale to compensate for the lack of industrial activity.

Second, finding and evaluating resources and actually providing supplies are very different matters. A distinction must be made between reserves and their availability. It takes time, capital and skills to locate and delineate new resources, but it takes even more time to develop a system for the production, transportation and delivery of energy. Furthermore, the development of a "connected capacity" is still more difficult when one is dealing with hostile climatic and/or offshore environments; additional difficulties may arise from legal, financial, manpower, equipment, or materials constraints. In addition, in any attempt to make ends meet (i.e., to have supply and demand balance) by stretching the supply, we will soon discover, like many other countries before us, that it takes time to change demand patterns whether this is attempted by energy conservation measures or by substitution between fuels.

Third, if bringing in new "conventional supplies" or changing demand patterns seem to be slow processes, then developing and introducing new technologies are even slower. While it may take as long as 10 years to develop and connect an oil field to markets, it can take 25–35 years, or even more, before society begins to enjoy the benefits of a new energy supply technology. It is thus certain that with regard to the projected shortages of the 1980s, we do not have many alternatives left.

Two factors can ameliorate this picture, but not before the mid-eighties – frontier oil and the oil sands.

Industry expects to be marketing oil from the Arctic and Atlantic regions by the mid-eighties. Successful developments would certainly relieve the situation for a while. This is so because when we divide the remaining recoverable conventional oil reserves of established producing regions of Canada by their annual production rate, we obtain a life index of only 14 years. Estimates of oil reserves recoverable from our frontier areas vary considerably depending upon geological assumptions such as size of pools, required pipeline connections, field prices and several other factors. An examination of these estimates – in the absence of any proven reserves to date and in the presence of firm indications of very expensive operations even by today's criteria – would suggest that reserves in the range of 4–5 times the remaining recoverable reserves of oil producing regions of Canada (i.e., 35–40 billion barrels) must be viewed as being optimistic. Even using these optimistic forecasts, it is apparent that domestic conventional crude oil is certain to become relatively less important as a basic energy source in Canada. Secondary and tertiary extraction techniques should increase production as the price per barrel rises, but it seems unlikely that this extra oil will contribute significantly to overcoming our long-term needs.

Will the vast oil sands of Western Canada be able to change this picture in the short term? Certainly the oil is there in quantities that exceed projections of Canadian demands over the relevant time frame, but there are considerable obstacles to be overcome before this oil can flow to market in the quantities required over the next few decades. Its exploitation with present technology is very capital-intensive: an investment of more than $1 billion can be anticipated for each project with a capacity of 125 000 barrels per day. Thus, to reach a projected oil sand output of about 1.5 million barrels per day by 1990, an investment well in excess of $12 billion will be required. This assumes, moreover, that the labour is available. As will be discussed later, neither assumption may be justified. It also assumes that as yet unsolved air and water pollution problems and other social concerns can be overcome.

One may easily be misled by the vastness of the potential supplies and erroneously associate ease of development with the size of the resource. In time, the oil sands will almost certainly produce large amounts of fuel for Canadians but not much before the end of the eighties. Gradually production may build up to a steady flow of one or two million barrels a day, a welcome contribution to Canada's supplies.

Canada's position on the role of oil in its total energy system will be determined by five major factors. First, there can be no argument with the fact that oil, a non-renewable resource, will become scarcer and more expensive and the rate at which this happens will profoundly influence change in our energy system. Second, there are a number of end uses of petroleum for which it is difficult at this time to identify economically feasible alternative fuels or feedstocks. Third, two dominant parameters in the supply picture are the extent to which oil will be found (or is present) in the frontier regions, and the rate at which it can be developed if found. Fourth, one must take into account the rate at which it will be possible to develop the Alberta oil sands. What this rate will be is currently far from clear. Fifth, it is impossible to predict with assurance the direction in which world prices of oil will move. Opinion on this question ranges from those who believe that we will have sufficient oil supplies at prices prevailing before 1973, to those who predict prices of $20 per barrel in the next decade.

The known and the unknown in all of these factors are together more than sufficiently compelling to counsel against any policy making Canada more dependent in relative terms on oil for its energy requirements. Instead, cautious, gradual substitutions, an increasing capability in the substitution of other forms of energy for petroleum, increased efficiency of use, and decreased exports, appear at this time to constitute the most desirable policy.

Natural Gas

Natural gas constitutes about 19 per cent of Canada's present primary energy supply; we use about 1.3 trillion cubic feet (Tcf) (37 km^3) annually and export a further 1 Tcf (28 km^3).

Canada's southern reserves of natural gas are limited in size, proven reserves being of the order of 53 Tcf (1500 km^3) compared to a total annual production of about 2.3 Tcf (65 km^3), and hence these existing reserves are insufficient to satisfy long-term escalating demands. However, in contrast to the experience in oil exploration, frontier exploration for gas has already resulted in significant discoveries in the Arctic and off the Labrador coast. This new gas may double our presently known reserves at current prices.

Reserves increase in size as the price of natural gas increases. If the well-head price were to rise, for example from 40¢ to about $2.00 per thousand cubic feet (28.3 m^3), it might increase the frontier potential about 5-fold from approximately 100 to 500 Tcf (3 000 to 15 000 km^3). Such an increase, however, would be more important in terms of increasing the time to exhaustion of the resource than it would be in terms of increasing the amounts which could be delivered to market in any one year, at least in the short term.

The factors influencing the use and availability of natural gas are similar to those operating in the case of oil. The level of exploration activity, the size of reserves, the influence of price on demand, the distance to market, the nature of export policies, and the existence or (in key cases) absence of transportation and distribution systems all interact to condition the present uses and future prospects of natural gas in Canada.

Coal

In 1972, coal production in Canada reached a high of about 20 million tonnes. Coal reserves available for mining, excluding any potential north of the Sixtieth parallel, have been estimated as exceeding 100 billion tonnes. About 98 per cent of these reserves occur in Saskatchewan, Alberta and British Columbia. Comparing Canada's recent coal production rate with measured coal reserves, it can be seen that Canada's coal has a life index of 500 years. The life index calculated in terms of more liberally evaluated reserves (based solely on geological considerations and excluding economic factors) is expressed in thousands of years. Thus, coal in Canada is a finite but vast fuel resource. It is at present experiencing a resurgence in its importance, although it still only provides about 10 per cent of our primary energy supply.

Surface mining operations in Saskatchewan and Alberta yield lignite and sub-bituminous coal for the expanding electric utility industry of the Prairie Provinces. These operations enjoy high productivities and have potential for strong expansion. The current production of some seven million tonnes will almost double during the next decade. Low-cost prairie lignite and sub-bituminous coals are likely to become the feedstock of gasification processes, when synthetic gas becomes economically attractive. At the present time there are no coal gasification or liquefaction plants in operation, but a gas company has announced its interest in introducing such technology into Canada.

The Rocky Mountain fields of Alberta and British Columbia produce metallurgical coals, and output has been increasing since 1967. At the present, the production is about 10 million tonnes per year; this output is expected to increase in the future, perhaps to 20–30 million tonnes per year by the mid-1980s. Most of this coal is exported to Japan and further development will depend upon acceptable international markets or upon economic transportation being provided in Canada.

In Central and Eastern Canada, steam-raising coal competes with oil, natural gas, uranium and hydro-electric power; the delivered cost of coal has always been a key consideration, and its sulphur content is now an important environmental consideration. High transportation costs from Western Canada make that coal less economically attractive than coal imported from nearer fields in the United States. About 17 million tonnes are imported annually. Of this total, nearly 10 million tonnes are used in thermal power plants by Ontario Hydro Commission, the remainder going to the steel industry. As in the case of oil mentioned earlier, our lack of adequate transportation systems has effects on the security of our supplies. A low cost transportation system is a prerequisite if coal is to be supplied to the expanding markets of Eastern Canada from the potentially highly productive mines of Western Canada.

The ability of Canadian coal to penetrate further or to maintain its position in electrical generation will depend upon many technological, environmental, social and economic factors – topics which are discussed later in this report.

Hydro-Electricity

Hydro-electric power, another form of primary energy, has always been important in Canada; we are the world's second highest per capita users of electricity. The total installed hydro capacity is in excess of 34 000 Mw representing about 63 per cent of our total installed electric power capacity. Hydro-electricity provides about 23 per cent of Canada's primary energy supply.

Remaining undeveloped hydro-electric potential might yield, if developed, as much as two and a half times the existing capacity, but the undeveloped hydro sites in Labrador, Quebec, Manitoba and the Yukon are far from existing load centres. Because of high transmission costs and losses which may account for 10 per cent of the power generated, hydro power encounters considerable competition from thermal generation that can be placed near the markets. Nuclear reactor plants are now emerging as particularly strong competitors.

The extent to which hydro-electricity will be developed further in Canada will depend on answers to questions about the rate of growth in demand and the degree of public tolerance of flooding of valleys. Hydro developments, like other major projects, should always be subject to a formal environmental assessment prior to commitment. However, recent rises in crude oil prices, and higher prices and eventual end-use control for natural gas, may tend to make even remote hydro sites more attractive in future, provided that progress is made on transmission technologies and suitable environmental practices are followed.

International trade in hydro power between Canada and the U.S., although a small fraction of the total production, has significant ramifications. In the short term, exchanges of electricity are relatively small but they are operationally important in that they allow improved use of facilities. In the long term, export of large blocks of power may facilitate the early full development of some hydro sites, but such accords could create problems at any future time when there was a need to terminate exports.

Uranium

Nuclear power in Canada has moved from the status of a developing possibility to a commercial reality, so the availability of uranium, the current nuclear fuel, is an important consideration.

Canada's known reserves of uranium are large. Current production, of about 5 000 tons per year, is more than eight times the amount of domestic consumption even though the industry is operating below full capacity. Internationally, uranium is emerging from a period of depressed markets and the industry can look forward to increasing levels of exploration, development and production as the world demand grows. The expected rapid growth in world demand could have the effect of driving uranium prices upwards, giving an additional stimulus to industrial activity in exploration and production.

Given our present state of knowledge, Canada's reasonably assured resources of uranium which could yield uranium oxide (U_3O_8) concentrate at prices of up to $15.00 per pound can be conservatively estimated as being at least double our domestic needs to the year A.D. 2000. The reserves recoverable at more than that price are many times greater and, since the cost of electricity from the CANDU system is largely insensitive to the cost of fuel, this should give us considerable confidence. Unlike other fuels such as coal, where transportation problems are considerable due to the bulk which has to be moved, uranium presents little difficulty since its energy content per pound is so very much higher than that of its competitors.

Canada's attitude to uranium exports is governed, currently, by two considerations: the adequacy of reserves available to satisfy domestic demand and the adequacy of international safeguards to ensure that exported uranium is used only for peaceful purposes. The federal government has announced a set of prudent guidelines covering the first of these two points and is believed now to be giving needed attention to the latter problem.

While the CANDU system uses natural uranium, many other nuclear power systems depend on the use of "enriched" uranium, that is uranium in which the proportion of the fissile isotope U^{235} has been enhanced. The available technology for uranium enrichment is both capital intensive and energy intensive. Any ventures into uranium enrichment in Canada (and two consortia are currently considering them) would be aimed entirely at export markets and would contribute to the problem of phasing in very large energy-related projects to which we will refer in the next chapter of this report.

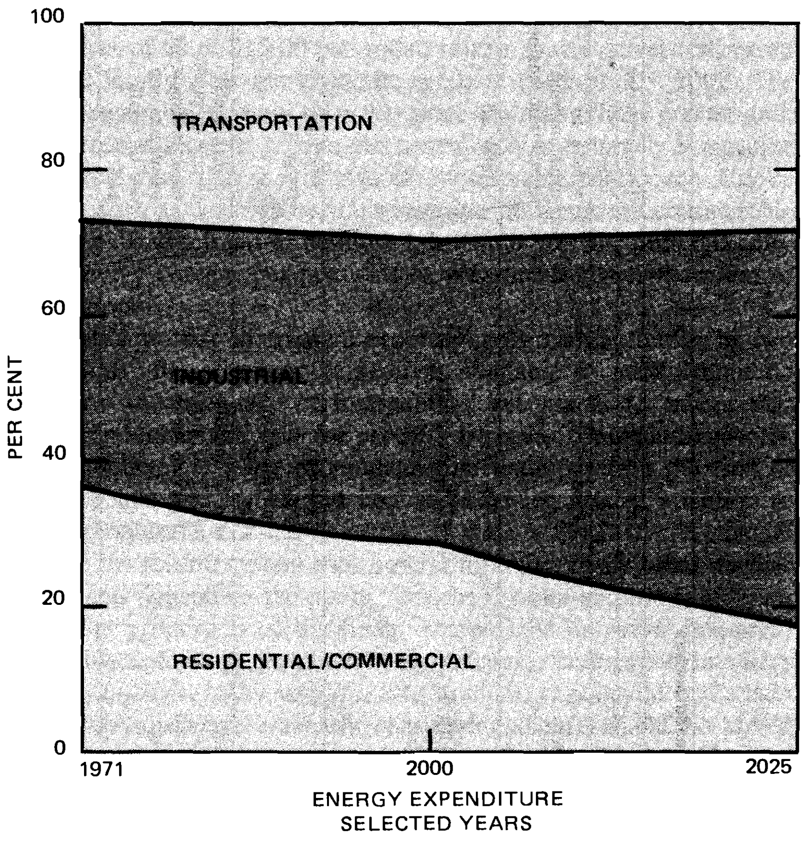
Present Energy Use

The major demands for energy derive from the residential, commercial, industrial and transportation sectors. The specific forms of energy that are used for satisfying the demand vary in the different regions of Canada, and they change with time. The price of alternative energy forms, the existing infra-structure, convenience, tradition and other factors determine the extent to which any one form is utilized for a specific end use. Table I provides a summary overview of the main demand sectors and illustrates our present overwhelming dependence on fossil fuels. In Figure 1, the relative share of the energy budget by each

Table I – Some Characteristics of the Various Demand Sectors

	Residential	Commercial	Transportation	Industrial
Share of total energy use	25%	15%	25%	~35%
Dominant use	80% for space and water heating	Varied	~99% to drive internal combustion engines	50% for 3 industries (pulp & paper, chemical, iron & steel)
Main sources	~80% oil & gas ~20% electricity	~75% oil & gas ~25% electricity	~99% oil	all major forms: mix dependent on industry (coal 12.7% (oil 28.7% (gas 34.6% (electricity 24.0% *Total 100.0%*
Increase in period cited	(1959–68) 10%	(1959–68) 103% (but rate dropped after 1968)	(1958–69) 156%	(1958–69) 177%
Present trends	toward a greater use of electricity; introduction of solar heating late in the century.	rate of increase related to growth of service sector.	to higher effi- ciency in public mass transport of passengers and use of smaller cars.	dramatic increase in natural gas use; large decline in coal.

Figure 1 – Energy Expenditure in Selected Years



Source: Derived from figures contained in Hedlin Menzies and Associates Limited, "Energy Scenarios for the Future", prepared for the Science Council of Canada, May 1974.

demand sector is projected to A.D. 2025. The assumption that present economic growth policies are pursued accounts for the growing importance of the industrial sector.

Residential Sector

Two countervailing sets of trends are affecting energy use in the residential sector. Additional energy is needed as a result of the increasing spaciousness of the average single family unit, of the increasing number of families with more than one home, and of the increasing standards of comfort in these homes including both heating and air-conditioning. On the other hand, residential energy use has a tendency to decrease due to the following three separate factors: substitution of higher efficiency fuels for low efficiency ones (e.g., wood and coal replaced by fuel oil products, then natural gas replacement of fuel oil), increased use of electricity for heating, and the continuing shift toward urbanization with the associated high ratio of apartment units to single dwelling units. These countervailing sets of trends have offset each other during the last decade and they may well continue to do so in the future.

Commercial Sector

The energy consumption in the commercial sector has increased much more rapidly during the last decade than the residential sector demand. While residential demands increased by only 10 per cent, the commercial demand doubled between 1958 and 1968. This growth rate, however, slowed down significantly after 1968. Rapid growth of energy use in the commercial sector is related to the expansion of the service sector, including the substantial increase in commercial sector building activity during the last decade. Together, oil and gas currently account for about three-quarters of the energy used by the commercial sector, the remainder coming from hydro-electricity.

Transportation Sector

The most striking characteristic of the transportation consumption demand is that almost all of it is in the form of crude petroleum derivatives. It should give us pause to think that in transportation we are at this time entirely dependent on a non-renewable energy resource.

There is a significant saving in energy to be obtained by increasing the use of public transport. The Science Council is encouraged by the steps currently being taken by all three levels of government throughout the country to reverse the trend of continuous erosion of the public transport system. Continued effort in this direction is required for success.

The sharp reduction in farm population and in the number of occupied farms in Canada after the 1940s coincided with a major trend toward mechanization in agriculture. The agricultural subsector now consumes about one-tenth of all Canadian motor gasoline and Canadian diesel fuel oil.

Industrial Sector

In one respect the industrial demand is different from the demands in the commercial, residential and transportation sectors. We pointed out earlier that in the transportation sector the demand is almost exclusively for petroleum derivatives, whereas in the commercial/residential sector the main fuels that are being drawn upon are gas and oil. In the industrial sector, however, *all* major energy forms are being drawn upon: coal, natural gas, oil, petroleum derivatives, and electric power. The expenditure distribution by industry for each energy type is shown in Table II.

Table II – Energy Resource Expenditures by Industry in 1970

	Coal	Natural Gas	Petroleum Derivatives	Total Fuels	Electric Power	Total Energy
	(Per cent of total expenditure by industry for each form of energy)					
Pulp, Paper and Allied	15	12	17	16	23	20
Chemical and Chemical Products	11	17	26	21	10	16
Iron and Steel Mills	45	7	5	17	6	12
Food and Beverages	2	11	11	8	8	8
Smelting and Refining	8	6	3	5	8	6
Cement and Lime	8	5	1	3	2	3
Other Non-Metallic	1	8	4	3	4	3
Total: All Industries	**100**	**100**	**100**	**100**	**100**	**100**

Source: Hedlin Menzies and Associates Limited, "Energy Scenarios for the Future", prepared for the Science Council of Canada, May 1974.

In addition, in the industrial sector, there are considerable regional variations in energy input by source. These variations are created by two separate factors: first, regional differences in industrial mix, and secondly, regional variations in resource availability. To cite two examples, coal and coke are very important in Ontario primarily because of the dominant position of the iron and steel industry in that province, while oil is relatively important in the Atlantic region because at present no natural gas is available there as an option.

Thus the significant points in this brief overview are as follows. The transportation sector is almost entirely dependent on oil and will remain so for some time to come, while oil and gas are the principal fuels in the residential and commercial sector. The latter sectors will increasingly depend on electric power. In contrast, industrial demand is satisfied by the full range of energy types. The implication of these points for Canada's energy future is encouraging in that much of the total energy demand can be satisfied with oil substitutes (e.g., nuclear power, coal), in the event of prolonged oil scarcity and/or higher oil prices.

Substitutions

Shock waves of concern run through our society when there is a threat of impending shortage of a particular form of energy, such as heavy oil, gasoline, or natural gas. While such concern is natural for sudden reductions in supply there should be much less apprehension when these reductions are gradual, or are only reductions in the rate of increase of the supply of a fuel. Most people do not appreciate the substantial flexibility in the type of energy acceptable for particular end uses. For example, home heating can be accomplished by means of wood, coal, oil, gas, electricity and even solar energy. Some of these forms are more efficient than others, some are more polluting, more labour intensive, more expensive or otherwise less desirable, but all can be used. There is, in general, too little appreciation that the current ways of satisfying specific demands are not the only ones. Moreover, they may not necessarily be the best if all factors are considered.

Substitutions in future are not just likely, they are inevitable. The question is whether we can afford to wait passively for these changes to occur, or whether we should more actively try to foresee and indeed influence them. Changes in one part of the system will be felt throughout the system. A smaller supply of oil need not mean a smaller supply of energy; it may mean instead a larger demand for and supply of some other energy form. To arrive at optimum solutions will require better planning, and this is the subject of Chapter IV.

Short-Range Considerations: a Summary

There are indications of energy shortages in the medium term. Insufficient domestic oil supplies could become a problem in the early 1980s. Natural gas shortages have been predicted both in the short term and, more critically, in the late 1980s.

To summarize our understanding of the short and medium term oil supply situation for Canada we are reproducing in Figure 2 an optimistic assessment* of the maximum volumes of domestic supplies which might be brought to market in the next fifteen years or so, from all relevant sources. Even this assessment indicates a shortfall of supply with respect to demand during part of the decade of the eighties.

More specifically, the diagram indicates that many new sources are important in the medium term, with Western Canada's present reserves declining markedly as the source of production.

