ENERGY ALTERNATIVES

HOUSE OF COMMONS
CANADA

A REPORT BY

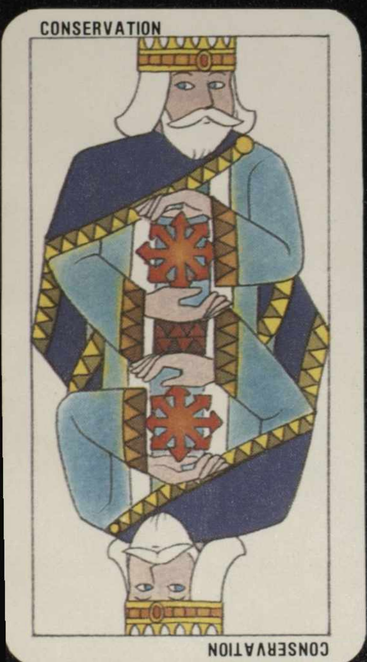
THE SPECIAL COMMITTEE
ON ALTERNATIVE ENERGY
AND OIL SUBSTITUTION

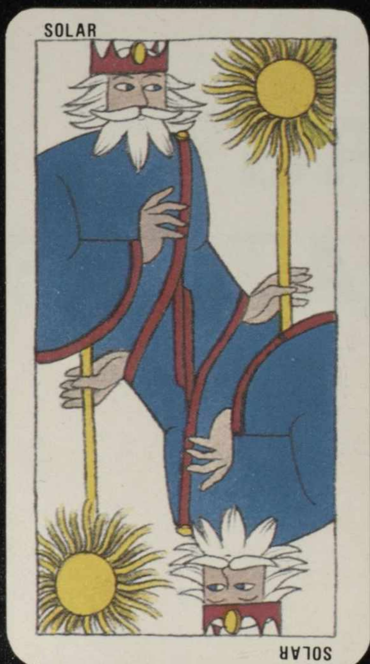
HOUSE OF COMMONS
CANADA

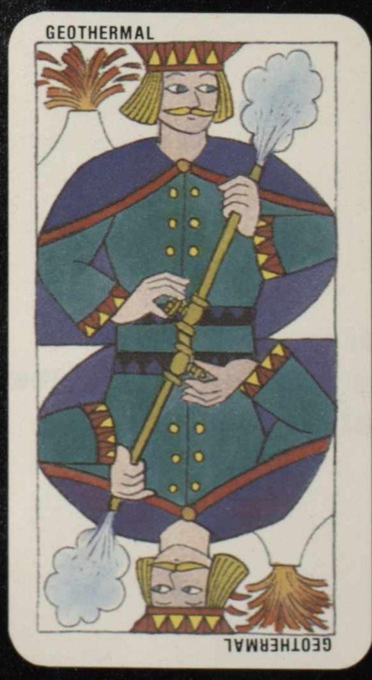
ENERGY ALTERNATIVES

Report of the
Special Committee on Alternative Energy and Oil Substitution
to the Parliament of Canada

ENERGY





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First Session of the
Thirty-second Parliament, 1980-1981

The Special Committee on Alternative Energy and Oil Substitution has the honour to present its

THIRD REPORT

In relation to its Order of Reference of Friday, May 23, 1980, your Committee has examined the following:

That a Special Committee of the House of Commons, to be composed of seven Members to be named at a later date, be appointed to act as a Parliamentary Task Force on Alternative Energy and Oil Substitution to explore and report upon utilization of alternative energy sources such as "gasohol", liquified coal, solar energy, methanol, wind and tidal power, biomass, and propane for heating oil and vehicles, with special attention paid to the feasibility, the impact on balance of payments and overall economic desirability;

That the Committee have all of the powers given to Standing Committees by section (8) of Standing Order 65;

That the Committee have the power to retain the services of expert, professional, technical and clerical staff as may be deemed necessary;

That the Committee, its sub-committees and Members of the Committee have the power, when the Committee deems it necessary, to adjourn or travel from place to place inside and outside Canada and that, when deemed necessary, the required staff accompany the Committee, sub-committees or Members of the Committee, as the case may be;

That the provisions of sections (4) and (9) of Standing Order 65 be suspended, unless otherwise agreed to by the said Committee, in application to the said Committee; and

That, notwithstanding the usual practices of this House, if the House is not sitting when an interim or final report of the Committee is completed, the Committee may make the said report public before it is laid before the House, but that, in any case the Committee shall report to the House finally no later than December 19, 1980.

NOTE: This mandate was extended by the House of Commons first to 31 March 1981 and then to 15 May 1981, at the request of the Committee.

ACKNOWLEDGEMENTS

Over the last year this Special Committee has called upon the assistance of a large number of people. We extend our thanks in general here and note that various appendices to the Report name those who supported or contributed to the Committee's work.