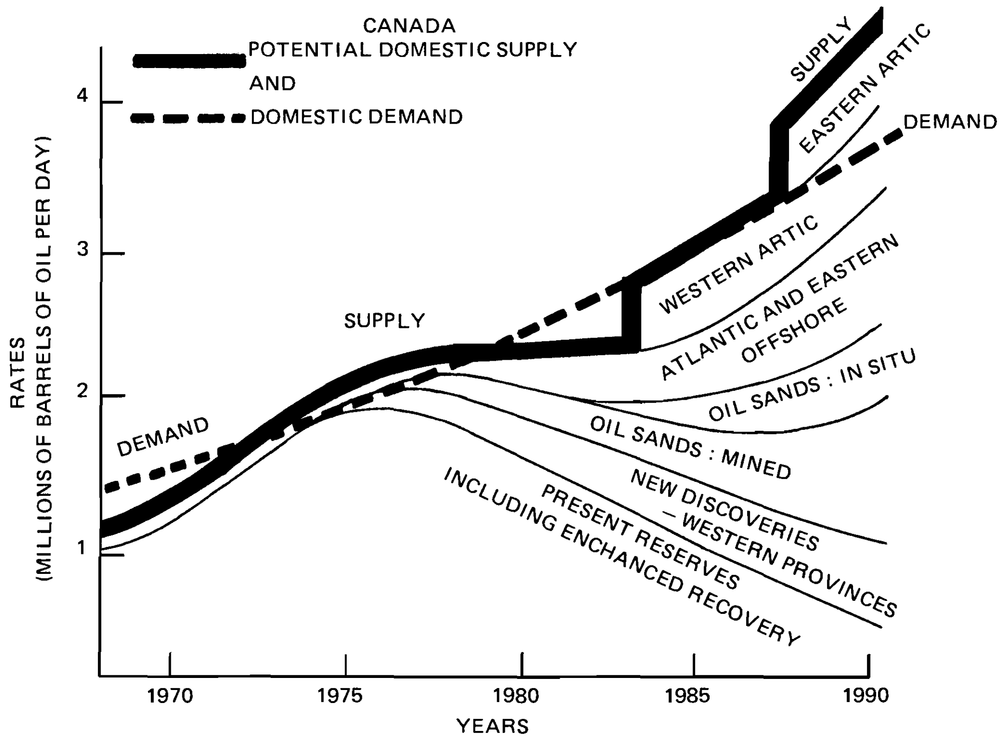
As can be seen from even a cursory glance at Figure 2, a host of actions in many places, almost all in hostile climates, and with uncertain economic outcomes will need to be put in motion and pursued if the needed new capacity to produce oil is to be established without serious slippage. Even if this can be achieved, there will be a shortfall in the 1980s if consumption continues to grow at historic rates.

To summarize the situation a series of short comments on the implications of each entry in the diagram will suffice.

– The "demand" for oil may be modified somewhat by conservation efforts, as we discuss later, but in the short term the extent of the reduction will not be very large. In the long term we could make significant economies, thus easing the supply problem.

* Taken from A.E. Pallister, "Energy for Tomorrow . . . and Beyond", address to the 10th Commonwealth Mining and Metallurgical Congress, Ottawa, 3 September 1974.

Figure 2 – Potential Future Oil Supplies



Source: A.E. Pallister, "Energy for Tomorrow...and Beyond", Address to the 10th Commonwealth Mining and Metallurgical Congress, Ottawa, 3 September 1974.

– Few surprising new discoveries are to be expected in the established production areas in Western Canada. Even the large scale introduction of enhanced recovery techniques will be time-consuming, expensive and will make only a modest contribution to solving our short-range supply problem.

– Production from the oil sands, either by mining or by as yet undeveloped "in situ" techniques, will be limited to a supply of only a few hundred thousand barrels per day during the early 1980s because of the long lead times involved and difficulties in meeting the large requirements for money, equipment and personnel.

– Oil production from the Atlantic and Eastern Offshore depends first on reserves being found, second on a technology being developed to allow us to operate offshore in ice-infested waters and third on the creation of a transportation system to bring supplies to market.

– The most promising avenue at present appears to be the development of capacity in the more accessible northern regions, particularly the western Arctic. This would be contingent on a substantial increase in the rate of exploration and development, perhaps a doubling in the next few years. Bringing these supplies to market would depend on our having an environmentally acceptable transportation system in place, in time. It would also presuppose that equitable solutions had been arrived at for several important social and political problems surrounding such issues as native rights, economic rent and foreign ownership.

Canada does not have the luxury of time to permit a slow development of oil production capacity if domestic oil production is to remain anywhere close to domestic oil consumption. Despite having this report focus primarily on actions whose effects will come to full fruition in the long term, we have clearly in mind that two sets of actions must be initiated now – those actions, largely political or depending on existing technical knowledge, which are needed to cope with near-term oil supply problems, and those R & D programs which have the potential of ensuring the continuity and adequacy of our long-term supplies of energy.

It should be noted that transportation problems rank high on the list of significant difficulties facing most of our energy resources. The technical and environmental issues surrounding potential transportation systems should be tackled with a sense of urgency as they certainly sit on the "critical path" in any scheme for increasing domestic energy supplies.

III. Pricing and Self-Sufficiency

In this report we will make frequent comments on Canada's future energy system. Can its shape be predicted with assurance? While one can do so reasonably for the longer term, it is much more difficult to reply affirmatively for the short to medium term. The single most important determinant giving rise to this uncertainty is the future price of the various forms of energy. There is in this respect a curious difference between the disparate worlds of economics and science. While the economist tends to underestimate the impact of technology as a means to reduce dependence on certain potentially scarce resources, the scientist tends to neglect the impact of price on the speed with which such reduced dependence in fact materializes.

When labour is cheap, fewer machines are used, when the cost of oil is low, less coal is burned. While it may seem that we are belabouring the obvious, one repeatedly encounters statements that result from overlooking this simple fact – the importance of the price of competing fuels and forms. Particularly when discussing new technologies, be they coal gasification, fusion or solar technologies, the impression is often given that such technologies will soon make major contributions to energy supply, merely because they are or soon will be technically feasible. Of course, technical feasibility is a prime requirement for any energy technology to succeed: no technology, however, will be introduced on a large scale when it is not competitively priced in comparison to other technologies. Sunlight is free, yet solar heating of homes and offices would not be widely introduced unless the cost of converting this free sunlight into usable heat were in the same range as heating by gas, oil or coal.

Prices of fuels, such as oil, gas and energy forms like electricity, change with time. When they move upward, previously uncompetitive fuels and forms may become competitive. When easily developed hydroelectric sites have all been utilized, additional hydro development will become more expensive in comparison to other means of generating power, for example, through fossil fuel or nuclear plants, unless, there are offsetting price increases in these latter also.

It is against this background that an R & D program in energy must be designed. When research and development was initiated on the CANDU reactors in the late forties, there was little hope that electricity could be generated at prices similar to then prevailing prices for electricity. It was only the vision of a few far-sighted individuals and their government sponsors that enabled an R & D program to start. In 25 years, just at the time that the fruits of this work have materialized, conditions have changed in such a way as to make nuclear power competitive with other electricity generating methods.

In a similar way we must prepare for the future. The most promising means for providing energy, be it solar energy, or any other, should be developed now, so that Canada is ready at the time when the conventional means of providing energy have become too expensive.

At various points in our report we will make reference to projections, particularly of demands for energy. It is important that we insert here a reservation about these projections which stems from questions of pricing. Almost all forecasts implicitly assume that the amount demanded is not influenced by overall price increases. This, of course, is in direct contradiction to economic theory. Elasticity, defined as the percentage change in the quantity demanded divided by the percentage change in price, is not negligible. Exclusion of price considerations has been dictated by the absence of reliable analysis documenting the precise long-term relationship between energy price and demand in Canada. Such a relationship, however, is known to exist. In the long term, an increase in the price of one fuel relative to another will foster a substitution, and hence a changed demand pattern; and an increase in the price of energy relative to other items will cause a decrease in energy demand.

We have said earlier that R & D funds are investments in future security. Where are they to come from? In its most simplistic form, the choice we have is between having the price we pay for energy today generate the investment capital to ensure the availability of energy in future or expecting to repay from the price of energy produced in the future money which will have to be borrowed or invested from sources outside the cash flow generated by present sales. The appropriate choice, of course, is influenced by, among other things, external factors such as inflation, interest rates, concern about the impact of foreign investments, and by the degree of confidence that we have in our ability to secure the funds from either approach.

There is a further aspect to pricing which is important in energy supply in Canada – that is the idea of a "national price" for specific fuels. As is witnessed by the federal-provincial negotiations over the winter of 1973-74 this is entirely a political concern. To the extent that revenues are redistributed to establish a "national price" they contribute to attainment of a political or social goal, but become unavailable for funding technical ventures. Such a redistribution is embroiled in the much wider negotiations over revenue sharing, particularly affecting oil, in Canada. The fact that the question of "national prices" is a political concern reflects in part our lack of a transportation system for delivering Canadian supplies to all Canadian markets.

Price not only is important in shaping our future energy system but enters into our discussions on that elusive concept of "self-sufficiency". Different people have attached different meanings to the term. With certain variations, two basic interpretations are current. The first and most literal interpretation of self-sufficiency is that all energy requirements of the country are satisfied from native sources. Thus, automobiles running in Canada use gasoline derived from Canadian produced oil; electricity from coal fired plants is generated from Canadian mined coal, etc. Though self-sufficiency of this kind is appealing from a security point of view, the cost could be very high, depending upon the comparative prices of domestic and imported fuels. The price we would be willing to pay would reflect our perception of the value of the security of our supplies.

The second interpretation of self-sufficiency is on a net basis, so that exports and imports of energy roughly balance. Canada is self-sufficient on this basis right now. It is appealing from an economic point of view in that costs to Canadian consumers can be lower, and that the effect on Canada's trade balance is neutral. Economic attractiveness, however, is bought at the expense of security. When imports are suddenly curtailed, or become very expensive, the country can not immediately reorient its production toward the domestic market. One has seen just this when in late 1973 the prices of imported oil increased suddenly and dramatically. Canada was neither in a position to immediately curtail its exports, nor had the transportation network necessary for delivering western oil to eastern markets.

There are three important prerequisites which a country must have if it is to be self-sufficient in energy:

- First, it must have the resource base, for without that there is no possibility of self-sufficiency.
- Second, it must have the technological capability to use its resource base.
- Third, it must install the physical plant to make self-sufficiency a reality.

Canada is fortunate in having an extensive resource base which could satisfy more than our conceivable needs in the long term; the picture in the short and medium term, to the end of the eighties, is quite different. This report lays out proposals for ensuring that the technological capability required is established. It is our belief that in the long term Canada's minimum expectation should be to maintain our position of self-sufficiency and to continue our policy of providing energy intensive products, such as those from our agricultural system, for export. We acknowledge that the rate at which we install the physical plant will be the result of political decisions reflecting concerns over factors such as cost-to-consumers, balance of international trade and short-term security of supplies.

As we have said, we are today self-sufficient, but on a net basis. In the intermediate term we will cease to be self-sufficient, at least in terms of oil supply, and perhaps even on an overall basis. The challenge for the long term is to return Canada to the position of being able to satisfy our own needs and being able to offer help to others in need.

IV. Coordination and Planning: The Key Issues

Whereas our main strength lies in the size and variety of our potential energy resources, our main potential weakness lies in whether or not we have the political and managerial* capability to develop these resources in the time-span available to us and in the face of increasing demands. There are five important questions about our capabilities:

(1) Do we have the technological capability to develop our energy resources? (The bulk of this report is aimed at guiding us toward an affirmative answer to this question.)

(2) Do we have access to the necessary financial resources?

(3) Are the requisite manpower resources available?

(4) Can the materials needed be made available?

(5) Can Canada as a country produce the political strength and unity of purpose to allow it both to plan its energy future, and to marshall the technological, financial, manpower and material resources that will be called for?

To get a feel for the magnitude of the projects which may be carried out in our energy sector in the next 30 or so years, one has only to catalogue the major publicly discussed plans

- the James Bay Project (estimated at $12 billion, as of July 1974)
- the development of several pipelines from the Arctic (current estimates for individual Arctic pipelines range from a low of $3–4 billion to a high of over $6 billion)
- a dozen or more oil sands projects (at least $1 billion each)
- numerous nuclear stations (probably $1–2 billion each).

A little thought about this far from complete "shopping list" of energy projects can lead to the two key questions which underlie any planning – "Where do we want to go?" and "How are we going to get there?". Re-phrasing the first question in terms of energy – "What do we want our energy system to look like in 25 years and beyond?" – yields a question which needs discussion and answers soon. These answers are not ones which we should be leaving to chance. Finding answers will involve making profound choices about the form in which energy will be made available in future. Will we approach an all-electric society or shall we expect equal contributions from gas and electricity, or what? Will Canada be reasonably uniform in terms of the energy forms it uses, or will each region develop according to the local availability of resources, and if so, will we use electricity as the unifying form of energy? Will our energy supply be dominated by ever larger energy producing installations (e.g., bigger power stations) or will smaller units and greater diversity be a feature of our system?

The nature and extent of the changes in the shape of our energy system in the next 20 or so years will largely be constrained by the limits of the technologies now in use or in fairly advanced stages of development; beyond that, the fruits of R & D programs initiated now will become operative and offer a wider range of options. Even in the

* In a national rather than a company sense.

shorter term, the choices involved in guiding the development of a national energy system will have ramifications far beyond the technical sphere. Energy is the lifeblood of our society: change the form of the supply and change in our society's structure will follow. The most immediate consequences could have serious implications for regional development. For instance, decisions in favour of one huge project in region A preceding another in region B will not be easily arrived at, but arrived at they must be.

A National Energy Policy for Canada should fulfil a series of essential functions. It should embody agreement on the kind of energy system to be developed across Canada, and it should set out development priorities for the many large projects which will need to be undertaken. It will have to encompass consideration of which energy resources are available for export and in what form, and which should be imported. It will have to be formulated at a time when cooperation among governments and between governments and the private energy sector is handicapped by a lack of fruitful dialogue. It will have to move toward long-range planning and away from ad hoc responses to sudden crises. It will have to replace the current over-dependence on across-the-board incentives for exploration and development, like depletion allowances*, that have proven to be too diffuse. And it must also overcome the difficulties created by federal-provincial battles over revenue sharing.

Once the general features of a national energy policy have been outlined, one can turn to the second question in planning, that of how to put the agreed upon system in place. It is in this short-to-medium term arena that the financial, manpower and materials supply constraints will be most keenly felt.

To turn now to these constraints, it is the opinion of the Science Council that, with proper scheduling of the major developments which will need to be put in place to meet domestic demand, the Canadian financial community has the resources necessary to cope, with a minimum of foreign help, provided that the world economic climate is relatively stable. Similarly, we believe that personnel and materials problems can be rendered more tractable.

The Financial Constraints

The financial problems are of two forms: can we find the money and, if we can, will such large investments seriously disturb the national economy?

Indeed, a concentration of huge investments within a short time span would have ill effects in terms of inflationary pressures and spiralling costs. There is however a guarded optimism that the financial demands from the energy sector of the economy can be met from within the normal money market. To quote a senior official of the federal Department of Finance:

* See, for example, M.W. Buchovetsky, *The Taxation of Mineral Extraction*, Studies of the Royal Commission on Taxation, Ottawa, 1964.

"Energy industries annually invest sums equal to 35 to 40 per cent of the value of their sales, or, in absolute terms, from 2.8 to 2.9 billion dollars in recent years. Such a level of investment gives this sector alone 25 to 30 per cent of all private investment of a productive nature – that is, excluding housing. . . .

"The first conclusion is that this provides a perspective for the interpretation of the individual energy projects of which we hear so much these days. In fact, when figures 4, 6, 8 billion are mentioned in connection with projects in preparation, we are struck by their colossal dimensions. But these projects are necessarily spread out over a period of several years, and their net impact is therefore somewhat diluted. Since, in addition, such projects simply replace others which have been completed, their economic effect is that much more attenuated. A project of six billion dollars, for example, strikes us as out of the ordinary. However, six billion spread out over four years is 1.5 billion per year. As this 1.5 billion replaces some other capital expenditures which are part of the about 2.8 billion annual investment, the net economic effect can easily go well below a billion dollars a year.

"This does not mean that such large investment projects would not produce economic instability. They inevitably do so. However, this instability is generally less than we fear. Neither does it mean that there is no need to make an effort to program large projects as carefully as possible, for this may eventually reduce instability."*

It must be underlined that this optimistic assessment rests on the key assumptions that there will be a fairly uniform growth in investment in the energy sector, and that steps will be taken to avoid the significant economic disruptions which would accompany the simultaneous launching of several very large projects. The financial management of the energy sector is largely dependent on some means being created that would permit Canada to tackle the problem of phasing in these huge investments by finding some way of negotiating agreement on priorities among the different actors in both the public and private sectors.

The concern about such large investments is partly over whether or not they will attract capital away from other sectors of the economy, which seems unlikely on the basis of past experience, and partly over whether they will cause too large a net inflow of foreign capital into the Canadian economy. In this latter case, it appears that our total financial pool is large enough for less than 10 per cent of the financial demands made by the energy sector to be in the form of a net inflow of investment capital and, as this would be less than 1 per cent of our GNP, it is unlikely to affect significantly the value of our dollar.

An important consideration which has much bearing on the financial picture is the export component of energy developments in

* See O.E. Thur, "Energy Resources – Manpower Considerations" in Royal Society of Canada, *Proceedings on Symposium on Energy Resources*, October 1973, pp. 433-434.

Canada. One kind of project,* which would utilize foreign money, manpower and materials to develop Canadian resources entirely for export, has little if any merit in our eyes. It would mean surrendering part of our sovereignty, it would exhaust our resources and it would bring few long-term benefits to Canada. A second kind of project, in which the scale is enlarged to meet both domestic and export demands, is more difficult to judge. Such projects could complicate the timing of purely domestic projects if the kind of financial stability described earlier were to be maintained, but they could also bring considerable benefits provided we decided to upgrade the resource involved before exportation. For example, a project designed to export electricity rather than natural uranium could be beneficial to Canada. Obviously individual cases would stand or fall on their own merits, and the overall financial picture should be regularly reviewed to monitor emerging problems.

Personnel Constraints

Personnel supply is a present problem but it need not impede energy developments in Canada since it can be tackled on two fronts. First, deliberate phasing of projects can moderate the absolute demand at any given time; second, training schemes can be upgraded to increase the flow of skilled workers. Energy developments may also require the attracting of skilled tradespeople from other countries, but this need not necessarily be the case.

While it is possible to point in the direction of solutions, it would be imprudent to minimize the magnitude or severity of the present manpower shortages. Already, as a result of serious shortages of both design and plant engineers and skilled tradespeople, the construction of more than one plant every second or third year to process the Athabasca oil sands seems unlikely in the short term. We have, in Canada, a limited number of skilled construction workers who move from job to job across the country. Some special trades present even greater restraints. At present, pipefitters are in the shortest supply and may well determine the rate at which such plants may be completed. Thus the overlap of several projects could cause a serious manpower problem. Only by spacing the plants out can we bring the demand created by oil sand plants down to a reasonable level. It must be appreciated that one or two Athabasca plants will provide only a small addition to our oil supply, but will be a significant drain on the labour and capital which are demanded by other sectors of our energy industry and by the support industries that are so vital to completion of energy developments.

It is disturbing to find that governments, industries and unions have no clear picture of our existing labour pool in any particular trade. Already, extensive recruiting campaigns for skilled tradespeople and for engineers in certain specialities have been mounted outside Canada by

* For example, the massive and rapid development of the Alberta oil sands as proposed by Dr. Herman Kahn of the Hudson Institute in the U.S.

some of the companies involved in oil sands projects. There exists a need to know the stock of tradespeople accurately and to increase the flow of people into apprenticeship programs in the scarce trade areas. As the seventies pass we are likely to enter a period when our labour force expands at a slower rate than that to which we are accustomed, thus compounding our difficulty. Indeed, the availability of labour is a real problem which deserves more long-term attention than it has received to date.

Problems may also arise with regard to the provision of highly educated manpower to staff the energy system. There is no clear indication whether the universities, which nurture this manpower, will be able to graduate the required mix of diverse skills needed at the right time. After all, in our society, it is not the university itself, but the individual decisions of aspiring students at any point in time, which determine the ultimate output of universities a few years later. Moreover, while the universities could in principle shape their manpower output, in practice it is difficult for them to do so because of financial stringencies. This concern is a reflection of a general ambiguity present in manpower planning. On the one hand, there is the belief that market forces will balance the supply and demand of the required manpower. On the other hand, when one sees the results of this laissez-faire attitude, for example, a glut of engineers one year, followed a few years later by definite shortage, this lack of planning is decried and condemned. It is as attractive as it is unrealistic to expect to eat one's cake and have it too.

These problems are made more difficult because the responsibilities for education are distributed among ten provincial governments. Two things must be said in this connection. First, in education policy there does not appear to be a close link between knowledge of the specific manpower requirements for any one field such as energy, and the number of people that are, in fact, educated to fill these requirements. Second, there has not always been sufficient recognition of the mobility of manpower and of the national rather than provincial requirements for energy manpower.

If we wish to enable the universities to carry out this manpower role better, two things are required. Most important, at the political level, a clearly enunciated energy policy must be spelled out, setting forth the outline of the new Canadian energy economy, the size of investments, the time sequence of projects, their regional distribution, etc. Second, at the technical level, a set of energy R & D priorities must be outlined at both the federal and provincial levels. These priorities must be in harmony with Canada's energy policy, while at the same time helping to shape that policy. It is only through knowledge of this kind that universities can rationally approach the problem of determining which programs should be emphasized.

Equipment and Materials Constraints

Even if the manpower problem were solved there is another similarly complex problem, that of materials supply. As an illustration, drag-lines and bucket wheels will be used extensively in open pit mining of the oil sands. Unfortunately, there are very few manufacturers in the world and their order books are filled well into the future. Plans to increase production are blocked by, among other things, a world steel shortage; this cannot be solved overnight. Any plan to give priority to oil sand development would conflict with the needs for this equipment in surface coal mining, both in Canada and in other countries, and so it would be a case of robbing Peter to pay Paul. Drag-lines and bucket wheels are only illustrative of the problem – refinery towers, electrical equipment, insulators, and so on are all in short supply. Increased industrial production throughout the world is unlikely to catch up easily with the growth in demands of the energy sector of the economy, especially as this sector is growing rapidly in many countries, not just in Canada.

These shortages are very real at this time: they have led to costly delays in energy development works, and have been a cause of rapidly increasing prices of materials and equipment. What is not clear is whether these difficulties are the normal concomitant of the exceptionally strong performance of the western economies during the past few years (in which case they would disappear during a softening of the economies) or whether they signal a more permanent change. Further study for the resolution of this question is urgently needed.

The Planning Problem

Throughout this chapter we have made frequent reference to "planning", to "scheduling major projects", to a "national energy policy". But how can Canada, as a federal state, formulate a national energy policy in the face of conflicting regional demands and aspirations and the uneven distribution of its energy resources?

In an earlier report,* the Science Council discussed the jurisdictional complexities of the resource fields in Canada, and specifically used as examples the problems of oil and gas. The burden of our argument at that time, when considering the questions of oil and gas, was that the National Energy Board, as a creature of the federal government, was not a forum in which federal-provincial differences could be settled. It is symptomatic of our system that it was a political group at the highest level, a conference of first ministers, which arrived at the single price for Canadian crude oil in March 1974. There appears to be no alternative in the Canadian jurisdictional milieu to having the political choices concerning (in this case energy) resource developments made by a meeting of federal and provincial politicians. At the more specialized, technical level, many of the powers may then be delegated to groups of officials, and they may involve negotiations with the representatives of industry or of consumer groups. Even at the official level, participation

* Science Council of Canada Report No. 19, *Natural Resource Policy Issues in Canada*, Ottawa, Information Canada, 1973.

by the federal and provincial governments is necessary and the relations of both levels with industry have considerable bearing on the possibility of implementing a national energy policy.

As the political importance of energy has been growing, each of the governments involved has been refining, strengthening and extending its own institutional mechanisms for coping with the policy issues to be faced. Alberta has expanded the terms of reference of its Energy Resource Conservation Board and established a provincial energy corporation; British Columbia has created an Energy Commission; the Saskatchewan and Manitoba governments have established instruments for active and direct participation; Ontario has appointed a Minister for Energy, expanded its Energy Board considerably and proposed a government energy company; Quebec has created a General Directorate for Energy; the Federal Government has been strengthening the energy policy groups within the Department of Energy, Mines and Resources and is establishing a federal oil corporation.

These are all, in themselves, moves in the right direction. They will, we hope, provide each government with an improved capability to formulate, plan, organize and coordinate policies for energy matters within its individual jurisdiction. What remains now is the need for some institutional innovation to improve the formal process of federal-provincial joint decision making at the political level. As a minimum, such an innovation should be designed to establish an acceptable set of ground rules to cover negotiations so that these ground rules can themselves cease to be a subject of controversy.

As we have said, the major decisions will continue to be made, as they should be, by Ministers meeting around a table. There are two shortcomings, however, in maintaining this device as the only locus of decision making. First, Ministers cannot be in permanent session and should not become bogged down with minor points of technical argument. Second, at present any Minister arriving at such a meeting is necessarily briefed primarily on analyses undertaken from the point of view of the particular government which he serves. There is no source of analysis which is not subservient to one of the participating parties.

The first of these two problems is relatively easy to overcome: committees of officials can undertake many detailed tasks by delegation from the committee of Ministers – a perfectly normal routine. The meetings of Ministers, however, should be regular and not simply reserved for reactions to crises. It is to be hoped that planning and coordination for the long-term future can be done in an atmosphere other than that which faced the First Ministers in 1973-74.

The second shortcoming could be overcome by providing a full-time staff whose function it would be to undertake analysis on behalf of the collective group. (In the international arena, organizations such as the OECD have developed secretariats to undertake such functions.)

One important function which supporting staff could undertake might be described as "option analysis". Present regulatory bodies, like the National Energy Board (NEB), for example, are usually faced with a single "yes or no" proposition in isolated, case-by-case deliberations. As an illustration, an application to build a northern gas pipeline will be considered mainly as a case on its own. The fact that a decision either way could have long-term ramifications for the shape of Canada's future energy systems and in fact for the entire economy, will not be examined in the broad context it deserves. Would it not be preferable to have the policy decision on whether or not to construct a pipeline arrived at after an evaluation of options? For example, the options to be analyzed might include the following:

(1) build the pipeline;

(2) delay its construction in order to maximize Canadian participation in its development and in the use of the natural gas it will deliver;

(3) provide the same energy by coal gasification;

(4) reduce the demand for gas over an anticipated critical period, perhaps by increasing the price or introducing allocation;

(5) buy gas or oil abroad;

(6) build nuclear power plants;

(7) provide heat, hydrogen or another fluid fuel instead of natural gas.

The immediate reaction of the interested officials to the suggestion of such an exercise is almost certain to be that it is not feasible. The study backing up the pipeline application was both extensive and expensive and could not have been reproduced for all the other hypothetical options. Such a criticism in fact demonstrates the critical shortcoming of our present system of decision making – it is predominantly reactive and permits few analyses of energy options at the earliest point in the life of a potential specific project, precisely when such exercises are eminently feasible and necessary, and when decisions are still reversible.

A means is needed to provide a kind of analysis that to a considerable extent, is different from that employed, for example, to support a pipeline application. The necessary analysis would not provide technical information so much as it would delineate political choices and attempt to identify their long-term implications.

As we look toward the future it becomes imperative that our society make an early and judicious choice as to the direction it will take in energy matters. This choice must be made after detailed analysis of available alternatives. We no longer can depend on the decision mechanisms of the past to adequately cope with projects that are growing in individual scale and impact. Delayed planning limits our options. Similarly, the selection of an unproven system – or its slow development – may lead to late energy deliveries. The cost of fuel to replace the energy production lost through delays or breakdowns can exceed the original estimated capital cost of the delayed system.

Canada needs to develop an informed decision-making process that will allow political choices to be made in the area of medium- to long-range planning and that will ensure that this planning is national in scope and perspective. The Science Council therefore recommends that the Federal and Provincial governments establish a regular series of Ministerial meetings to deal with the problems of devising a long-term national energy policy for Canada. To support these Ministerial meetings a small and high quality intergovernmental staff body should be established; this body should interact closely with the universities and industry, should be equipped to collect and analyze information and should be capable of describing energy development options, together with their consequences.

Energy R & D cannot exist in isolation. A rational policy for energy R & D must instead be closely linked to a long-range energy policy. This requires that we have a clear view of the direction in which the energy system will be going. The first step in obtaining such a view is the creation of a mechanism which would enable us to coordinate and plan for the longer-term future.

V. The Future: Demand

Canada is the world's second highest per capita user of energy, each Canadian using on average the equivalent of 55 barrels of oil per year. Our national level of energy use is also increasing at a prodigious rate, to the extent that one of our background studies* suggests that, on the basis of a standard projection, primary energy consumption by the year 2000 could be almost three times greater than it was at the beginning of the seventies.

Energy drives our society. It heats our homes, moves our cars, runs our mines and factories. It has superseded our muscles and given us prosperity. Its total use has doubled, and doubled again, but we now question whether this can continue at historical rates. If the rate of growth of supply drops, do we face disaster or merely discomfort, or is some of our growing consumption simply waste which we would be wise to avoid in the first place?

Traditionally Canada, in common with other developed countries, has allowed projections of energy demands to dictate policies for energy supplies, with little thought being given to the efficiency with which we use our energy resources. Faced as we are with a difficult and expensive supply problem we should ensure henceforth that supply projections strongly influence policies for the shaping and moderation of demand and we should promote an energy conservation ethic throughout Canadian life. In response to the question "Why shape energy demand?" the Science Council would offer three general reasons:

(1) To make the problem of providing energy supplies less difficult
(2) To reduce the waste in our energy system (about 48 per cent of our current fuel supplies are directly rejected as waste)
(3) To reduce the environmental impact of energy production and use in Canada.

We will discuss the first two of these topics in this Chapter and have devoted a later chapter to the matter of environmental problems.

Our consultants have made careful attempts to estimate potential savings in our "energy budget" as a result of applying the various measures and practices which we will refer to as "energy conservation". As a result of their work the Science Council has concluded that it is reasonable to believe that we could reduce the projected energy demand for the year 2000 by about 15 to 20 per cent, by appropriate regulations and actions, without adverse impact on our economic system. To put this in context, 15 to 20 per cent of that demand represents 45 to 60 per cent of today's demand, so that we are talking of easing the problem of building our future supply system by an amount of around ⅔ the size of our present system.

We expect that total energy demand will grow in Canada, as a

* Hedlin Menzies and Associates Limited, "Energy Scenarios for the Future", prepared for the Science Council of Canada, May 1974, Appendix B. Note that the "Standard Forecast" in *An Energy Policy for Canada*, Department of Energy, Mines and Resources, Information Canada, 1973, appears too high.

result of a variety of pressures which we will mention – we do not dispute this. Our intent is to draw attention to the unnecessary problems which will be created if energy use is continually and carelessly expanded. Canada has an expanding population and this growth will have an impact which reverberates through all sectors of energy demand. We have committed ourselves as a nation, as we should, to improving the lot of the underprivileged and the poor in our society: improving their lifestyles will take more energy. We are committed to improving the economic future of large regions of our country: this will take more energy. We talk of developing the North: this most assuredly will take more energy. The Science Council has no disagreement over the importance of moves on all of these fronts – what the Council rejects is a proliferation of wasteful uses of energy which, in fact, imperil our ability to supply all of the energy which the Canada of tomorrow will require.

The Science Council's attention to questions of controlling demand is a natural outgrowth of the Council's concern, as expressed in an earlier report on resource policy, that "Canadians as individuals, and their governments, institutions and industries, begin the transition from a consumer society preoccupied with resource exploitation to a conserver society engaged in more constructive endeavours."* A strategy to eliminate waste and to promote efficiency of use in our energy system would be an integral part of any attempt to create a "conserver society".

Attempts to introduce an energy conservation ethic into Canada have seemed unimportant in the past because of the widely held belief that the country was so rich in resources that, provided we were prudent in the development of supplies, demand reduction was not needed. Canada is indeed endowed with energy resources of all kinds, but estimates of huge potential reserves are misleading inasmuch as they can lead to the mistaken belief that energy resources can be made available as actual supplies on short notice, without difficulty, when needed. Such a belief ignores the considerable difficulties which we have described earlier and which lie ahead as we attempt to cope with even a moderated growth in energy demand. As Canada exhausts her easily accessible, and hence cheap, sources of energy, we must turn to increasingly expensive alternatives, thereby lowering the net energy return per dollar invested. Demand shaping offers some hope of attenuating the strains on our economic system that the expansion of our energy supply systems are likely to create.

The rationale for conservation and a selective growth is especially strong in the case of oil. The transportation sector and agriculture are heavily dependent on oil and its derivatives, and no practicable alternatives are in sight. The production of a wide array of petrochemical products are dependent on the availability of oil or natural gas as a feedstock. In the face of these hard realities, any demand for growth in

* Science Council of Canada Report No. 19, *Natural Resource Policy Issues in Canada*, Ottawa, Information Canada, 1973, p. 39.

the use of oil in circumstances where substitutes are available (e.g., for the generation of electricity) should not be accepted lightly.

Technical Directions for Energy Conservation

The Science Council believes that there are four important technical directions in which Canada should move, to promote energy conservation. Briefly, we should take the appropriate steps

1) to increase the efficiency of energy use
2) to improve energy conversion efficiencies
3) to promote substitutions to optimize the use of scarcer fuels
4) to reduce unnecessary demands.

Improved efficiency of energy use can fulfil demands while reducing the input supplies of energy. For example, lower fuel consumption would result from improved insulation and design of buildings to maintain desired heating levels, reducing the weight of automobiles, and experiments with making productive use of currently wasted heat, particularly from power stations. We could promote, with greater vigour, mass transit systems as more efficient substitutes for the private automobile. To improve energy conversion efficiencies we could insist on improvements in the efficiency of operation of furnaces, motors and air conditioners and could build energy conservation concepts into industrial processes. Among desirable substitutions, we could substitute coal, hydro or nuclear power for electricity generated from oil or natural gas, or develop technologies to permit us to use solar energy instead of fossil fuels for part of our space or water heating. To reduce unnecessary demands we could recycle materials whose initial production is energy intensive, and we could produce more durable goods and improve design and maintenance to reduce the need for replacements. At the individual's level, domestic waste of energy could be reduced by taking a little care.

We have introduced these examples to provide an impression of how pervasive an energy conservation ethic might become. In many areas there are opportunities for our industries to assume a position of leadership, by promoting "energy conservation conscious designs". Canada's Industrial Associations could contribute by activating task forces to identify ways and means of enhancing the efficiency of energy use in their industries and by their products.

Some Problems Surrounding the Prospect of Reduced Demands

The benefits of reducing the rate of growth of energy demand, in an age of growing concern over environmental degradation and rapid resource depletion, can be convincingly portrayed. Critics will question, however, whether the costs of energy conservation may not outweigh the advantages to be gained, thereby putting in doubt the wisdom of slowing down our present rate of increase in energy consumption.

Implicit in this argument is the belief that a close correlation between energy consumption and the size of the GNP exists for most countries. To infer from this, however, that an increase in energy consumption will be matched by a parallel increase in GNP is misleading. The correlation between economic growth and rising levels of energy consumption remains to be proven, but a fear nevertheless persists in some circles that a shift toward a reduced rate of increase in energy demand will inevitably lead to reduced economic growth and greater unemployment, resulting perhaps in a depression. Is this fear well founded?

It is true that a sudden large drop in energy supply or demand would be as disruptive as any similar sudden change in other areas of the economy. However, what evidence is there to suggest that, over an extended period of time, a gradual and selective transition from high rates of energy demand growth to much lower rates will inevitably affect the economy in an adverse way? This question is worth careful study.

What about employment? A program of energy conservation will inevitably result in fewer jobs in some sectors of the economy. These losses, however, taken by themselves overstate the impact of a reduction in the growth of energy demand on employment as it is likely that the elimination of jobs in one sector of the economy would be counter-balanced somewhat by the creation of new jobs in other sectors. One must therefore distinguish between a structural shift in employment opportunities and an absolute decline in available jobs. Labour and capital can be substituted for each other within a practical range, depending on the industry being considered. As energy prices rise – particularly if they continue to do so faster than real wages – we may see a substitution of labour for capital, thereby resulting in greater employment. We do not have firm data to go into greater detail in this important area of the impact of energy conservation on employment. This is a gap which should be plugged.

On the level of the individual firm, energy conservation can sometimes yield unexpected results. Under the pressure of rising prices, many companies are discovering ways to cut back waste and improve efficiency. This new incentive to rationalize energy consumption could reduce energy use on a national scale and possibly result in money savings for the firms in question. It is interesting to note that at least one U.S. oil company is advertising that it can help U.S. industries reduce their energy demands by a target of 15 per cent, while increasing both output and employment. It is somewhat distressing to hear of the successes in energy conservation being achieved by some U.S. corporations while their Canadian subsidiaries sit idly by, seemingly unaware.

Reducing the rate of growth of energy demand without reducing our economic potential constitutes the first step toward establishing a conserver society. Eradicating waste where it exists will contribute to a wiser management of our resources and thus lead to a richer society, and one in closer harmony with nature.

Nevertheless, the problems which have been raised in this section need considerably more investigation. If conservation and demand shaping are to become significant elements of energy policy, the social and economic effects of the measures to be taken should be more clearly identified and evaluated.

Demand Policy — The Needs for Action

In this chapter, we have stressed the importance of considering the demand side in planning for our energy future. While Canada may look forward to its energy future with greater confidence than most other countries, there are nevertheless problems which will not be solved by an emphasis on increasing supplies alone. The Science Council believes that reduction in the growth rate of consumption is a necessary part of a sensible future energy policy for Canada.

The importance of implementing energy conservation measures now and not just in future, is underlined by the difficulties that may be encountered in satisfying Canadian requirements in the short run. Far from constituting a "necessary evil", energy conservation will bring with it economic and social benefits associated with more careful resource management.

So far, in Canada, the institutional mechanisms within which a policy on demand can be formulated have been lacking. At the federal level an Office of Energy Conservation has only recently been created within the Department of Energy, Mines and Resources. Provincial governments can and will play an important role in the planning and implementation of a conservation program. Coordination is needed.

Earlier in this chapter we raised a number of questions that are of fundamental importance: those relating to economic growth, employment opportunities, and the structure of the Canadian economy. These questions, for which we have unsatisfactory data on which to formulate answers, need to be much more fully explored. Many other questions should also be posed. What would be the impact of rising energy prices on Canadian industry? Contrary to firmly held beliefs, our preliminary background work suggests that, with a few important exceptions, such impacts are generally not very great. What would be the burden of rising prices on the less fortunate in our society? Some have suggested that the poor will be left holding the bag. What are the price elasticities of various energy forms? On these and other questions we simply do not have sufficient information.

Beyond the concern about the impact of reduced demand growth on Canadian society or on groups within the society, there is a range of questions with regard to the best means of implementing conservation measures for specific end uses. For example, how do we assure that new office buildings and homes are provided with better insulation? Many ways are possible, but we do not know which are the best. How can the efficiency of home furnaces be improved? Through technological innovation, better maintenance, different energy forms? We can continue listing questions ad infinitum, and the answers are either too general or nonexistent without R & D.

Last but not least, there needs to be a continuous drive in research and development which will both satisfy the needs of our modern society and lead to more efficient energy converters, furnaces, heat pumps, automobile engines and so on. The proper place for the performance of such R & D work is in the private sector. Some of this work, in fact, is going on in Canadian industry, but on the whole the trend over the past few decades has been in the direction of extravagant energy use. Heavy automobiles, non-returnable containers and a host of gadgets, all have tended to use more energy. This trend must be reversed through government stimulation of R & D in the private sector into quality-of-life enhancing, energy-conserving technology. In some specific cases, after having exhausted its powers of persuasion and incentives, the government itself may have to assume a more direct role in the R & D effort to ensure that the required technology, suited to Canadian needs, is developed domestically.

The development and implementation of an active energy demand policy will require a greatly expanded R & D effort. This effort will range from economic and social studies to the physical sciences and engineering. One can essentially distinguish three levels of concern. The first of these tries to come to grips with the macro questions relating to the impact on Canadian society of reducing the growth of demand. The second level deals with the area of policy instruments, i.e., what is the best way to accomplish specific reductions in growth rate? The third level is largely technological and concerned with acquiring the required plant, equipment and appliances.

As one moves from the first to the third level, the actions concerned become increasingly atomistic throughout the political system. The first level, however, involves questions of national moment and the Federal Government should therefore provide the focus of concerted decision activity. The area of policy instruments is relevant to all levels of government, depending on jurisdictional competence, while finally the technological and commercial aspects belong predominantly to the business sector, assisted as required by the two levels of government, and by the universities.

As a first step, at the federal level, the Science Council believes that the Office of Energy Conservation needs a broadening of its mandate to encompass all policy areas related to energy demand and needs also to be accorded a more prominent position in the Department of Energy, Mines and Resources. Secondly, while it is more difficult to be as specific at the provincial level, it is recommended that the provinces initiate or expand their efforts to formulate policies for shaping energy demand, particularly emphasizing studies of policy instruments. Thirdly, the Council recommends that Canadian processing and manufacturing industries be catalyzed to increase technological R & D in energy saving processes and equipment. Industrial and standards associations have an important role to play; the latter, for example, should be much more active in setting requirements for the inclusion of energy efficiency in the labelling of machinery, appliances, and automobiles.

At the industrial level, the concern for the efficiency of energy use should extend into the energy industries themselves. It is necessary that we consider how much energy we expend in winning new energy resources. Processes, such as those used in the recovery of oil sands, should be designed with a view to minimizing the proportion of the resource expended as we extract supplies for later use.*

Throughout the process of formulating policies or regulations for demand shaping, it will be necessary for regular government-industry consultations to take place. In our society of today, the criterion for virtually all decision making in the energy field is that of maximization of profit; the knowledge of how to plan in both the public and the corporate or utility interest will be a prerequisite of a more rational energy conserving society.

* See for example, "The new math for figuring energy costs", *Business Week,* 18 June 1974. Also H. Georgescu-Rœgen, *Entropy Law and the Economic Process,* Harvard University Press, 1971.

VI. The Future: Supplies

We have discussed so far the need for planning and controlling the growth of demand and have suggested broad mechanisms to implement these measures. The need for rational planning is even more important in terms of future supplies. Canada's natural endowment and development perspective is such that we enjoy real options as to how to supply our energy needs.