We first thank the individuals and organizations across Canada who came forward as witnesses or who provided information and opinions to us. The Committee members and the staff have relied heavily upon these thoughtful contributions.

The Governments of all ten Provinces and of the Yukon and Northwest Territories responded to our invitation for meetings. Not only did we benefit from the regional views thereby expressed but we also appreciated the fact that Government representatives accommodated themselves to the Committee's tight schedule.

Many agencies and facilities welcomed the Committee in its travels in Canada and abroad. We found such visits to be of great value to the study and the hospitality which we were accorded was a welcome tonic during a tiring schedule. We asked for the time of many busy people and it was freely given.

The Department of External Affairs gave yeoman service in setting up complex international travel itineraries under pressing time constraints. Many people in the Department contributed to the success of this aspect of the Committee's operation, both in Ottawa and in the countries visited. We are also grateful to the Departments of National Defence and Transport for providing government aircraft for parts of the Committee's travel, some of which could not have been otherwise accomplished.

We thank the Research Branch of the Library of Parliament for providing an unprecedented level of professional research assistance to a Parliamentary Committee, and the Information and Reference Branch for supplying reference material. Other services of the House of Commons, which are often taken for granted, should be formally acknowledged. These include the Committee Reporting Service, the Printing Operations Branch, and Simultaneous Interpretation. In holding public hearings in Ottawa and across Canada and in appending technical documents to our *Minutes of Proceedings and Evidence,* we have placed a heavy burden on these services and we have been well pleased with the results. To those who performed the secretarial tasks for the Committee we extend our gratitude for persevering in sometimes trying and hectic circumstances.

Lastly we thank our families who tolerated with patience and good humour the excessive demands that the Committee work made upon our time. We regret that this time cannot be recaptured now that the Report is finished.

TABLE OF CONTENTS

PREFACE

Chairing the Special Committee of the House of Commons on Alternative Energy and Oil Substitution has been an exciting and appealing challenge. The experience of working closely for many months with a small and dedicated group of Members of Parliament, supported by a competent professional staff, was particularly satisfying. Our mandate was one of the most complex and technical ever given a Committee of the House and it demanded months of intense study by the Members before they could state their conclusions and recommendations.

Our work we hope demonstrates that a group of Parliamentarians with various backgrounds, representing three political parties and possessing different degrees of knowledge about energy, is able to prepare a report which is comprehensive, credible and understandable to the Canadian public.

During the public hearings held in Ottawa and in each Province and Territory, Committee members had an opportunity to hear testimony from private citizens, interested groups, professional people, officials from corporations large and small, and government representatives. Furthermore, officials in a number of foreign countries welcomed our inquiries and opened their doors to us. We could not have completed our study without the cooperation and time freely given by all these people and we sincerely thank everyone who contributed to the Committee's learning process. We hope that this Report justifies the efforts they made on our behalf.

The Committee had to cope with an avalanche of material and it has been an immense task to weigh the opinions and to consider the information contained in these documents. Similarly, we found it difficult to present our findings concisely. This Report reviews the present energy system in Canada and, by means of its recommendations, suggests ways that alternative sources of energy and conservation should be promoted. We hope that our conclusions will convince Canadians that, while our country does not yet face a true energy crisis, there is an urgent need to find appropriate substitutes for oil and to move Canada's energy system towards one based upon sustainable energy sources.

Canada has the resources to be a leader in the global energy transition. In this century we have the opportunity not only to secure our own energy future, but also to export new energy technologies we develop along the way. We appreciate that this transformation of our energy system will not be easily achieved, and our recommendations reflect the magnitude of the effort required. We are however optimistic that with a concerted effort, and an enthusiastic and sustained commitment, the task can be accomplished.

Thomas H. Lefebvre, M.P.
Chairman

ORGANIZATION OF THE STUDY

The Committee was established on 23 May 1980 and we recognized at the beginning of the investigation that our order of reference required some interpretation. We decided that *alternative energy* would refer to those energy sources, energy technologies and fuels (energy currencies or carriers) not presently exploited in Canada to any significant degree. Coal liquefaction, for example, is a commercial enterprise in South Africa but it is not a technology developed in this country and thus represented a legitimate area for study. Initially the following subjects were selected for consideration: biomass, coal conversion, co-generation, district heating, fluidized bed combustion, fuel cells, fusion energy, geothermal energy, heat pumps, hydrogen, nonconventionally-powered vehicles, ocean, solar and wind energy. This list underwent some modification as the study progressed and the subjects were accorded varying degrees of importance.