What some have described as an "energy crisis" in Canada in the fall of 1973 was mostly a problem of supplying petroleum in sufficient quantity where it was needed and on short notice. As a result of the 1961 National Oil Policy, Canada has been divided into two markets with the western half of the country the preserve of western crude oil and the eastern half dependent on imported oil. As a result of the October War in the Middle East and the subsequent Arab oil embargo (1973), Canada has redesigned the National Oil Policy by deciding to extend the Interprovincial Oil Pipeline to Montreal. Although Canada is nominally self-sufficient in oil, it is still vulnerable to an abrupt withholding of foreign supplies, such as happened in the fall of 1973.

Oil, at present, is of major importance in providing energy in the world. Canada is no exception: in 1970, more than half of the energy used in Canada came from petroleum resources. It would therefore be easy to believe that short-falls in actual supply, or potential difficulties in supply, will continue to have grave consequences for Canada. The Science Council does not share this pessimistic view. In the longer-term perspective, the transient importance of oil becomes much clearer.

The basic driving force behind the remarkable economic development of the industrially advanced countries has been the provision of energy – usable energy, not necessarily or exclusively oil. A specific form of energy, historically, grows incrementally, then rapidly, undergoes successive development stages by adaptive sequences in response to circumstances and events, reaches a peak, matures, and eventually declines to terminate its life cycle. In all western countries we observe very much the same cycle. Initially the dominant energy forms were wood, wind and water. When wood became scarce, coal took its place, and when the relative merit of oil became apparent, it replaced coal. We are in a similar period of transition now from oil to new sources. It is unlikely that, in earlier times, the transition from wood to coal was characterized as a crisis, and that from coal to oil certainly was not. These transitions happened naturally. For the population at large it was obvious that these "new" forms of the past, oil and especially natural gas, were easier to obtain and cleaner to use. There is little reason to expect a different perspective now, in spite of some real immediate difficulty. Over the longer term crude oil as an energy source will begin to wane in importance, although the role of petroleum products will not diminish suddenly. Thus, in a real sense, we are beginning to experience the end of the oil era.

This should not concern us greatly. What should concern us instead, and this cannot be over-emphasized, is the impact on society of shifting from one dominant form of energy (oil) to another. This shift has been called the "energy revolution"* – defined as a radical change of circumstances or a turning point of the system. Just as the previous shifts – from wood to coal, and coal to oil – had a profound impact on human society, so will this new transition.

The first transition from wood to coal together with the development of the steam engine gave rise to the industrial revolution. As David Cass-Beggs has pointed out, the revolutionary change was not merely the creation of factories and more efficient ways of production.† The real revolutionary impact experienced by the members of our society was a transformation from rural to urban man, from agricultural to industrial man, with a rapid introduction of universal education, the birth of mass communication, and the introduction of new forms of management and administration.

Similarly, the shift from coal to oil, resulting in modern agricultural practices, the automobile and the petrochemical industry led to equally profound changes. The extremely rapid growth of world population was in no small part made possible by it. Large scale urban growth, different ways of marketing, astounding increases in individual mobility, to name just a few of its consequences, changed our life styles fundamentally.

Some, but by no means all, of these changes were judged in retrospect to be favourable. If we learn only one lesson from these previous shifts, it should be that our concern must not be focussed exclusively on the forms in which energy is going to be made available, be they coal, nuclear or solar. Rather we should also recognize that the main future form or mix of forms of energy supply will have pervasive impacts on society, quite outside the energy field itself. Many of these impacts can be foreseen, at least approximately so. They may be different, and desirable or undesirable, depending on the options we choose to develop. Any research and development program in energy must be based on a recognition that oil will be diminishing in importance. It must be based also on the best possible projection of the impact on society of the energy forms we select now for development in the long term.

If we do this, we will gradually discontinue the practice of spending ever greater amounts of capital on the search for ever more remote and scarce, and thus costly, crude oil resources. What makes more sense is to invest capital resources in the development of new long term or, even better, renewable energy resources.

Accepting that the relative roles of crude oil and natural gas are going to decrease in our energy supply mix does not mean that these fuels are going to disappear over the next decades. It means instead that in the total energy budget the shares filled by crude oil and natural gas cannot possibly be maintained at current proportions. This shift will express itself through lowered growth rates of oil and gas consumption

* David Cass-Beggs, "The Energy Revolution and the Environment", Address to the Vancouver Institute, 27 October 1973.
† *Ibid.*

and increased growth rates of other forms. The life cycles of component energy forms in such a system may be modified by the demand, as well as the adequacy of information, quality of decisions, strategic planning and organizational effectiveness associated with the supply. A new energy economy will arise and the question we must try to answer is what will it be like?

In the future, we will continue to need an easily transportable high energy content fuel. In nature, these fuels are based on hydrogen-carbon bonds. What we know is that the higher the ratio of hydrogen to carbon atoms, the higher the energy of the fuel. On this basis natural gas leads the pack and oil is very desirable but because of their expected eventual scarcity we may have to contend with second best choices. The Athabasca bitumen has a reduced hydrogen-carbon ratio and needs upgrading. Similarly lignite coal may require upgrading by liquefaction and or by gasification. In the framework of such an overview, the development of the oil sands and the further transformation of coal are both logical developments and each is therefore in due course almost inevitable.

In the past we have used hydrocarbon fuels, such as coal, oil and gas to produce electricity. In the very long term we may use ample electricity from nuclear resources to produce hydrocarbons out of water and limestone.

It is impossible to predict the precise structure of the new energy economy. Will it be based on an electric society, a hydrogen society, or a synthetic gas society? In all likelihood for a considerable time it will be a combination of these and many others, and the only point at issue is the extent to which each of the competing forms becomes important and over what period. Just as at different times, direct use of wood, then coal, then oil and gas, provided the backbone for the overall energy economy, electric power is likely to play this role in the future, and while regional differences will be important, nuclear energy will probably in turn be the mainstay of electric power generation.

While electricity will then provide the common energy basis, many other feasible energy forms are likely to make complementary contributions. Petroleum will continue to be used, be it only in reduced proportions and for a more limited range of applications. Coal and derivatives of coal will have a role. The contribution of gas may even be enhanced by synthetic forms. Then, there is the likely development of new power sources. "Exotic" sources such as solar, wind and biomass, most probably limited in terms of individual utilization, will together be capable of making sizeable contributions. Hydrogen will also probably play its part.

It would be foolhardy to make specific predictions on what concrete contributions each of these forms will in fact make. This is particularly so because while conceptually any of these forms are conducive to development, even "paper studies" which would give a reasonable indication of their economics have not yet been carried out. Rather than making predictions which may be misleading, the Science Council believes that all these forms require attention in Canada on a scale much beyond that occurring at the present. In this connection the Council wishes to contrast the billions of dollars that are expended on new gas pipelines, oil sand plants and construction of nuclear power stations, with the minuscule efforts devoted to research work on solar or wind energy, for example. The amount of money spent in one day on exploratory drilling alone, exceeds our entire annual effort on solar energy.

Our only energy R & D effort that has been funded adequately – that in atomic energy – has been outstandingly successful, though nobody should forget the roadblocks with which the program has had to contend. This program alone should convince us that Canada has the capability to carry out energy research and development as effectively as any nation in the world. We add to this illustration, the observation that energy research and development is low in cost in comparison to the benefits that will be gained when success is encountered.

The replacement of the now predominant energy resource, oil, will affect Canadian society in many ways. There are naturally the direct impacts, conversion to electric home heating, trucking giving way to goods movement by train, disappearance of the factory smoke stack, electrification in railroads, upgrading of public transit, possibly battery-powered cars, flywheel cars, or cars running on methanol and hydrogen (or even no cars at all in our downtown cores), and widespread improvement in environmental conditions caused by a shift from combustion to less polluting energy sources and conversions. More important though will be the indirect impacts. They will once more lead to fundamental changes in our life style. We must ensure that they are as much as possible of a desirable kind so that the undesirable effects on some groups are mitigated. All of these are areas where action should be initiated now.

This brings us back to the need for planning. We surely do not wish to slide blindly into a future over which, in essence, we can have a large measure of control if we exercise it. We can shape our energy future to a decisive extent if we have the political will to commence the long-term planning now.

We lack at this time much of the needed strategic information for making well-based decisions on those options in energy R & D we should act upon and those we should not. Some of the information, indeed, cannot be determined with assurance. For example, we do not know the percentage that will actually be found of the oil the experts think is in the ground in Canadian territory, nor can we tell what amount of this oil will prove to be in circumstances that will permit recovery.

One set of questions requiring answers pertains to the potential contributions of particular energy forms in satisfying total future demands. Another set relates to the economics of specific production, transportation, conversion and associated processes. Yet other questions and answers relate to the social and environmental impacts. These, and additional questions should be addressed by the coordination and planning mechanisms that we recommend in Chapter IV.

To obtain valid answers will require an intelligent R & D program that provides the means both of seeing, discriminating between and excluding options and of making critical and hard-nosed decisions as to when and where to move on the program in the progressively more expensive stages of development. Some of the elements of this program are quite obvious and in many cases already active. Below we discuss in greater detail the required R & D programs on energy supplies.

Fossil Fuels

The oil, gas and coal industries in Canada are generally owned privately, largely by non-Canadians, and depend for a great deal of their R & D requirements upon their research organizations outside Canada. To a large extent the continued development of oil, natural gas and coal technologies will lie in the hands of leading international companies and the funding of R & D will be based on private investment capital. The oil and gas companies, some with extensive interests in the coal industry, are basically self-sufficient in research funds, wish to remain so, and are willing to invest large amounts on the condition that they see prospects of substantial long-term profits from the intervening investments. Government entry is handicapped by lack of detailed knowledge of the technologies being developed and the secrecy that surrounds such developments. Government funded research, however, where accepted, has made significant contributions (for example, Mines Branch of EMR in coal; the Research Council of Alberta in oil sands). Canada must continue to improve its technological ability in the fossil fuel area and the question arises as to the amount of control we have over the rate of development of enhanced or new technologies. As an illustration, how would we go about speeding up coal gasification development, should this become a national priority? Could we persuade the business sector to invest more? Should we simply give the industry money with the provision it be spent on gasification R & D? Should Canada in a case of perceived emergency buy out a company and build a pilot plant? What leverage and control do we really have in such an important area? This problem is widespread throughout the fossil fuel energy industries in Canada and must be faced squarely by those involved in developing our R & D policy. This dependency is not solely a Canadian problem nor one confined to the energy fields. Thus, Australia recently asked the United Nations to consider setting guidelines that would induce multinationals to respond more sensitively to the needs and wishes of countries in which they operate. Such guidelines might in fact allow us to shape and implement our own energy policy more effectively.

R & D effort must be maintained, with proper discrimination, in all phases of our fossil fuel industries: exploration, recovery, transportation, refining and the associated environmental protection. Much of the R & D in petroleum and coal industries is of world-wide interest and progress will be achieved in many countries on many fronts. Certainly, Canada can profit therefrom. Certain problems, however, are specific to Canadian conditions and for these we must develop our own solutions, techniques and expertise.

The future supplies of both oil and gas are expected to come from geographical and technological frontier regions. This implies that a critical step in the energy delivery system will be transportation or transmission. These new sources confront us with a combination of technological difficulties which are specifically northern and vast in character, and need distinct R & D efforts. Logistics and transportation techniques for Arctic conditions are not yet well developed as is reflected in part by the very high resource development costs when compared to those in southern Canada. Climatic conditions compound these difficulties in offshore exploration and drilling away from our northern land boundaries or eastern coastline. As economic quantities of oil and gas are found in these areas, their rational recovery, processing and transportation to market become a major challenge, and planned R & D efforts are aimed at producing timely solutions.

Our extended R & D expertise will eventually give us an opportunity to increase the Canadian content of the facilities employed at home. It will also enhance both our capability to export materials designed for cold weather conditions and our expertise in working in hostile environments, thereby facilitating our participation in offshore developments around the globe. Cooperation with Norway, Denmark, the U.S.A. and the U.S.S.R., all of which have extensive Arctic interests, is of particular benefit in regard to this type of research and should be strengthened. Logistics aspects should receive special consideration in any systematic research for northern development.

As oil and gas fields mature, their delivery flexibility under varied demand conditions decreases, so that production stimulation and supporting techniques become more important. Price increases may permit the economical exploitation of low permeability reservoirs and the introduction of new operational techniques in marginal fields, in order to increase the total ultimate recovery of oil and gas.

A second important area of specific concern to Canada is the extraction of the oil from the heavy oil deposits and oil sands in Western Canada. At the moment, we have a single commercial scale oil sand plant for surface mining in production, and a few in the planning or construction stages. The technologies employed in these plants will no doubt evolve steadily during their productive life as we have by no means solved all the problems of running large scale open pit mines under the cold winter climate of Northern Alberta or those of working with the abrasive sand component of the deposits.

Recently, the federal government has announced a $40 million fund for research in the area of oil sands recovery and the Alberta government has proposed to spend an additional $100 million. This promised funding of R & D is a step in the right direction, however, it is not clear in what framework these contributions from public funds will be used. Furthermore, one may question whether the oil sands are the most promising energy source in which to spend such funds at this time, since rushing them into production may not be the most appropriate strategic decision. Until recently, industry itself appeared prepared to develop technologies to the full and it seems very unlikely that a significant influence can be exercised by government R & D funding on the rate at which the commercial plants will become operational. R & D funding here as much as in any other area must stand sober scrutiny and, if public money is to be used, the question must be asked, where can it be most effectively and equitably applied? Immediately three areas are obvious: one, new and unconventional extraction processes, the second, the environmental impact of the oil sands exploitation, and the third, net energy balances.

Most of the bitumen plant extraction technologies under study require very large amounts of fresh water, an average in fact of five barrels for every barrel of oil produced. In the process the water becomes heavily contaminated with petroleum products, salts and silt. It cannot therefore be returned to the environment without cleaning nor can it be immediately recycled. A government-led strategic R & D program dealing with this problem would involve all companies interested in extracting the bitumen from the mined sands. It would be directed at reducing the impact of the overall development on the environment and would thus allow more plants in a given time period while still maintaining high environmental standards. At present, it is possible that the total number of plants that can be constructed in one area will be limited by the availability of clean water and the inability to return some of this water back to the rivers without considerable delays.

Another environmental problem is the large amount of sulphur dioxide (SO_2) released from the refining process. This problem is similar to that in many other industrial processes. Its solution would not only help to reduce the impact of the oil sand extraction plants but would help to reduce the undesirable effects of many other energy and industrial projects. Continued funding at an appropriate level would be justified.

The methods being tested at present for the extraction and refining of the oil sands are based largely on conventional technologies. There is an obvious challenge to develop alternative, and less conventional, technologies and to test really original ideas and approaches, especially if they seem likely to enhance the resource recovery. This type of research is taking place in the industry itself, but R & D funds should also be used to develop expertise, personnel and facilities in universities and organizations such as the Research Council of Alberta where less conventional approaches may be developed for effective oil recovery from the maximum amount of oil sands. The funding of the Hydrocarbon Research Centre at the University of Alberta in Edmonton and of the Canadian Energy Research Institute at the University of Calgary are welcome small steps.

In addition, from an examination of energy balances extended over the entire production cycle, more energy efficient processes may be identified. Presently, the equivalent of over 25 per cent of the energy extracted from the sands is used in the mining and processing cycle. Obvious benefits are to be derived from improving the efficiency of present technology. Because of the relatively small total volume of the reserves which are covered by a shallow overburden, the long-term production from most of the oil sands will be dependent upon development of in situ extraction techniques. Some of these techniques are notorious for their inefficient use of energy. At the moment a number of companies have active programs of research and development on in situ technology. Some have reached the small pilot project stage (5 000 barrels per day) and expect to confirm commercial feasibility for economic production by the early 1980s. The techniques range from steam extraction of bitumen to subsurface thermal recovery methods, and all have so far been developed without government funding. Eventually, such research might result in the replacement of present technologies by more efficient and environmentally more acceptable recovery and processing methods.

Coal in Canada constitutes a major source of fossil fuels, but it has remained undeveloped because its potential markets were taken over by oil and natural gas. The sudden interest shown in this resource by international buyers has thus found it somewhat unprepared in both technology and production capability. With notable exceptions, Canada's coal industry is on the whole quite advanced. Coal mines use the best available equipment with good results, particularly on the Prairies. In future, many mines will be exploited by open pit operations and we are unlikely to see a large scale return to traditional working of underground mines. Remaining underground miners will have to be highly skilled technicians tending machines that do the work. Such an orientation toward automation has both technical and social aspects and a satisfactory capability will not be created quickly. The mechanization of deep mining has been the object of much R & D in recent years, particularly in Europe. Solutions would have to be adapted to Canada's conditions.

Government R & D funds are probably best applied in the areas of basic chemical research, processing technologies and, of course, in better defining the quality and extent of our national coal reserves. Along with developing new ways of transporting coal, especially by pipeline, new solutions in these areas would be of considerable benefit to the industry and would certainly aid in upgrading the economic value of our coal resources.

The long-term prospects for coal may be largely in the area of gasification and liquefaction. We, in Canada, must be able to be in a position to gasify coal if we choose to opt for that alternative development as a national policy. There are one or two economically viable processes that are established today. In addition, there are several new methods under development in the United States. At the moment, the world demand for plants and the unproven nature of the new processes are such that a sudden decision to gasify coal in this country could not be implemented in an optimal way in less than 6–10 years. The Science Council believes that industry must acquire a capability that would shorten this lead time to the extent that we would be gasifying coal with no more than a five-year lead time. Also, we should survey the research efforts underway in the field of in situ gasification, as the associated technique would probably alleviate the problem caused by the lack of adequate water supplies in the regions of our coal deposits that may be used for long-term energy supplies.

Present R & D tends to concentrate on production of a high BTU gas interchangeable with natural gas. Attention should also be directed to methods of increasing BTU value of coal gas other than by the expensive methanation process now generally proposed. While currently considered processes would permit a simple commercial substitution, many other applications of gas from coal would not require the high BTU value. Evaluations of the optimum BTU level, taking into account all applicable production and transmission costs, would be relevant. This is particularly useful in cases where gasification is considered as an alternative to direct burning of coal in power plants and major industrial heat applications. Moreover, environmental problems related to coal mining and gasification require R & D spearheaded and sustained by governments.

In summary, our fossil fuel resources will continue to play an important role in Canada's energy future in both conventional and synthetic forms. To make the best use of them we must continue to improve our management and technical capabilities. Most of the R & D funds are likely to be raised by the industry and only a catalytic action will then be needed; but in certain areas, particularly those associated with improved definition and recovery of our resources and environmentally enhanced methods of extraction, processing and transportation, government funding does have a definite role. Government R & D policy should always tend toward increasing Canadian expertise and manufacturing strengths. R & D should also be aimed at strengthening our independent expertise in the area of evaluation of operations, because the need for basic information and understanding is essential if we are going to plan the allocation of these resources over time and regionally to the benefit of all Canadians. To date, we have relied too heavily on industry for the strategic information on which we make policy decisions. In addition, much of this industry is foreign-owned and subject to policies determined elsewhere. Improving our technology and increasing our resource management expertise require a lively research atmosphere and for that reason government funds should complement industry's contributions and stimulate the establishment and maintenance of key areas of excellence in the fossil fuel fields: in universities, research institutes, government departments, and Crown corporations.

Hydro-Electricity

Hydro power developments in Canada have had a long and successful history. By and large, the technologies used are mature, so future developments, while important, may not be dramatic. Four general areas of concern are likely to be the focus of attention:

– the efficiency of long-distance transmission of electricity;

– the assessment of the environmental impact of hydro generation and transmission projects;

– innovation in urban distribution systems (this is applicable to electricity from all sources); and

– new developments in the storage of electricity.

Most of the significant and obvious sites for hydro development close to centres of demand have now been utilized, so interest and attention are now being turned toward very remote sites. A primary concern will be to reduce the amounts of power lost in transmission. A trend toward ultra-high voltage transmission may be evident in the future – where there are long, untapped distances involved, techniques of extra-high voltage DC transmission may be attractive.

R & D may contribute significantly to the reconciliation of hydro developments and environmental interests. However, en route to any eventual solution, it will be necessary to confront, head-on, many multi-faceted environmental problems. Studies are needed on the impact of damming on the nutrient-rich spring run-off from rivers draining into the Gulf of St. Lawrence and on the potential damage to fisheries in the area. There is work to be done on man's potential for inducing climatic change by substantially altering run-off patterns in extensive areas of the country. On the positive side we should investigate the potential side benefits of hydro development, such as flood control, irrigation, improvements in navigation and so forth.

The continued growth of Canada's urban population will lead us to look for innovations in urban distribution systems, partly for reasons of efficiency, partly for reasons of aesthetics. There will be a continued trend toward improving and reducing the capital cost of underground distribution systems, and toward reducing the size of switchgear and switching yards. We would expect to see experiments with both cryogenic and gas-filled pipe systems of distribution.

Solutions to the problem of storing massive amounts of electricity would enhance the efficiency of hydro systems during periods of seasonal, weekly, daily, or special load fluctuations. There is the distinct possibility that large fuel cells will be employed in substations as peaking devices, and that some offpeak production and distribution of an alternative fuel such as hydrogen will occur before the end of the century. Economic development of super-conducting solenoids or large bubblechamber magnets could lead, one day, to inductive energy storage.

The principal Canadian centre for much of the work in this field is at the Institut de recherche de l'Hydro-Québec (IREQ), at Varennes.

More visible attention to these problem areas by other hydro utilities would be welcome.

The Department of Energy, Mines and Resources has published data, by province, showing estimates of untapped hydro potential. The evaluation process is being improved, a welcome move, and a systematic inventory of hydro-resources should be maintained and such important factors as transmission costs assessed.

Fission Energy

As Canada uses more energy in the form of electricity, the outstanding success of Atomic Energy of Canada Limited (AECL) in the development of the first CANDU series of reactors must not be curtailed by lack of funds for further development. Instead, this development should be expanded so that the country can be provided with better and more efficient reactors, designed in such a way as to use a wider range of our diverse natural resources. Canada is one of the few countries that has a large professional body of nuclear engineers and scientists and thus has the ability to determine its nuclear future without outside help. This ability will be of particular value in the next few years since the present CANDU design has extensive development potential that can be exploited in the near future.

"CANDU" is not simply a reactor, but rather a concept, which has brought into operation a power-generating system having a broad and flexible basis for future development. An outstanding characteristic of the system is that it can be modified in an evolutionary rather than a revolutionary fashion, both in terms of fuel cycles and coolant options.

In Canada we have chosen heavy water as moderator, largely because there is no better conserver of neutrons. Over the next decade or so, and in several regions, we will provide most of our new electric power from the present design of CANDU heavy water reactor. Development, however, should not stop here. Our national nuclear energy program should develop further in at least four different areas:

- the development of a commercial version of the organic-cooled CANDU;
- the expansion of our technological capabilities to include thorium as a fuel;
- the development of a capability to use the plutonium obtained as a by-product of our present reactors; and
- the eventual use of fusion technology to provide neutron sources for CANDU.

A fuel program that incorporates plutonium might well be designed in cooperation with another heavy water reactor system, the British Steam Generating Heavy Water Reactor (SGHWR). Such a joint effort might well aid in our export market development. If we do not develop our capabilities in each of these areas, then we seriously limit the choices available to us in the future and in particular restrict ourselves to the energy contained within our uranium reserves. In addition, we will limit our export potential of both reactors and uranium (which in itself will become an increasingly valuable commodity).

We must beware of the possibility of the whole program losing its momentum. If steady development is not maintained the result may be a break-down of our capabilities followed by a perhaps hasty decision that something must be done immediately. On-off funding usually leads to higher costs, major mistakes and far-reaching consequences. Thus R & D should continue steadily toward developing the preferred options for the future.

Perhaps more than in any other area, rational decisions are required on the future role of CANDU.

An area where less success has been achieved is in the establishment of research and design capabilities in the various phases of nuclear support technology in Canada. This, however, is somewhat like the chicken and the egg problem. Until we have a substantial construction program, we cannot develop a nuclear service industry; however, the construction program depends to some extent on the capability of the relevant Canadian industries to make and supply new products. This situation demands that the R & D capabilities be within industry. More money in contract research and development is necessary and should be accompanied by additional funds to allow AECL to maintain the research personnel necessary to direct and monitor the industries' efforts. Complacency in this area will mean less Canadian content in our reactors and increased dependency on other countries for certain vital materials or parts.

A case in point is a lack of a satisfactory steam turbine technology in Canada. The market and service needs for this strategic component are now large enough to support the establishment of a steam turbine capability.

In supporting policy initiatives designed to make nuclear-generated electricity an increasingly important component of Canada's energy system, we are fully aware of the attendant concerns which will arise about nuclear safety and the impact of radiation on the population. For this reason, we feel it important to mention some changes which we feel ought to be implemented over the next few years in the existing, and capable, agency charged with regulating nuclear activities in Canada – the Atomic Energy Control Board (AECB).

The expansion of nuclear power, and increasing demands for public participation in its regulation, will see three important trends affect the operations of the AECB.

1) A considerable increase in the total volume of work which the Board and its staff must handle. Today we have six or seven power reactors in operation, four in construction – by the end of the century the number of reactors may have reached 100 or more, some perhaps even reaching the stage of decommissioning.

2) An increasing demand for public hearings as part of the routine process of licencing power reactors. This will certainly mean additional

work for the Board, but will also allow an important public educational function to be performed.

3) An increasing demand to have the Board expand research activity in Canada on the biological and medical effects of radiation. This will mean a shift in the research funding activities undertaken by the Board away from its present interest in nuclear structure and high energy physics, which can be looked after by NRC, toward studies of the biological impact of radiation and toward analyses related to nuclear safety and siting. The AECB today does not have its own laboratories and should not seek to develop any; rather, it should have the funds to contract with existing agencies and institutions to have a research program developed and maintained.

There is one very particular point which we wish to make about nuclear safety. There is a tendency, in public debates, to lump all nuclear reactors together, to believe that they are all essentially alike and hence potentially subject to the same kinds of problems. This view is erroneous. The postulated problems which might be encountered in, for example, a "pressure-vessel" reactor like the American Light Water Reactor are quite different in kind, and magnitude, from those postulated for "pressure-tube" reactors like CANDU. It is entirely inappropriate to assume that concern over the potential safety problems of the American pressure-vessel type reactor is automatically a problem in CANDU, it is not. We must, however, still remain concerned with radioisotope release, reactor safety, nuclear theft and sabotage, waste heat and long-term radioactive wastes management, and must ourselves actively seek acceptable solutions.

Beyond the domestic questions of nuclear safety and radiation protection, the attempts by Canada to sell CANDU reactors in export markets have run into severe and concerned criticism as a result of the diversion of plutonium generated in a Canadian-designed reactor, into a nuclear explosive program. The potential that exists for the proliferation, on an international scale, of military technologies incorporating nuclear devices casts a dark shadow over our, and other countries', export prospects. Our world needs the energy which the peaceful use of nuclear fission can provide. To satisfy that need it is incumbent upon us to devise and implement systems of safeguards that will prevent the world's capability for nuclear self-destruction from expanding.

Fusion Energy

There are those who will argue that, in a short time, the world's energy supply problems will be over because there will be available an almost infinite supply of inexpensive energy from controlled thermonuclear fusion. Others point out that the practicability of continuous power generation from fusion reactions is not yet experimentally proven, and that there is no assurance that it will be proven before the end of the century.

The experimental proof of the theoretical possibilities would leave us still many years away from the practical realization of fusion power. Even when we can control the release of energy from fusion reactions, the engineering of a containment vessel, and the associated design problems regarding temperature and neutron bombardment levels never before tackled, will delay development until at least the next century. According to a leading proponent of fusion, "present estimates indicate that an orderly aggressive program might provide commercial fusion power about the year 2000, so that fusion could then have a significant impact on electric power production by the year 2020". This, then, is the limit to which the optimistic view extends.

Canada can neither wait for fusion to solve its energy problems nor afford alone the many billions of dollars that will be required to prove and develop the technology. In this situation we should buy our way into future advances in the fusion field by cooperating with interested groups such as the U.S., Euratom or perhaps the Soviet Union, undertaking to develop one particular aspect of the total program. The contribution would amount to several million dollars in the first five years or so. In the long run, if it gained us access to the total technology, it might be a very profitable investment. On the other hand, with present knowledge it is clearly a gamble and should be considered as such by Canada.

We can offset the risk of losses considerably by concentrating on an area of fusion technology which would have extensive spin-off benefits for Canadian industry. On the list of fusion problems one stands out as ideal for Canada: materials technology. Canada might well initiate one or two programs of metals and materials technology, concentrating on the problems posed by the operational needs to withstand high temperatures and high neutron fluxes. These programs, if closely coordinated with activities already commenced in AECL and our nuclear industry, could add significantly to our technological capability and accredit Canada in the context of world fusion programs. Such a program of international collaboration with domestic specialization appears to be the most attractive alternative for Canada. At the same time our national programs would improve our technology for nuclear power and the materials industries generally. Paralleling the development of such programs one would want a sustained effort to develop the ability of supporting industries in utilizing new research knowledge and turning it into profitable Canadian projects.

In other areas of fusion, except for continuous monitoring, we should leave the R & D to other nations until the processes are delineated, proven and established. This will require the maintenance of one or two groups of plasma physicists and engineers assigned to follow developments on the world scene on Canada's behalf. AECL has developed such a capability and should be encouraged to keep it active. In addition, universities have been involved, especially in plasma physics. There is therefore a need to provide a focus for coordinating and integrating plasma physics developments in Canada to ensure not only that they are adequately funded but that the work proceeds in a coherent manner. A Task Force appointed by the Minister of State for Science and Technology is expected to provide some guidance for future R & D orientation. We would expect this advice to be along the lines we have sketched.

Moreover, it has been suggested that we should also concentrate on developing laser technology further in Canada. This may well be true, but it seems unlikely that the type of lasers needed in fusion will have sufficient industrial spinoff. For this reason, and also because new materials knowledge will be needed to support several fusion concepts, we should initially concentrate on materials research. As it is, the TEA-CO_2 laser was developed by the Defence Research Board (DRB) at Valcartier and research capabilities are still maintained in this area. Eventually, further R & D in laser technology as a part of fusion research will depend primarily on its bargaining value in the overall process of fusion energy technology exchange.

Complementary Sources

The fossil fuels and hydro-electric power serve us now and so does nuclear energy. The former two will gradually decline in importance, whereas the latter will greatly increase in importance. In addition to these sources, new ones need to be considered. These are solar, wind, geothermal and tidal energy, as well as the energy technologies associated with hydrogen and direct conversion. All of them are feasible although none of them are in widespread use at present. Some of them can be used nationwide and others have regional importance. None of them will, over the 25-year term, be able to become a dominant energy supply, but in combination, their share of the total energy supply may be significant. Presently, few if any of them are competitive with conventional sources, but this is likely to change as the latter become more expensive.

Solar Energy

The earth receives the equivalent of 5 000 times as much energy from the sun as mankind is expected to utilize in the year 2000. Before being dissipated back into space as heat, this energy drives four great natural cycles: (1) the hydrologic cycle, (2) the ocean currents, (3) atmospheric circulation, and (4) the biological production and decay cycle, which has produced the fossil fuels, and also provides food and fibre. Forms of energy derived from these cycles are discussed elsewhere in this report. Attention is given here to radiant energy itself.

Solar power varies with latitude, cloudcover and season. More than 90 per cent of all Canadians live below 50°N, where the average solar radiation is about 150 watts/m^2, with four to eight times as much power in June as in December. Although this energy is plentiful, its diffuse nature makes efficient collection crucial and at the same time its variability requires either storage capacity or a coupling of the solar power system with other energy sources.

There are a number of broad pathways along which R & D can travel in developing radiation receptors – photothermal, photovoltaic, photosynthetic, photolytic – but the first two are likely to be the main converters of solar radiation in the 21st century. While capital intensive schemes for central solar electricity generation stimulate the heroic imagination, the use of individual radiation receptors on buildings for space heating and cooling and for water heating deserves the most immediate and extensive attention. Current plans include flatplate collectors on the roofs or sides of buildings, with fluid transporting the heat to be used as space or water heating, to drive a cooling unit, or to be stored for later use. To avoid the expense of building an oversize solar energy system to offset periods of extended cloudiness, an auxiliary conventional energy supply is coupled with the solar house system. (This arrangement however calls for increased capital investment in equipment.) Present figures indicate that solar energy could supply 40 per cent of residential heating and cooling requirements (i.e., about 8 per cent of total national energy use) and save money over the life of the house compared with conventional electric or fossil fuel heating in Canada, even with present technology. In any specific sense, however, these figures vary with geographical locations, urban and rural settings, and other factors.

The benefits to the country as a whole are in reduced pollution, conservation of fossil fuels, money savings to consumers, and employment opportunities in a Canadian solar heating design and production industry.

Our ability to make full use of the sun's radiation is about as well developed today as nuclear energy was in the late forties. We know it can be done and is worth doing, but we have not really begun seriously to tackle the problem. Technologies for collection and storage are known but are expensive. What is still more important is that we do not have an organization in charge of developing solar energy to a viable state.

Not only do we lack an institutional structure to encourage development of the new technologies that would allow us to tap our radiant energy, but we have hardly begun to develop the core of expertise in our industry and universities that is a prerequisite for such development. Solar energy will only become a commercial reality when we have concentrated research and development effort in conjunction with industrial entrepreneurship. But even more than this is required, since it seems desirable that in Canada solar energy should develop first toward receptors for heating individual buildings. Thus, the housing industry must be directly involved in order that the new techniques not remain unapplied in the design shops, nor be restricted by outdated building codes and regulations.

While the use of solar radiation for electricity generation is limited by the high cost of collector and conversion equipment, for space and water heating and perhaps for space cooling the energy costs may already be competitive with conventional sources. Tests are necessary, however, to determine feasibility under Canadian conditions. For these uses, moreover, there are three roadblocks of an institutional nature. First, the design of an optimum balance of solar versus conventional energy sources, and of expenditure on thermal efficiency versus expenditure on energy supply, requires a fairly sophisticated design capacity to integrate local factors of climate, insulation, fuel costs, and capital costs for heating and insulation. Second, the effective use of solar radiation is unfamiliar to most parties in the designer/builder/financier/consumer chain and will require government-funded demonstrations. Third, it is usually the builder, not the owner, who chooses the heating system. Because, from a marketing point of view, low initial cost is often more important than lifetime cost, no solar heating is in fact installed. Special financial incentives by government and especially utilities, which could provide installations to houseowners on a packaged rental basis, are required to break this vicious circle.

The development of a sophisticated design capability which is easily accessible to architects and builders, the implementation of educational and demonstration projects, and the setting of incentives and standards for solar-thermal efficiency in residential houses and commercial buildings deserves special attention. Otherwise we will be burdening Canadians with new housing which is more energy-wasteful than it need be. A period of increased building activity would act as an opportunity for rapid innovation in this field.

The expansion of world interest (for example, United States and Japan) in solar receptors in all their forms, will probably lead to a technology improved to the point where solar energy as a supplement to present sources will become a reality within the next few decades. The economics of solar receptors are improving and this together with the increasing cost of fossil fuels may bring the two sources into the same cost area for heating. One role of a Canadian centre for solar energy would be to integrate our work with that of other countries and to follow developments that may profitably be applied under our particular climatic conditions. At the same time basic research efforts and development of expertise must be expanded as we continue to search for entirely new ways of approaching the problem. At present the scale of our efforts in this area is entirely inadequate in universities and non-existent in industry.

Biomass Energy

The utilization of the energy fixed in organic matter by photosynthesis is as old as mankind. Partly owing to the emerging conservation ethic, partly to the rising costs of alternate energy sources and to the embarrassing amounts of organic waste that accumulate in our present environment, interest is growing in the idea of utilizing biomass energy. This interest, however, focusses not only in the direct combustion of biomass energy sources, but also in their conversion to synthetic fuels with higher energy content.

The production of synthetic fuels (either oils or gases like methane and hydrogen) from biomass appears attractive for at least three reasons. First, the amount of fuel is potentially quite large (i.e., more than 5 per cent of Canada's present energy consumption). Second, the potential additions to supplies are of a most desirable kind: they derive from renewable resources and have low amounts of polluting impurities like sulphur. Third, an important side benefit of the process of manufacturing the fuel can be the alleviation of waste disposal problems.

In comparison with our ancestors, we have regressed in some ways in our use of biomass. Apparent cheapness of fossil fuels in the past has led us to consider the by-products of food and wood production as wastes. This habit must be changed.

Proposals exist for the combustion of air-dried wood in central electricity generation plants, and others have suggested as an illustration the harvesting and conversion of the reedswamp that can be culled from some Manitoba waters. Although additional uses for the products from most areas of land may be more attractive, energy plantations may, in the lower ranges of their estimated costs, be able to compete with fossil fuel for electricity generation. Thus, emphasis on biomass plantation concepts for fueling power plants may be warranted. Moreover, a tremendous multiplication of the energy now obtainable from an acre of land could be realized from the growth of algae on nutrient-rich water, provided that the costs of collecting and drying can be controlled. In spite of our technical inability to harvest plankton efficiently, the energy from this source could presently compete with oil at $11 a barrel or so. The value of the biomass approach, however, must be compared at all times with its potential as a food supplier. Several other forms of energy may be used to produce food. Thus in biomass technology there are strategic choices to be made and anticipated developments in agriculture are primary considerations.

Moreover, energy from agricultural biomass and the extensive use of biomass energy are subject to precepts of land-use management and protection of the environment.

Are we on the threshold of making good some of the promise of biomass energy? To this end a biomass research and development program would provide research in support of industry's potential development programs. It would also house on-going inquiries and concept development for projects like algal culture and diverse energy plantations, single-celled protein cultures and artificial photosynthesis, any one of which may be more or less ready to be advanced into one of the development programs.

In view of the potentially large amounts of clean and renewable energy that can be developed for use, having regard to the potential alleviation of waste disposal, and finally, considering possible significant contributions in food and chemical feedstock, biomass energy programs should be funded in the order of several millions of dollars. After all, parts of Canada are better suited than lower latitudes for abundant production of low-grade cellulose.

Research and development of unconventional uses of biomass crops promises to pay dividends in areas extraneous to energy and food, as well. The forest industry is beginning to look closely at the conversion of tree fibre into chemical feedstock as the cost of petroleum rises. Moreover, in the face of a possible global protein deficiency, algal culture can not only produce energy, but can also be a prolific source of single-celled protein.

An incipient focal coordination point exists in the form of the Biomass Energy Institute in Winnipeg.

Energy From Waste

The amount of energy that could be available just from our current wastes is surprisingly large.

Alberta's Agriculture Department has calculated that fermentation of the province's annual production of cattle manure alone could supply 6 per cent of the province's present gas consumption. Canada-wide figures for 1971 suggest that *all* the farmers' tractors, cars and trucks could have been fuelled, their homes heated and their electricity provided, with methane from one-third of the country's crop residue and one-fifth of the animal wastes. And the remaining "sludge" would have been available as an odourless, biologically-stabilized fertilizer.

Turning municipal waste into usable energy can have a considerable impact. Some European cities are heated in part by steam produced by the incineration of urban solid refuse. Alternatively, if the oil, gas or char produced from garbage in one of the conversion processes is sold as fuel or chemical feedstock, urban waste disposal can actually begin to pay for itself, a welcome shift from most current practices, which are a drain on the civic purse and a cause of conflict between the cities producing the garbage and the surrounding areas which are expected to receive it. If a city chooses to ferment its solid organic wastes – at a cost about the same as incineration, but without its air pollution – the products will be marketable gas plus a lighter and more compact residue that is cleaner and less apt to "settle" if it is used as landfill. An attempt should be made to retrieve all recyclable goods before incineration, since this operation is a worthwhile enterprise from an energy saving point of view.

Domestic waste can also be used more locally: a 300-unit Toronto apartment block is being designed to provide all its own hot water by burning its own garbage.

What about prices? Are they competitive? Municipal fuel production from urban waste may already be competitive with municipal waste disposal. Recent increases in oil and gas prices and anticipated further increases will no doubt give considerable impetus to the development of energy from wastes. Commercial firms could play an important role within any well-planned waste collecting, processing and conversion system. A possibly important reason for the lack of development in this area is the dispersed nature of waste generation, and the consequent difficulty and cost of collection. Another disincentive is the lack of institutions for effective collection, conversion and distribution.

Agriculturally, the increasing use of feedlots is easing the collection of animal wastes, but new interfarm cooperation may be required to complete the systems by spreading the initial costs of the conversion equipment, as well as rationalizing the distribution of the energy produced. Canadian municipalities generally have good waste collection systems, but are rarely if at all geared to conversion and distribution of the available energy.

What impact could the energetic use of municipal and agricultural wastes have? Roughly, the conversion of 5 pounds of dried organic waste per Canadian each day could supply 3–4 per cent of our current total energy consumption. Adding the potential of current crop and animal wastes, the proportion rises to 6–7 per cent, and there is possibly a further realizable potential in the wastes from forestry and from municipal sewage which are not now used.

Our current R & D needs are not primarily for basic research, but for assertive programs with entrepreneurial initiative to transform our old habits of "waste disposal" into working systems of "energy collection, production and delivery." Programs could be defined in several ways, but two areas merit attention. A rural energy development program would facilitate the use of crop residue, animal wastes and forestry wastes. An urban energy development program would fund and encourage demonstrations of the use of local heating, particularly for newly designed communities, and would ease the transition from existing to new energy systems. This is a golden opportunity for the National Capital Commission to provide leadership in the area of urban waste-energy utilization by conducting demonstration projects that may serve as imaginative and practical inducements for many Canadian cities.

The required funding need not be high. The reason is that leverage should be relatively easily found in the apparent advantages of waste-energy developments to different jurisdictions, to individuals, and to businesses wishing to become involved in the exploitation of wastes.

Wind Power

A characteristic of wind power is its variable input and output, which requires either storage capacity or connection into a large grid. The cost of wind energy, essentially the cost of the collection and storage equipment amortized over its useful life, is two or three times the cost of conventional energy in Canada's populated areas. In the remote areas, however, the advantage might easily be reversed, particularly if the cost of purchasing and transporting conventional fuels increases and as the technology for storing energy improves.

The capacity of operating plants range from a few hundred watts to several hundred kilowatts, with plans for generators in excess of a megawatt. Currently, the best storage system appears to rely on batteries, but significant improvements (and cost reductions) in storage techniques are necessary before wind can be utilized as the sole energy source in any large operation. Electrolysis of water to produce hydrogen that can be stored and later used in fuel cells is promising, if expensive, and compressed air or pumped water can hold energy mechanically. Further developments of flywheel technologies may well offer an attractive form of storage.

In Canada, a close watch should be kept on improvements in storage capabilities; and support for the development of larger versions of wind generators should be matched with a commitment to demonstration projects.

Especially in new northern settlements, as the level of activity increases along that frontier, windpower may well be preferred over diesel power for electricity. Moreover, the addition of windpower generators to remote systems already having diesel-electric plants is being reconsidered.

Finally, current meteorological data need structuring and upgrading to refine the assessment of wind potential at particular locations, but this is not a difficult task for well funded weather and aerospace institutes.

Geothermal Energy

A small number of geothermal water sources in the form of geysers and fumaroles have long been used for heat and electric generation in several countries, but the less obvious geothermal sources have hardly been touched as we have not yet developed the necessary technologies.

Geothermal resources may be classified into three main types.* One small group is in the range of very high temperature, where reservoirs exist at or above the boiling point. These characteristics exist only in areas of recent volcanism and all geothermal electric developments in the world to date have been associated with them. Some regions in British Columbia and Yukon may be placed in this class.

The second type of reservoir exists in areas where the temperature gradient is barely above normal and consequently its value is mainly as a source of hot water for space heating (for example, Reykjavik) and industrial applications like wood-pulp processings, agricultural production, nurseries, etc., rather than electrical generation. In Canada, aside from the Western Cordillera region, it is anticipated that various areas in British Columbia such as Lillooet, the area around Sable Island off Nova Scotia, and the deep gas field areas of northeastern British Columbia will all be interesting prospects.

Geothermal reservoirs of a third type exist in Canada in the form of the heat stored deep within the earth's "hot rock" in areas where the geothermal gradient is normal.

It is widely – and erroneously – believed that geothermal energy is pollution free. This, however, is not the case. Since most easily developed

* A.M. Jessop, "Geothermal Energy", prepared for the Department of Energy, Mines and Resources, Note 173-1.

geothermal resources are located in areas of crustal mobility, possible difficulties may be associated with the drilling of large installations, storage structures or energy transmission systems in regions of geological instability.

Preliminary analysis of the economic feasibility of geothermal energy for electricity production indicates that from the experience of operations in California and Iceland it can compete favourably with hydro and nuclear power generation.

At the present time in Canada, little research is being done on advanced technologies in this area. It would appear more reasonable for Canada to monitor developments in other countries such as the U.S. and Italy than for Canada to embark, itself, on a program to develop these technologies. There remains our inadequate knowledge of our geothermal resources with respect to identification, evaluation and inventory. We should correct this situation now and be ready to import and exploit any of the extant or future technologies as soon as they become available and applicable.

The federal Department of Energy, Mines and Resources and the B.C. Hydro and Power Authority are currently engaged in an inventory of geothermal resources. A more integrated and intensive effort is required since the information is a prerequisite to any decision on geothermal energy developments by industry and government. This barrier can and should be removed.

On another front, the governments should develop a consistent body of regulations spelling out the rules for the exploitation of our geothermal resources, since the lack of guidance in this field will seriously hamper the future development of geothermal energy in Canada.*

Tidal Power

The potential energy of tides has been used for many hundreds of years by small coastal settlements to provide local energy requirements in the range of 30 to 100 horsepower. The advent of new energy sources, however, considerably decreased the interest in tidal energy.

More recently, modern people, in their quest for alternative sources of energy, have begun to show renewed interest in the tides. Canada is no exception to this trend. Assuming a conversion efficiency of 20 per cent, utilization of all available sites in the Maritime provinces would yield an annual energy output of 51×10^9kwh. This is roughly six times the present power generated in the Maritime Power Pool, and approximately equivalent to the total projected requirements for New Brunswick, Nova Scotia, and Prince Edward Island by the year 2000. Thus, in theory, systematic development of potential sites could provide the Maritime Power Pool with most of its electrical energy needs for this century.

* The government of at least one province has enacted a policy on ownership and development of geothermal resources.

Unfortunately, the tides produce power on an intermittent basis and, in addition, the peaks in power do not coincide at all times with the peaks in demand. This characteristic requires storage facilities, making tidal schemes more expensive.

While comparative economic evaluations of electric power generation did not appear favourable to tidal power a few years ago, the situation has changed recently and the economics should be reviewed to determine the feasibility of particular tidal schemes.

The value of multi-purpose tidal dams offering social amenities in terms of highway crossings, new railway routes or power cable routes should also be considered. Moreover, research on long-term environmental implications should be implemented well in advance of any decisions to commence tidal power development.

Hydrogen Technology

Concerns over the long-term availability of conventional oil and its derivatives, and a continuing interest in new means of storing energy, have given rise to scientific interest in what are referred to as "alternative fluid fuels".

The upsurge of scientific interest in hydrogen as a fuel results from a growing acceptance that it is one of the prime contenders for the position of the dominant energy carrier of the future. As the growth in natural gas supplies decreases and petroleum becomes increasingly scarcer in the long run, the search for an alternative energy fuel, particularly one which is portable and compact, will be intensified.

Hydrogen can be used in place of natural gas in many situations: it can fuel cars and aeroplanes using present technologies; it possibly could be transported less expensively than electricity over long distances; and it could be burnt in fuel cells to provide both heat and power for residential and commercial use. The technology needed to produce hydrogen electrically is well established – in fact, a Canadian company is the world leader in the field. Since the potential of reactors is relevant to the generation of hydrogen, full development of our nuclear program could result in the ability to provide hydrogen as a by-product.

The major disadvantage of hydrogen is its low BTU value, only about a third of that of natural gas, so that, if it were not for its low viscosity, direct substitution in a piped system would require a substantial increase in the pipeline capacity. A second important disadvantage of hydrogen technology as presently perceived is its poor net energy yields.

What is much needed in Canada is an effective watching-brief type of effort in the area of hydrogen production, transportation and storage. We can produce hydrogen now but we have not developed the detailed designs necessary to obtain valid information on costs and efficiencies of industrial scale production. Only when complete cost figures on potential processes are available can we see clearly the economics of hydrogen as an alternative fuel. If we conclude that hydrogen is an economic alternative we must find out how to move and store it efficiently. Hydrogen has been piped long distances for many years but the technology of storage is still in early development. Whether it can be stored below ground or packed in metal hydrides at an economic cost is still not known. Research is now being carried out on hydride storage but we in Canada are only marginally involved, and considerable R & D effort is needed simply to keep us informed of developments on the world scene.

As we move toward higher temperature CANDU reactors, the sequential cracking of water becomes a possible alternative to electrolysis for producing hydrogen. This possibility should be considered in any decision making on R & D in this area, since some nuclear power plants, in the long term, may well produce more energy in the form of hydrogen and steam than electricity. This nuclear technology might even be extended to provide hydrogen for bitumen (oil sands) upgrading, coal conversion, fertilizer production or petrochemical diversification, thus prolonging the life of our fossil fuel reserves. Such energy industry complexes would have oxygen and heavy water as profitable by-products.

The potential for hydrogen in our total energy picture is noteworthy. Not only can it do many of the jobs of present fuels, but it might well be able to do them more cheaply. Because of this we are encouraged to foresee a hydrogen technology. Furthermore, hydrogen is environmentally one of the most innocuous of substances, producing only water and some oxides of nitrogen in combustion. For these and many additional reasons our R & D effort on this promising energy carrier should be expanded in industry, government and universities within a well coordinated program.

Direct Energy Conversion

Direct energy conversion is the generation of electricity from a primary source without intervening transformations. At present, several transformations are interposed in this process, each of which has a limited efficiency. Considering all the mechanical and heat losses throughout the sequence of transformation, steam power plants have an overall efficiency ranging from 15 to 35 per cent. A typical large modern plant in Canada operates at about 33 per cent efficiency. Direct conversion would seek to eliminate many of the losses.

Research has clarified the potential of several new methods of producing electricity more efficiently by direct energy conversion. Some of these potential techniques (for example, thermionic and thermoelectric generation, and magneto-hydrodynamics) are discussed in our background reports.* We will comment here only on the promise offered by fuel cell technologies but will note that the development of magnetohydrodynamic (MHD) electrical power generation requires monitoring now and possible action during the late 1980s.

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

Fuel Cells

A fuel cell is an electrochemical battery which can continuously change the chemical energy of a fuel plus an oxidant to electrical energy by an isothermal process, involving an essentially unchanging electrode-electrolyte system.

The number of possible fuel cells is extremely large; the electrode systems can come in different combinations, the electrolytes can be varied, oxidants can take various forms, and cell pressure can vary. The temperature of operation can also vary considerably.

By contrast with a combustion engine, the fuel cell bypasses the chemical-to-heat, heat-to-mechanical and mechanical-to-electrical energy transformations. Unlike a battery, the fuel cell need not charge and discharge. In comparison with the thermionic and thermoelectric "generators", and magneto-hydrodynamics (MHD), the fuel cell does not transform the chemical energy into heat. In some fuel cells, however, conversion takes place indirectly, for example a hydrocarbon such as natural gas is first converted into hydrogen in a reformer, and this is then oxidized in the electrochemical cell.

A fuel power plant with a generating capacity up to 75 kw has already been tested. In this case units of 12.5 kw were added in series to evaluate its modular capability. Fuel cell facilities producing hundreds of kws are being considered for apartment buildings, shopping centres and schools. A 26 Mw installation for a large U.S. electric utility is under development.

Advantages of fuel cells in comparison with conventional means of energy conversion may be summarized as follows: high efficiency; a capability to conserve scarce resources; environmental acceptability; and modular construction and adaptability.

Main disadvantages of fuel cell systems are: relatively high initial cost; critical aspects of electrocatalysis and direct oxidation of hydrocarbons; relatively great weight per unit power; limited life; high maintenance costs; and the required delivery of a fuel that, so far, is frequently highly specialized and involves a significant back-up installation.

Transportation of Energy

In Canada, distances between many fossil fuel resources or hydropower developments and centres of demand are immense, and are increasing as we push further for new energy into the frontier areas. Already the energy transportation costs are an important consideration in the allocation of energy resources to markets, and in some cases they alone determine whether these resources will be used at all. In addition, there are many modes of energy transportation, each with its own physical, economic and social characteristics. Thus, Canada has a special interest in an integrated R & D effort which will improve the means of transporting energy precisely because we can expect our range of choice of new energy sources to increase to the extent that R & D can indicate ways of lowering the overall costs of energy transportation. Two basic parameters are important. One is optimized integration of diverse transportation modes in the energy network in order to minimize costs. The other is the design of new technological improvements in a given method of transport.

The integrated management of our energy transportation systems is a basic part of energy policy formulation. It requires not only a systems overview in the analysis phase, but also agreement between the various participants on the nature and extent of its objectives. The systems approach is not yet established in Canada although some aspects are present in the electric transmission and gas pipelines networks. Maximizing long-term benefits for Canadians may require some companies to forego short-term advantages. Because of this it will be some time before a fully integrated and nationally optimized energy transportation network can be established. These difficulties, however, should not prevent us from striving toward such a system, even if it were to occur stepwise by incremental trade-offs among the interested participants.

The technological opportunities cover a very broad spectrum and our R & D effort over this entire span should be raised substantially. Improved and efficient design for products and multi-commodity pipelines is especially important, since pipelines already move the largest amount of energy at the lowest cost, and do this with an acceptable impact on our environment. Development of petro-chemical processing complexes in strategic centres in Canada will determine our network of future product pipelines. Substantial changes in the pattern of coal exports and consumption within Canada might result from an economically efficient and environmentally satisfactory pipeline that could move large quantities of coal from the mining areas to coastal harbours and to inland industrialized regions. An alternative is to improve unit trains, especially the design of continuous loading and unloading facilities. Large scale gas pipelines use more than 10 per cent of their throughput as fuel for compressors to drive the gas. Such a high energy consumption deserves a purposeful effort in pipeline and compressor design as the potential pay-off is substantial. Alternatives must also be researched, for example, the use of electric power. There may be advantages in liquefying the gas at source, but again economic and social aspects must be carefully researched. The pumping horsepower requirements for Liquified Natural Gas (LNG) pipelines are about one-tenth of those required for the same quantity of gas, but the cost of cooling and insulation are high. If we could reduce the total costs of liquefaction and refrigeration, we would realize substantial savings.

In electric power transmission, certain trends are emerging as we move from AC to DC and toward higher voltages. We, in Canada, are among the leaders in these fields and should make sure we maintain our prominence (e.g., at the Hydro-Quebec Research Institute).

Extensions to the existing energy transportation system closely relate to aspects of regional development policy. The building of an important energy artery can affect the economic welfare of several regions. Consequently, R & D in energy transportation should consider both the overall design of the system and efficient methods of transport, together with the economic, social and environmental impacts of alternative choices. It is necessary to carefully consider the optimal timing for the inception of a large energy transportation subsystem; design the route for maximum economic and social benefit; rationally integrate a new system component in the overall framework; select an optimal size that takes into account both the present and the potential growth of the system; and do all this while minimizing undesirable environmental and aesthetic effects.

Energy transportation is a complex issue. Many organizations perform diverse functions (e.g., Transportation Development Agency, National Research Council, Ministry of Transport, Canadian Transport Commission, the National Energy Board, the utilities). R & D policies in energy transportation must be integrated nationwide in both energy and transport policies. An equitable and just national policy may be possible only through design of inter-regional (e.g., west, centre) and intersectoral (e.g., energy, transport, agriculture) trade-offs. At the moment, however, we do not have a mechanism in Canada which is able to research and integrate all aspects of energy transportation. This deficiency must be remedied now if we are to optimize the management of our energy resources.

VII. Environment

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

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

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

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

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

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

Global Considerations

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

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

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

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

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

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

Local Impacts

If the global aspects of the energy-environment interface are difficult to trace, the local impacts of energy use are much better known. The use of energy affects the environment at every step of the exploration - extraction - processing - transportation - conversion - consumption - waste product disposal cycle. The severity of the impact is, of course, a function of the technology used, local environmental conditions and the energy resource in question. A tripling of Canadian energy consumption within the next twenty-five years will thus exert an inevitable, although not necessarily proportional, impact on the environment. The cost of the environmental protection measures directly related to excessive energy use within the next decade is estimated conservatively at ½ of 1 per cent of GNP.

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

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

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

Environmental Quality: What are the Issues?

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

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

Table III – Tabulated Environmental Overview

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Mining of coal and uranium	Restoration techniques.	Developing	Increasing	Restoration performance legislation recommended. Strict mining regulations necessary. Restoration performance bond not a strong enough incentive. Require return of land to its original or better productivity.
	Neutralization techniques.	Available	Medium	
	Control of 'acid mine drainage' and siltation.	Not available		Elliot Lake acid drainage is a continuing concern. Study by Environment Canada, 1974.
	Health improvements. Improvements in mine atmospheres.			
Athabasca Tar Sands	Reclamation	Undeveloped	High	Affects life style and livelihood of natives.
	Pond technology.	Under study	High	Affects life style and livelihood of natives.
	Effluent treatment.	Undeveloped	Medium	Possible major ecological impacts downstream. Low level SO_2 concentrations may be acceptable.
Arctic Pipeline	Construction techniques with minimized impact.	Incipient	High	Base line studies in progress are important. Multiple environmental impacts to be considered.
Marine Oil Tankers	Collision avoidance. Clean-up techniques. Ice-infested off-shore operation.	Needs application of available technology	Growing	Ecology of continental shelves, estuaries and oceans important to Canada. International legislation needed. Control of traffic in ice infested northern waters.
Hydro Electric Power	Impact Studies needed.	Incipient	High	Regional impacts can be severe. Careful consideration of all alternatives needed.

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Fossil Fuel Electric Power	Stack Gas Cleanup. Fuel Treatment.	Researched but unavailable	High	High regional importance, if low sulphur fuels unavailable.
	Particulate removal.	Unavailable but under development	High	Global climatic effects require intensive study now.
	Air Cooling.	Available but more costly	Growing	Possible beneficial uses of waste heat in Canada require pilot test.
Heavy Water Production	Control of H_2S releases. Waste heat disposal.	Under development	Growing	Search for alternative production techniques potentially important from environmental point of view. Use of cooling tower being tried.
Nuclear Fission Power Plants	Reactor accident prevention.	Highly developed	High	Increased research on pathways and health impact questions is needed.
	Routine release minimization.	Improving	High	
	Radioactive wastes control.	Inadequate	Growing	Development of improved techniques important.
Nuclear Fuel Reprocessing & Transport	Routine and accidental release control.	Inadequate	Potentially high	Important if plutonium recycling started. Much development needed. International and social factors involved.
Transmission of Electricity	Aesthetic improvements, undergrounding.	Being developed, costly	Low	Wire can be underground now in cities and sensitive areas. Development of undergrounding techniques and aesthetic treatment of transmission right-of-way should be encouraged.
Home and Industrial Heating	Combustion improvement.			Immediate benefits from improved home design and construction, improved building codes.
	Substitute heating methods. Improved construction standards.	Largely undeveloped	Growing	Solar heating and area heating pilot studies should be tried.

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Automotive Transport	Substitute modes of transport.	Developing	High	Primarily a social choice problem.
	Improved engine technology.	Under development.	High	Much improvement possible from advanced technologies.
	Improved engine, tire, roadway and road planning.	Slow improvements.	High	High impact for people in cities, wildlife in sensitive areas.
Fusion Power	Tritium containment. Cooling technology. Fast neutron flux absorption.	Undeveloped	Unknown yet, potentially high	Holds promise of reducing environmental concerns of large scale fission power or continued fossil fuel use. Possible benefits and problems in Canadian waters. Unlimited fusion power could make thermal effects on climate significant compared to dust, CO_2 and albedo effects.
Solar Energy Heating	Nil Basic technology is environmentally benign.		Undetermined, potentially high	Environment impacts would be very favourable if economically feasible. Varied pilot studies recommended on environmental grounds.
Solar Energy Biomass Concepts	Largely undetermined as yet.	Undeveloped	Potentially high	Requires careful systems studies and some pilot experiments in promising areas. Possibilities include isolated agricultural communities, coordination with forest product industries, municipal waste applications. Study impact on wildlife.
Tidal Power	Techniques to minimize tidal amplitude changes.	Undeveloped	Locally important	More propensity for environmental damage than benefit. Environmental studies very incomplete.
Geothermal	Minimize release of dissolved minerals, gases.	Partially developed	Possibly high	Potential in Canada undetermined. Could provide environmentally preferable power source. Requires careful environmental impact assessment as geothermal sources considered.

Technology	Environmental Requirement	Technology Status	Present or Potential Importance to Canada's Environment	Recommendations and Remarks (Based on Environmental Considerations)
Magneto-hydrodynamics	Basic technology improves thermodynamic efficiency, seed recovery removes sulphur.	Slowly developing	Moderate	Possible benefit in allowing higher sulphur content fuels to be used, more efficiently, with less thermal and SO_2 pollution.
Fuel Cells	Basic technology is environmentally benign.	Developing	Possibly high	Permits environmentally benign power and heat in isolated communities. Potential for allowing more dispersed population. Recommended for continued research, pilot studies.
Windmill Power	Basic technology is environmentally benign.	Developing	Could be locally important	Environmentally benign local power sources, possibilities in Arctic, Newfoundland, other isolated areas. Recommended for further research, pilot studies.
Hydrogen (or other synthetic) fuel	Basic technology environmentally benign.	Theoretical only	Could be very important	Major environmental gains possible through elimination of pollutant release in transportation, heating and other activities. Strongly recommended for research and pilot studies in Canada.

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

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

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

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

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

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

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

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

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

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

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

Managing Energy and the Environment

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

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

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

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

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

From the discussion in this chapter, it is clear that energy and environmental concerns represent two sides of the same coin. To treat each in isolation cannot succeed over the long term as energy and the environment interact in too many ways. Just as we are now learning to integrate environmental "externalities" in the planning and coordination process, we must ensure that, in the future, the energy variable is included in that process as well. A background study and a commentary by the Chairman of the Science Council, already published,* describe and recommend a comprehensive approach to shaping the decision-making processes involved in major developments. They stress the need to identify all factors and to consult all groups affected. The Science Council recommends therefore that governments and industry strive to develop a comprehensive management framework that will successfully handle both environmental and energy planning and coordination.

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

VIII. The Roles of the Main Participants

It is no mean task to design a management and organizational system responsible for seeing that all necessary things get done, that they are paid for, and that each task is performed by the proper sector, even assuming that clear policy statements on future energy production and use patterns are forthcoming. While one's first inclination may well be to recommend the concept of a super-agency, responsible for all energy research and development, the Science Council does not believe that such an agency is desirable, or even feasible. The complexity of the energy sector within the Canadian economy is just too great. Any organization of the national R & D effort must reflect the diversity of interests of the various participants in energy demand, supply and transportation, and take effective advantage of the different powers vested in these sectors, and of the different functions they perform. At the same time, while a super-agency is not feasible, the alternative of a number of institutions, each with well-defined functions, also has certain drawbacks. These include difficulties of coordination, under- or over-emphasis on certain R & D aspects, and above all, the real possibility that R & D programs do not dovetail with the kind of trends which might lead toward a preferred new energy economy. To open up this whole question we must first discuss the roles and functions of the various participants.

1) *The Federal Government*

The substantial involvement of the federal government in energy is based on its ownership of mineral rights in the Northwest Territories and the Yukon, on its responsibility in interprovincial and foreign trade (including oil and gas exports), on its jurisdiction over strategic materials such as uranium, and on its power over taxation matters. As we go north, or offshore, or develop new energy technologies, the federal government role appears to increase. In the long term, the federal government should be a major stimulant for the development of new sources of energy, as it has already been in the case of nuclear power. Such a role includes supporting the basic research which plays an important part in the assessment of Canada's future energy options.

The most important federal responsibility is to provide overall leadership in developing, with the provinces, an integrated and comprehensive energy policy from which will come clear priorities for R & D, and which will be capable of sustained evolution.

The federal government also has responsibility for specific areas of R & D. One of these involves upgrading the basic knowledge of the size and extent of all our energy resources, in partnership with the provinces, and keeping an accurate account of the effects of consumption on the long-term reserves. This task must involve the provinces, though their perspectives may differ from that of the nation as a whole. At the moment this aspect of the federal role is shared among the Department of Energy, Mines and Resources, the Department of Indian Affairs and Northern Development, the National Energy Board and the Atomic Energy Control Board, and we recommend that this basic data gathering system be integrated in a way which permits each agency to satisfy its own requirements while contributing to the synthesis of a strategic overview of our resource endowment.

In the area of R & D a primary federal role is to fund development activities in seven distinct fields. One is the national program in nuclear energy under the auspices of AECL. Since this subject has already been discussed earlier in the report, we will emphasize here only that the effort, which has been scaled down recently, should be reemphasized immediately as nuclear power most likely will become the principal source of our energy supplies in the medium and long term. One would hope that as the number of nuclear reactors increases, private industry, in partnership with AECL, will begin to spend more on R & D, and to participate more actively in the evolution of more advanced reactor systems for the future.

A second area for federal involvement is in the newer technologies. Solar and biomass energy, fuel cells and hydrogen as an energy storage and carrier medium are of particular interest among the many ideas that should be encouraged and tested. The private sector is unlikely to satisfactorily fund R & D in new areas until such ideas have been developed to near-commercial application.

Because of regional interests, federal action may be required to support R & D leading to a greater flexibility and resiliency of our energy system. Research and analysis is required to introduce the right kind of components in the proper places and at the appropriate times.

A fourth area for federal activity is transportation of energy for Canadian requirements in the national and international context. We have repeatedly mentioned transportation problems requiring urgent attention, including the question of pipelines for Arctic supplies, the transportation of western coal to eastern markets, and the problems of oil tankers.

The federal government, of course, is responsible for the national defence aspects of energy, which, while they involve R & D, have not been expanded upon in this report.

As we argued earlier, a unified program for R & D in energy conservation should receive increased federal funding. At the moment Canadians have little or no expertise in this area. Basic and applied research should be encouraged and the competence of consulting firms developed so that they will be in a better position to transfer practical knowledge to industries, cities, towns, and other potential beneficiaries.

Finally, the federal government has a significant responsibility for fostering R & D related to environmental management.

2) *The Provincial Governments*

The provinces own the land and administer a substantial fraction of Canada's mineral energy resources; they have constitutional rights over the resources and production of energy within their boundaries. They also play an important role in the internal distribution and consumption of energy. Simple as this direct ownership may seem in theory, in practice the matter is more complicated.

First, while the provinces are the owners of the resources, they are not, in general, the producers. This is a role reserved for the energy industries. Electric power, however, with few exceptions, is being developed by public utilities controlled by provinces.

Second, the ownership is constrained by federal jurisdiction over interprovincial and foreign trade, over strategic minerals such as uranium, and by taxation.

The regulatory role of the provinces derives from the first factor – ownership of resources. In terms of scientific activities this means that there is a need in the provinces for further development of expertise in the area of evaluation of energy resources, their development potential, and their environmental impact. Since the interests of the owner (the province) will not in all instances coincide with the interests of the producer (the energy industry) provincial emphasis on such scientific activities would go a long way toward making the provinces less dependent on private companies as the source of the basic data on which regulations are based. The second factor, federal jurisdiction over certain areas directly relevant to the energy scene, implies that an integrated and comprehensive national energy policy can be developed only when both levels of government are actively involved. Development of such a policy has, of course, implications for R & D priorities in energy in the provinces. We have already discussed this matter in Chapter IV, but would add here that the Canadian provinces are by no means uniform. Some are owners of extensive energy resources, while others are resource poor, and predominantly purchasers and users. These fundamentally different positions will naturally be reflected in the R & D priorities. Thus, while a province such as Alberta may carry out or wish to fund a comprehensive program in oil production techniques, such a program would not be meaningful for New Brunswick or Ontario. It is precisely this divergence of interest that makes it so necessary to formulate a national energy policy.

The provinces are also interested – in different ways and for unlike reasons – in study, research and development related to important components or by-products of the energy industries within their boundaries (e.g., heavy water plants in Ontario, sulphur plants in Alberta, petrochemical complexes in both Alberta and Ontario). Moreover, producing provinces are involved in R & D applicable to the upgrading of energy destined for markets situated beyond their boundaries. In addition, provinces must be concerned with energy supply for future generations and support R & D leading to conservation of non-renewable fuels, increased efficiency of supply and use, and the timely provision of adequate substitutes.

Electricity and gas utilities, viewed as companies owned by the public at large and operating in an area considered essential for the public interest, will be required to play important and new roles in the country's energy system. Canada's electric utilities alone will spend about

$10 billion during the next five years to add the generating capacity and associated transmission and distribution systems needed to satisfy our requirement for power. Utilities, therefore, should fund research leading to efficient expansion of energy supply systems. Utility companies should be interested in all forms of energy and support R & D programs promoting efficiency. To facilitate financing and expansion programs, utilities must become more cost conscious, yet, to provide continuity of supplies, they must learn to take more risks than in the past. As an illustration, provincial utilities should invest in Canada in exploration and development of resources and in new technologies to ensure longer-range supplies. For example, they could be involved in natural gas exploration in frontier areas, in prospecting for and mining of uranium and thorium, in coal transportation by slurry pipelines and in the production of heavy water. Utilities should diversify to ensure stability and optimize the mix of energy forms in order to provide services at reasonable cost. Multidisciplinary research would be required to assist in making strategic decisions.

Utilities should urge conservation rather than increased use of energy. They should conduct research on behalf of consumers and indicate how to cut down on use of such major appliances as heating furnaces, air-conditioners, washers and dryers, especially during peak daytime hours. In any case, utilities should strengthen their planning rather than sales promotion departments.

To enable the utilities to meet future needs, systems planners and utility executives perform medium- and long-range forecasting and planning. Alternatives are studied and evaluated to determine the most economical method of meeting power requirements. Commitments are grounded on continuing growth and expansion. Because of 6–7-year lead times, capital must be committed well before the actual customer demand for energy emerges. The process of making a forecast of demand conditions before a decision to invest in new capacity has a built-in bias toward erring in the direction of excess capacity out of fear of not being able to provide the required service.

To compound the difficulty, the process is circular. Volume of sales affect the utility's finances and costs. Utilities therefore must be involved in shaping both the supply and consumption. They must develop a long-term demand study and plant expansion and siting plan. They must build a more secure supply reserve, but they must avoid idle pre-investments. More broadly still, utilities should be conscious of the national interest in the production, distribution and conservation of energy. In doing so, utilities should support provincial and municipal environmental measures by becoming forerunners of environmentally well-managed companies.

Finally, a public utility should educate and inform its shareholders: the consumers. Although few other industries do a comparable amount of long-range planning or have a similar record of achievement, the general public does not recognize the full and expanding importance of the utilities to the Canadian economy because of lack of information about utility expenditures and expansion plans. The reluctance on the part of utilities and their associations to disclose any but the most general information on future plans contributes to the lack of public understanding of the significant role utilities must play in Canada. It is important that this be corrected.

3) *The Energy Industries*

The goal of the energy industry in Canada is to serve its shareholders and it does this by developing our energy resources within certain constraints (economic, environmental and social) placed upon it by governments and by the market place. The function of industry in western societies leads at the same time to great strengths and definite weaknesses. The strengths are well known – rapid adaptation to new conditions, diversity of available products in line with the desires of most people, low price through competition, efficient distribution and delivery systems, to mention a few of them. The weaknesses, on the other hand, are equally pronounced, and they are of considerable relevance to R & D, particularly in the energy sector.

A specifically Canadian weakness is the dominating influence of foreign-owned multinational corporations, especially in oil, gas, and coal. In earlier reports,* the Science Council has analyzed the unfavourable consequences of foreign ownership on Canadian industry's R & D expenditures. The energy supply industry, apart from the electric utilities, is no exception. Many critics, including the Science Council, have decried the exploitation of Canadian resources by foreign technology and foreign expertise, and have recommended policies to stimulate the expansion of domestic R & D activities. Recent moves by several governments have led to greater involvement by Canadians in energy resource development as well as to the strengthening of expertise and the expansion of R & D programs initiated by foreign-owned corporations in Canada. R & D jointly funded by industry and governments may offer a satisfactory solution in the case of long-term programs. These moves are encouraging and should be extended because it is unacceptable that we be too dependent on R & D and basic design work performed outside the country for the development of resources such as the Alberta oil sands or Arctic oil and gas. These are Canadian resources and their development must be carried out under specifically Canadian conditions. Self-sufficiency considerations alone require the development of Canadian expertise and technology in the energy industries, even if this were to lead initially to slightly higher cost or to some delay in development.

There are other, less specifically Canadian, weaknesses in ensuring industry's participation. Long-range projects present greater risk, and, except from the large companies, it is difficult to obtain investment funds unless the probability of return is safely high. Thus, many companies look quite understandably for projects with rapid return on investment. More-

*Arthur C. Cordell, *The Multinational Firm, Foreign Direct Investment, and Canadian Science Policy*, Science Council of Canada Background Study No. 22, Ottawa, Information Canada, 1971.

over, many companies like other institutions are conservative and will undergo major change only under crisis conditions. These kinds of weaknesses have a real bearing on R & D, and account to a large extent for the lack of development in such promising fields as solar and biomass energy.

4) *The Universities*

The university role vis-à-vis energy is two-fold. It encompasses the education of students and the performance of research. The first role, education of students, was discussed earlier in Chapter IV. As to the second role, research, the contribution of Canadian universities has been a modest one. This must now change.

First, we will discuss basic research. The long-term solutions Canada is seeking will come from new ideas. Nuclear reactors were not invented by experts from an electric utility, nor quicker transportation by horse breeders, nor manned flight by bird watchers, and nor television by newspaper people or theatre owners. Is it too much to hope that eventually the oil sands will yield oil without resort to the rather crude methods that are currently employed – requiring very large amounts of energy in the process – possibly, for instance, by biological means? Or is it too much to expect that entirely new ways will be thought of to convert solar energy? Of course it is not. One cannot, however, plan such discoveries. One must constantly endeavour to create an environment which increases the likelihood of novel ideas emerging. The university is one, though not an exclusive, location for such activity; and one necessary requirement for creating the proper environment at the university is sufficient funding for basic research and analysis activities.

Basic research, however, is not the only required activity in the universities. The universities have a unique opportunity in the applied fields of science and in the study of energy policy as well. The complexity of the energy system, composed as it is of social, economic and technical elements, demands both extensive and intensive study. The universities should accept the challenge of critical integrated analysis and synthesis. This challenge has not as yet been accepted. As a first step there is need for a few university-based energy institutes for research and analysis, founded on a recognition that a systems approach is now required and that many disciplines have contributions to make. Energy research institutes recently formed at the University of Alberta and the University of Calgary are good steps in the right direction. They are funded by governments and the private sector in the energy industry, and provided with facilities and support staff by universities. We would hope to see others emerge.

IX. Technical Directions for Energy Supplies

A great number of R & D activities in the energy field, costing several hundred million dollars annually, are being carried out right now by governments, industry and universities. Moreover, much of that work is done well; funding was good but is now slipping. Nevertheless, equally important work – usually related to longer-term needs – is not being performed at all, or only at a very subcritical level.

As one would expect, specific projects and programs of research and development often relate directly to the roles and missions of the industrial companies and government agencies that perform and usually pay for the research. Thus, one finds, for example, quite considerable activity on the extraction of oil from the Alberta oil sands in a number of oil companies, work on hydro-electric generation, transmission and distribution in the utilities, and study on nuclear reactor developments in AECL. These are obviously proper activities and without them Canada's energy needs could not be met. Moreover, in the examples given, the financial strength of the participants is such that the scale of effort required for success is usually adequate (although not always so, as can be seen by AECL's inability to develop some of the attractive CANDU options to a pilot stage).

If one contrasts the above activities with for instance those on development of the utilization of solar radiation, wind power, geothermal energy, biomass energy, magneto-hydrodynamics (MHD), or the manufacture of hydrogen, one is struck by two facts. First, the scale of effort in these latter areas is inadequate, and there is no way in which our presently insufficient efforts can yield the desired result of a valuable contribution to our long-term energy supplies. Second, no financially strong organizations have specific mandates for developing these options. Whatever work is going on in these areas is poorly funded and is also often performed in the wrong sector of the economy. In sum, while we appear to manage adequately in a number of the more traditional areas, the novel, modern and more exotic areas fall by the wayside even though they may hold the potential for playing an important role in the future.

We do not wish to imply that all of the areas previously mentioned, as well as others not mentioned, should be blindly funded. Some do require considerable funding to reach an effective threshold, while others require only a modest effort. The choices which must necessarily be made should be based on the broad policy decisions evolving from the Intergovernmental Ministers Conference. We have indicated earlier that Canada has a greater opportunity for choice of its energy future than have other countries. Canada can elect to supply its future energy needs to a greater or lesser extent by means of electricity, gas, coal, or by exotic means. The need is for making these choices explicitly. Making these choices wisely involves consideration of relevant options and factors, all of which must be integrated through systems studies.

Regional considerations will be important in making energy choices. As an illustrative example only, a possible scenario for Canada's future energy supply system would be one emphasizing hydro and geothermal power for British Columbia, energy from coal and gas for the prairies, nuclear energy for Ontario, hydro and nuclear energy for Quebec, nuclear and oil for the Maritime Provinces, and hydro and oil for Newfoundland, the whole augmented by solar and other exotic forms of energy across the country with storage perhaps in the form of hydrogen or an equivalent fluid. Such a scenario would, of course, have to stand the tests of economics and of environmental protection. Advocacy of this scenario should only follow thorough study.

But assuming for the moment that this scenario would stand the various tests, and that it could be shown to be the most desirable one, then an important fact becomes immediately clear – we do not, right now, know enough to make it happen. Canada has no experience in the exploitation of geothermal resources, it does not have coal gasification experience, it has not generated hydrogen on a large scale, it has not heated homes and offices predominantly with solar energy, and it does not have the companies or utilities to exploit biomass energy. Above all, Canada does not have the mechanisms required to set research programs in motion in a coordinated manner, or the funding necessary to grasp opportunities.

As a prelude to our recommendations on technical directions, we wish to insert a general comment about cost. It is extremely important to understand that the magnitude of funding that can be expended in any one program is very dependent on the stage of development of the technology in question. A broadly accepted sequence, as one goes from initial research, to applied research and development, to pilot plant construction, is that the associated expenditures increase by one or more orders of magnitude from one stage to the next. As an illustration, the original research, by scientists such as Fermi, Hahn, Meisner and others, which first discovered fission and then established the scientific feasibility of chain reactions cost in the order of $100,000. Their pioneer effort led to expanded programs involving expenditures of millions of dollars when larger fission R & D programs were initiated. Currently, when nuclear reactors are being constructed all over the world, expenditures easily exceed $1 billion annually. Thus, the magnitude of expenditure on specific programs at any one time reveals as much or more about the current state of development of the field in question as it does about the inherent importance of the field. Also, commitment of funding at a low level to a relatively undeveloped field may lead to greatly increased spending on it a few years later, if the preliminary research uncovers promising avenues for the more costly development phases. Such increased funding should not be made available, however, unless and until these promising avenues are shown to exist.

Given this reminder on costs, the Science Council recommends that expanded or new R & D programs be developed along three separate avenues, encompassing

(i) expanded technological activity aimed at development of our fossil fuel reserves

(ii) increased effort on the evolution of the successful CANDU reactor program
(iii) initiation of exploratory research programs on a variety of complementary energy sources with a view to identifying those forms which should eventually be developed to a commercial stage.

We will treat each of these initiatives in more detail below.

Fossil Fuels

We will begin our proposals for R & D related to fossil fuels by attempting to place these fuels in the context of their changing significance in the energy supply system. In the short and medium terms, because of the long lead times associated with the introduction of new energy forms, the responsibility of meeting the bulk of energy demands will fall on fossil fuels. Specifically, they are important as transportable fuels. Only in the long term may R & D provide us with alternatives such as hydrogen or methanol, which will be easy to transport and store and be clean to use.

While fossil fuels will decrease in relative importance, in absolute terms they will be required in increasing volumes until satisfactory substitutes can be delivered in competitive forms. In the long run, despite the prospects of new fuel and petrochemical technologies, crude oil is likely to remain important for special uses such as in agriculture, as a feedstock, and in transportation.

Consistent with the role of fossil fuels in an energy policy, priorities would have to be established to design an R & D program capable, first of meeting demand in the short and medium term, and then of giving us the capability to choose and implement the long term supply and use of fossil fuels according to whatever pattern we might choose. Independent of the time of its fruition, R & D must be planned and commenced now, because of the lengthy lead times involved.

As we move the emphasis from crude oil and natural gas to bitumen and coal in the direction of increasing carbon-hydrogen ratios, the role of conversion and up-grading processes increases. We need to improve the efficiency and net energy balance of extraction, processing and especially chemical enhancing operations. Continued and increased effort is required to develop an advanced oil sands technology and build prototype plants for the effective and economic separation of the bitumen from the sands, and its up-grading. Because of the enormous volumes of bitumen which would be recoverable from our oil sands by in situ techniques, research in this area is of unique national importance.

Maintaining a satisfactory energy inventory through exploration and evaluation of oil, gas and coal reserves is a vital consideration. For example, the inventory study of coal deposits by Federal and Nova Scotia governments should be repeated in other parts of Canada. Moreover, technology must be developed and/or adapted to the harnessing of the oil and gas potential of the Arctic Islands and the Continental Shelf; we must be competent to cope with conditions in the sedimentary basins, the Scotia Shelf and in the offshore regions around Northeastern Newfoundland, the Labrador Coast and Baffin Island. R & D addressed to enhanced recovery from conventional hydro-carbon sources, oil, gas and coal, should be a continuing concern. Activities such as secondary oil recovery, production from water drive and marginal gas pools, development of techniques and equipment for mining of coal to suit our conditions, particularly in the Rocky Mountain region, all would tend to enhance our supply position.

Of special and continuing significance to Canada is a program for the evaluation and management of environmental effects of fossil fuel production. Environmental regulations should be established to cover such considerations as strip-mine land replacement, soil rehabilitation and drainage quality control. Water requirements may be large and act as constraints. Open pit mining may compete with agriculture for land and difficult decisions must be made in the presence of conflicting interests. Traffic of tankers carrying crude oil, refined products and liquefied gas will expand; effective traffic monitoring and control systems must be developed, and contingency plans for coping with emergencies must be prepared. Health and social studies are required on underground mining of coal and uranium. Continuing environmental studies are required to improve preventive action and to permit us to cope with the effects of accidents. All of these concerns can be met only if we are prepared to commit adequate resources to environmental R & D.

Many R & D activities necessary for the development of Canadian resources have international connotations. The world's fossil fuel resources still to be developed or produced are extensive so that much R & D, generally applicable to Canada, will take place elsewhere. Cooperation with U.S., U.S.S.R. and other countries may be beneficial in regard to research associated with aspects of survival in hostile climates, stability and safety of operations either on permafrost or offshore, and logistics of transportation of personnel and materials. Cooperation with U.S., West Germany, Poland, U.K., France, U.S.S.R. and Japan may be useful in developing new mining equipment and systems (e.g., underground hydraulic mining, long wall equipment, coal processing, "liquid from gas" and other conversion and upgrading processes). Research directed to the improved utilization of fossil fuels as well as the evaluation of the impact of combustion emission on human, animal and plant renewable resources, oceans and global atmosphere is best conducted in a worldwide framework. Canada should maintain a watching brief on relevant techniques that are likely to be developed to a satisfactory degree elsewhere. Limited research in these areas in Canada will be able to draw on developments throughout the world.

A coherent program, based on a partnership between governments and industry, will facilitate the coordination of R & D in production, transportation, processing and use of fossil fuels. Table IV attempts to display the necessary R & D activities in an ordered manner.

In a general sense, therefore, there is a need for a common understanding, organization and application of national research resources,

Table IV – R & D in Fossil Fuels

	A. Oil and Gas	B. Oil Sands (and Heavy Oils)	C. Coal
1. Exploration and Evaluation	Maintenance of satisfactory rate of additions to new reserves; development of Arctic and offshore technology; resource inventory; logistics. Monitoring of exploration and development techniques in established supply areas.	Drilling program. Resource inventory – updating.	Improvement of identification and evaluation of reserves. Resource inventory – updating.
2. Development and Capacity	Improvement of drilling and completion methods for Arctic and offshore conditions. Monitoring of stimulation techniques.	Strategic information for long-term planning. Improve efficiency (90% plus). Electro-magnetic heating; hot water stimulation – heavy oils.	Research on extraction; marginal deposits. Economies of scale; size of equipment.
3. Recovery	Increasing recovery factors – enhanced recovery by process and modelling research and laboratory research; attention directed to low pressure, shallow reservoirs with heterogeneous multi-layer, poor porosity developments.	Economic removal of thick overburden. Primary extraction. Froth treatment. Basic and long term mission-oriented research on in situ extraction at high net energy output. Improve recovery (95%).	Open pit mining techniques. Enhanced recovery, hydraulic mining; long wall equipment; social and health studies.
4. Production	Oil field installations and equipment. Multi-phase research applicable to gas and condensate reservoirs undergoing large pressure changes. Rationalization of operations; optimization of production of reservoirs under Arctic conditions; oil field automation for Canadian conditions. Sulphur technology.	Build prototype plants. Improve energy efficiency above 65%.	Improve productivity. Economies of scale; size of equipment. Reduction of production costs but inclusion of social costs. Development of techniques and equipment to suit conditions.
5. Conversion	Arctic and offshore processing. Natural gas reforming to produce pipeline quality gas from propane, butane and naptha (process developed by British Gas Council). Gas polymerization.	Bitumen upgrading. Reduce residuals and sulphur.	Coal processing techniques. Mission-oriented research in coal gasification. Pilot plant for surface coal gasification in 1980–85. Monitor in situ coal gasification. "Oil from coal" processes.

6. Transportation	Refrigerated natural gas; liquefied natural gas. Ocean tanker and deep port technology.	Pipelines. Corridor concepts.	Flow of complex mixtures; Coal-in-oil and coal-in-water. Unit trains.
7. Storage and Refining	Improving gas storage. Maintaining capacity and flexibility – refining.	Novel solutions.	Bulk storage. Effective materials handling.
8. Supply	Systems analysis and multidisciplinary research.	Optimal rate of development; economic impact studies.	Economics of trans-continental supply.
9. Distribution and Marketing	Development of new strategies.		
10. Use	Study of special uses (e.g., agriculture, transportation, feedstocks). Upgrading by use as feedstock in varied petrochemical processes and food industry.	End-use selection.	Use in thermal power plants. Process coal.
11. Quality – Environmental	All aspects of supply. Anti-pollution auto-control devices.	Water requirements and pollution – spacing of plants. Air pollution – land use and aesthetics – surface recovery; Reclamation. Return to quality.	Land use – open pit mining. Aesthetics – reclamation measures. Air quality – SO_2; NO_x and particulates. River and ground water protection. Control of surface operations. Power plants of advanced design utilizing fluidized bed gasification and combustion at elevated pressure to reduce SO_2, NO_x and particulate emissions.

that is, a systems approach to R & D in fossil fuels industries. The ranking of important R & D opportunities should be attempted from a national perspective. A leading role for the energy industry in implementing this R & D program is mandatory.

While the elements of a fossil fuel program we outlined here are important, they are not necessarily the only ones. In terms of cost, the initial *additional* expenditures for such a program would begin by being in the order of 25 to 35 million dollars annually.

Nuclear Power

By the turn of the century we expect that nuclear energy will be Canada's largest single source of electrical energy and that this energy will be generated by advanced versions of the CANDU family of reactors. The main lines of future development which we would support would be

– the commercial demonstration of an organic-cooled CANDU system aimed at achieving higher net station efficiencies;

– increasing emphasis on the introduction of thorium into the CANDU fuel cycle, as a means of dramatically increasing the resource base of our nuclear fuel;

– continuing evaluation as to the desirability of re-cycling the plutonium generated in current CANDU plants; (The expectation of improvements in fuel cycle economics must be carefully balanced against the undesirable features of the reprocessing system which would of necessity be involved.)

– increased attention to the development of new technologies for the processing of uranium ores of decreasing quality.

This main development program will cost of the order of $100 million per year in the immediate future.

To complement the nuclear development program, a separate activity is required to underpin our regulations of the nuclear industry. Such an initiative should involve R & D and survey activity concerning the impact of radiation on humanity, and concerning the security of systems for the transport, storage and long-term management of radioactive wastes. The cost of an orderly program in these areas could reach $5 million per year in the near future.

Our recommendations with respect to the development of fusion technology are that Canada

– should not attempt to develop a full program for fusion power generation but

– should seek to collaborate with other national programs by specializing in some specific aspects of the problem: our preference would be for a concentration on aspects of materials technology, and

– should initially concentrate on fusion as a neutron source, for use in breeding fissile material, rather than on fusion as a net energy generator. In this way our involvement in fusion technology could become a natural long term adjunct to our nuclear fission power program. Finally,

– we would envisage that Canada's contribution to fusion technology would cost in the range of $10 to $20 million annually, averaged over the next 20–25 years.

Complementary Energy Forms

Canada matured as a nation during a period in history when technological innovation was unprecedentedly rapid. Our first phase of development has been essentially completed, the land has been made habitable, the people have become educated, the infra-structure has been put in place. Previous generations of Canadians can be proud of what has been accomplished. However, to unlock the land and at the same time participate in a large way in technological innovation has not proved to be feasible. Thus, the process of nation building has deferred our full industrialization. In fact, we are still weak in the manufacturing sector. Oil, gas and coal were, probably by necessity, developed largely by foreign capital. The resource industries associated with this development are overwhelmingly in foreign hands. In the present situation, it should be recognized that these industries have reached maturity and will certainly decline in relative importance in the future. On the other hand, examining the most modern of the energy industries, the nuclear industry, we note that we have fully participated, and with considerable success, in developing this complex technology. This should be held up as an example to follow for Canada as we set out to develop the energy sources for the future.

In other words, the second phase in Canada's development begins with an existing infra-structure, a better developed capital market, and a highly educated population. To utilize this set of resources for the wise exploitation of the new opportunities in energy is the challenge before us. If we accept it, as we must, the successors to the petroleum companies and the knowledge and skills in this area can be Canadian. To accomplish this task will require a concerted R & D drive by industry and universities aided by the governments of Canada. It will require a sustained effort and it will require adequate funding. The success of Canada's nuclear program surely gives us the confidence to accept the challenge.

The complementary and as yet economically or technically unproven energy sources will be entering the energy scene in diverse ways. These energy forms and associated technologies are: solar energy, biomass, energy from waste, wind power, geothermal energy, tides, hydrogen as a fuel, fuel cells, magneto-hydrodynamic conversion, etc. Their impact or evolutionary influences do not appear to be great enough in the short run to modify seriously the overall pattern of development over the remaining years of this century. Rather, their significance will begin to be felt during the first decades of the next century, provided we begin research and development on them now.

The first general need in this area is for "paper" studies on the various forms and technologies, leading to greater clarity on the potential contribution of the complementary forms, their probable costs, environmental impacts, scientific and technological problems, and so on. In other words, these studies would provide Canada with the knowledge needed for making well-based decisions as to the specific technologies with which to proceed.

The annual funding level in these complementary energy forms for the entire program outlined below would be in the order of $7–10 million initially. As we pointed out earlier, however, this modest sum would be likely to rise rapidly over perhaps a 5- to 10-year period, possibly to tens of millions of dollars annually. Before such an amount could be justified, more information is required on the actual promise of each of these options.

Solar Energy, which presently suffers from a lack of funding, will eventually play a significant role in supplementing the world's energy and electric generation needs. Whereas R & D ought not at this time to be directed to central solar electricity generation, a research program should be initiated which involved all organizations interested in the use of individual radiation receptors for space and water heating and space cooling. This R & D effort should be complemented by a number of demonstration projects, which are necessary to familiarize the decision makers in this field (for example, contractors, house owners) with the actual potential of existing technology. Incentives would have to be provided accordingly (for example, by Central Mortgage and Housing Corporation).

A *Biomass Energy* research and development program is recommended involving the appropriate departments of forestry and agriculture, as well as organizations already interested. In addition, there is a need for the implementation of some pilot scale demonstration projects (e.g., plantations, algal culture) which would aid in obtaining firmer information on cost under actual operating conditions.

Energy from Waste should be pursued by polarizing R & D efforts into two distinct but related programs, one agricultural and one urban. The involvement of entrepreneurial initiative in developing technology, and of the three levels of government in fostering a much needed public discipline, are paramount conditions for an effective and economic utilization of waste.

Wind power, its potential scope and supporting technology should be the object of a coordinated R & D program possibly under the administration of the National Research Council. This program should be complemented by demonstration projects concentrating on energy storage capabilities and the development of Canadian versions of wind generators. Canadian firms should be invited to participate at an early stage.

Geothermal energy will be utilized only gradually – and regionally – between now and the year 2000. Because of certain affinities with existing technology, geothermal energy will be developed without the need for a technical breakthrough. The research program for resource identification and evaluation should be continued. The energy industry should be induced to play a role just as soon as legislation is enacted by the provinces and the federal government in regard to the production of all forms of this energy.

Tidal power development in Canada has a distinct regional importance. The economics of this form of energy have been and should continue to be reviewed periodically to determine feasibility and benefits. The technologies of interest in connection with the kinetic energy of sea waves and the thermal energy of ocean layers at different temperatures can be surveyed at a relatively small cost.

Hydrogen technology, or the technology of an equivalent fuel, could well play an all-pervasive role in the next century. An R & D program should be organized now to evaluate the role of hydrogen as a fuel and to determine its characteristics in terms of the economics of generation, transportation, storage and use. The overall thermal efficiency possible with this fuel should also be determined, as well as the materials and protection techniques it would require.

Direct conversion of other forms of energy into electricity is important since the simplicity and potential efficiency of this conversion makes it attractive in principle. Relevant technologies have practical limitations that at present rule them out as significant contributors unless breakthroughs are forthcoming soon. The fuel cell could play an important role in the storage and integration of solar and wind energy into an energy system. An R & D program is recommended that would monitor and coordinate the various existing developments. A watching brief should be maintained on all other direct conversion developments (e.g., magneto-hydrodynamics).

Research and developments in thermal low temperature conversions and in heat conservation should be surveyed continuously, perhaps by the National Research Council, Energy, Mines & Resources and the electrical utilities for possible future applications (e.g., making use of low grade waste heat for district heating, and in a variety of aquacultural and agricultural endeavours).

The Major Program Approach: An Organizational Vehicle

If Canada is to launch these new ventures in energy R & D, then what institutional arrangements are appropriate? Some of the ventures which we see as necessary bear all the hallmarks of the Major Programs which we have discussed on many occasions.* They require the participation of governments, universities and the private sector, of those who will design and build the systems and of those who will use them. Given the magnitude and extensiveness of the needed programs, it will be instructive to see what lessons can be drawn from the execution of Canada's most successful Major Program to date – the nuclear energy program.

The first important feature of the nuclear power program to note is that it was given a clear objective whose attainment would be measurable – the program was to develop an economic and safe power source

*Particularly in Science Council of Canada Report No. 4, *Towards a National Science Policy for Canada,* Information Canada, Ottawa, 1968.

utilizing nuclear energy. The organizational form chosen to implement the program was a Federal Crown Corporation – a form considered appropriate since the R & D involved was funded, almost exclusively, by the Federal Government. This has had the advantage of allowing the formation of a strong management team and a well coordinated research, development and design effort. But it has also been vulnerable to the criticism that industrial corporations which have become participants in the nuclear program, whether as manufacturers, consultants or whatever, have had a substantially smaller share of R & D activity than is necessary to let the program reap maximum potential benefits. We would say here only that while such a position may be largely tenable, any analysis of the problem would necessarily have to weigh the purchasing policies of the utilities involved against the contracting policies of AECL.

The choice of a Crown corporation as the prime mover behind the nuclear energy Major Program was probably made inevitable in the post-war Canadian context by several factors, including:

– the strategic and military overtones covering nuclear research in its early days;

– the magnitude of the financial commitment needed (more than $1 billion over nearly three decades to date) which ruled out the private sector as the leading agent in any country, even in the U.S.;

– the lack of conflict in this field between the Provinces and the Federal Government.

Turning from what has existed, organizationally, in the case of nuclear energy to what should exist for new Major Programs in fossil fuels and in exotic technologies, a set of criteria can be set out which should be satisfied by such programs. These criteria include:

(a) the need to select clear goals for the programs which would be maintained over the long term;

(b) the need for a reliable source of significant levels of funding over what will probably be a long-term R & D program;

(c) the need to create a "systems management capability" which will exercise overall control over the R & D program;

(d) the need to secure the involvement, in the R & D phase, of those who will be the operators of any technology developed;

(e) the need to involve the potential hardware manufacturers in the R & D phase of the program.

While these criteria will need to be met in any "Major Program", each specific program within the two broad areas – fossil fuels and complementary sources – will bring its own specific organizational/political problems. To take a possible case in point, suppose that Canada were to adopt as a goal "the development of economic and environmentally acceptable technologies for the liquefaction of Canadian coals". Some obvious questions arise from the preceding list of parameters:

– Who should fund the R & D phase? the federal government? Those provinces with major coal reserves? The (mainly foreign-owned) coal companies? Oil companies? Some combination of these?

– Who should operate the coal liquefaction plants? A provincial utility? A coal company? An oil company? A chemical company?
– Do any appropriate "potential hardware manufacturers" for such a system exist?
– Who should own any successfully developed technologies? (This could become a key issue in the case of any program funded by government(s) and executed by multinational corporations.)
– Who owns or controls the resources to which any new technology would be applied?
– What demands would such a program place on our educational institutes, both in terms of direct participation in the R & D activities and in terms of how they would use new personnel information and reach students?

The nature of the answers arrived at to each of these and many other questions would go far toward delineating an appropriate institutional structure for the execution of the program.

As was noted above, the role of the federal government in the early days of the nuclear program went undisputed by the provinces. Such a circumstance will not prevail in the case of any Major Programs on fossil fuels or on the exotic forms of energy since in both areas there are very significant provincial interests. If joint participation in funding is to be the order of the day, and it should be, can a program organization be devised which is simultaneously accountable to its sponsors, the governments, and free enough to vigorously pursue its stated objectives? It should be observed that attempts have been made in the past, in the international arena, to mount programs in a variety of technological fields, including nuclear energy. Some of the projects involved have failed to achieve a great deal, often because of poor decisions on management structures at the outset. The problems encountered are well documented* and merit some study before we in Canada attempt to launch any program involving intergovernmental collaboration in the highest levels of decision making.

As general conclusions, the Science Council would note the following: government, federal, provincial or more likely some combination of the two, is likely to have to assume a significant role in funding the Major Programs which we have proposed. Because of this, government should also assume responsibility for establishing or designating the "systems manager organization" for each of the programs. (AECL already plays this role in the nuclear program.)

Once the terms of reference of the "systems manager organization" are set, the organization should be given the required amount of power and responsibility to see that its mandate is fulfilled.

The "systems manager organization" (e.g., a federal-provincial-industry joint corporation) should control the development of the required

*See for example, R. Williams, *European Technology (The politics of collaboration)*, Croom Helm, 1974, for an overview.

R & D program and, in the development of a technological capability in the area, should make maximum possible use of the private sector and the universities in the performance of the R & D program. Where new R & D groups or facilities need to be created, industrial involvement should be sought from the beginning. In many of the areas we have discussed there are good opportunities for establishing new and innovative means of government-industry-university collaboration in R & D.

X. Epilogue

In this report we have talked about energy and energy R & D. The Science Council is optimistic about Canada's opportunities. If we do the right things we will be able to enter the 21st century with confidence. We have the resources and we have the skills.

To exercise these opportunities we must do three things. We must bring all actors, federal government, provincial governments, universities, the energy industry, and the consumer, closer together with a view to planning for the longer haul. Second, we must look seriously at the demand side, and implement policies that lead to a less wasteful use of our resources through demand shaping and conservation. Third, we must increase, and increase now, our R & D effort in both existing and potential energy conversion processes.

If we do these three things, together, as a team, we will indeed be able to capitalize on Canada's Energy Opportunities.

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A National Statement by the Schools of Forestry at Canadian Universities, October 1973

A National Statement by the Faculties of Agriculture and Veterinary Medicine at Canadian Universities, 1975.

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Please add
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to the list of members of the Science Council Committee on Energy Scientific Policies

Erratum
p. 135

Prière d'ajouter:
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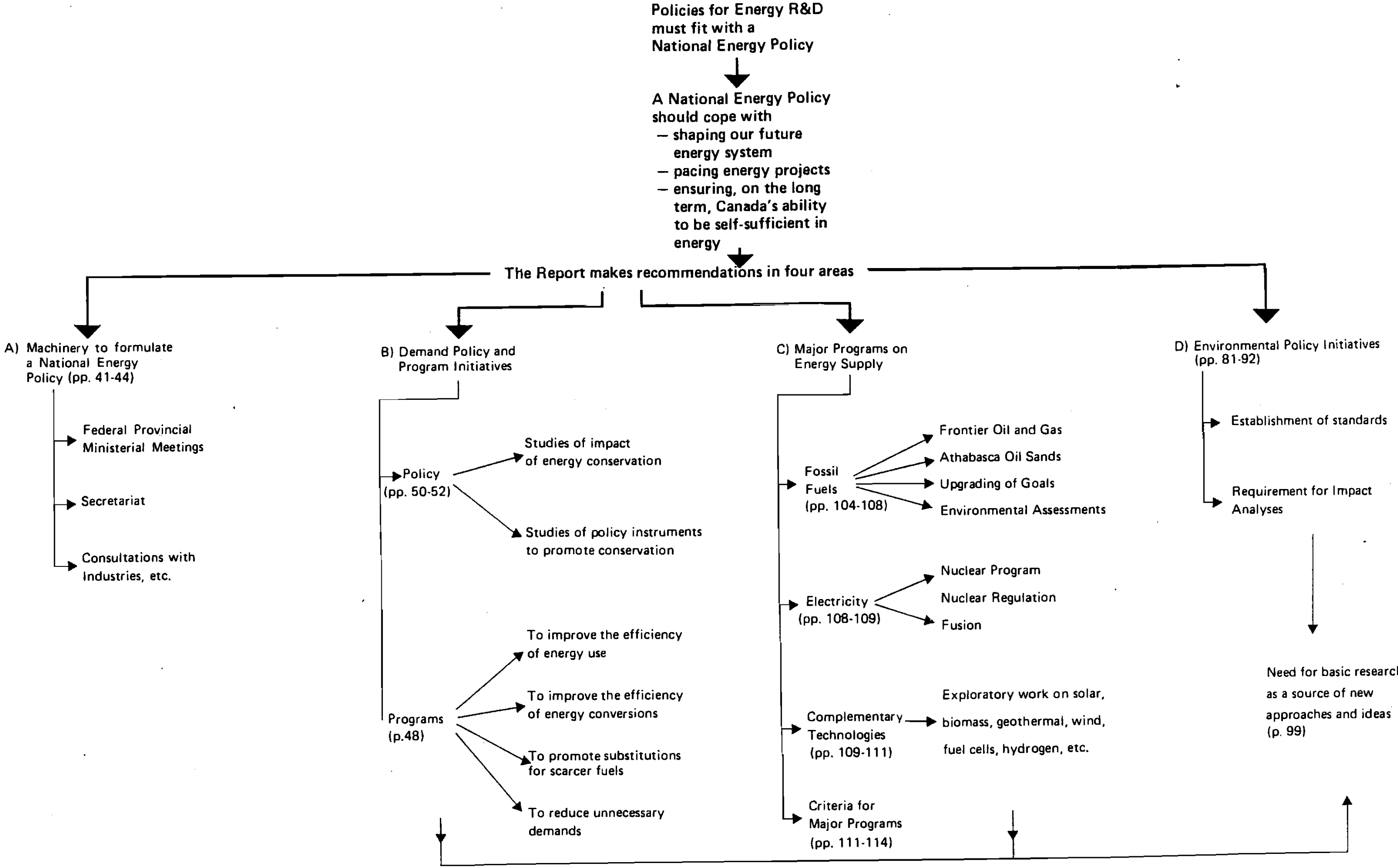
à la liste des membres du Comité du Conseil des sciences pour la politique scientifique de l'énergie.


Policies for Energy R&D must fit with a National Energy Policy
A National Energy Policy should cope with
— shaping our future energy system
— pacing energy projects
— ensuring, on the long term, Canada's ability to be self-sufficient in energy
The Report makes recommendations in four areas
A) Machinery to formulate a National Energy Policy (pp. 41-44)
Federal Provincial Ministerial Meetings
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Consultations with Industries, etc.
B) Demand Policy and Program Initiatives
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Studies of policy instruments to promote conservation
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To improve the efficiency of energy use
To improve the efficiency of energy conversions
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