The order of reference made no mention of Canada's conventional energy sources: crude oil, natural gas, coal, hydro-electricity and nuclear-electricity. Neither did it mention the subject of energy conservation. It soon became apparent, however, that one cannot study the potential contribution of alternative energy to Canada's energy system without considering the manner in which the conventional mix will evolve. Similarly, one cannot discuss the evolution of a complex energy system without referring to the impact of conservation. In other words, although we were not directed to look beyond the area of alternative energy, we had no choice but to touch upon many elements of Canada's energy affairs. The Committee was therefore presented with an immense task and, notwithstanding the extension of its reporting deadline from 19 December 1980 to 15 May 1981, time has been the overwhelming constraint on its operation.

In approaching this task the Committee called upon the services of the Library of Parliament. Eight Research Officers from the Research Branch of the Library, trained in the fields of science and economics, assisted in the Committee's investigation. Six of these people worked with the Committee from the beginning to the end of its mandate.

On 25 June 1980, the Committee opened its first round of public hearings in Ottawa. Concerned with exploring the range of the mandate, these hearings laid the groundwork for more detailed investigation. This phase of the Committee's operation carried through to the end of July and included 16 public sessions.

In advertisements carried in mid-July in most daily newspapers and in a number of weeklies across Canada, the Committee next invited public submissions relating to its mandate. Some 150 individuals and organizations corresponded with the Committee in response to this advertising, the majority submitting briefs of varying length and complexity. Following the analysis of these submissions in late August, the Committee held public hearings across Canada in the month of September. The domestic travel allowed us to hear representative presentations drawn from the public response to our advertising, to meet with government officials in every Province and in the Yukon and Northwest Territories, and to see facilities of interest in various parts of the country. The Committee visited the cities of Quebec, Montreal, Toronto, Victoria, Vancouver, Edmonton, Regina, Winnipeg, Yellowknife, Whitehorse, Hay River, St. John's, Halifax, Charlottetown and Fredericton.

In October the Committee turned its attention to the international scene. Dividing into subcommittees, members and staff visited the United States, Brazil, France, West Germany, Italy, Ireland, Sweden and Iceland. Meeting with government officials and representatives of the private sector and visiting selected energy facilities, we learned much about the alternative energy programs in those countries.

Having acquired some perspective on developments abroad, it was time to add depth to the inquiry and a final round of 28 public hearings was held in Ottawa. Those hearings pursued more detailed aspects of alternative energy and were completed on 11 December 1980. Thereafter the Committee began preparing its Report to Parliament.

During its study the Committee exercised its authority to retain the services of experts. Assistance on specific issues was provided by Middleton Associates of Toronto, by the Economic Council of Canada and by Professor John Holdren of the University of California at Berkeley. To help convey its ideas and findings to the public, the Committee hired the graphics firm Les Illustrateurs of Hull, Québec and Rockland, Ontario. And, under the aegis of the Library of Parliament, the Committee engaged Professor Benoît Jean, of the Institut national de la recherche scientifique in Varennes, Québec, to provide peer review for the final Report.

The reader will note that the order of reference directed the Committee to report upon the "utilization of alternative energy sources". We recognize the point of view which stresses dealing with the demand side of the energy equation rather than the supply side. While we agree that the management of energy demand is of at least comparable importance in Canada, our Report necessarily treats only the subject of alternative energy supply in detail.

We further recognize that our investigation has not exhausted all avenues of approach even in the restricted domain of alternative energy. Rather we have laid the subject out in broad terms, leaving many signposts along the way where we think more detailed work is desirable (or essential). In so doing, the Report outlines the Committee's view of the appropriate evolution of Canada's energy system.

Our final comment here is a technical one. Energy statistics can be baffling both because of terminology (not always consistently used) and because Canada has recently instituted a new system of measurement (SI or the International System of Units). In the spirit of "going metric", we have emphasized the new system in this Report while putting considerable effort into showing the equivalence between English and SI units. The problem of terminology in the energy field is less easily handled. We have selected those definitions which seemed most appropriate for our purposes and have tried to be consistent in their application. Terms and concepts are defined as they arise, and units and conversion factors are gathered into Appendix A for ease of reference. Monetary values are understood to be in current Canadian dollars unless otherwise specified.

AFTERTHOUGHTS

In a number of ways the operation of the Special Committee on Alternative Energy and Oil Substitution has represented a departure from normal Committee operation. This is also true for the other five Task Forces established at the same time but, to our knowledge, no Canadian Parliamentary Committee has ever before been given such a technically demanding subject for investigation. This led to an unprecedented commitment of professional support to a Committee by the Library of Parliament. In another departure, the research staff was allowed to participate regularly in questioning during public hearings and during visits to other countries. Upon occasion, the staff also was given the opportunity to represent the Committee when Members themselves were unavailable. Given the technical nature of the mandate, the rapport these new developments engendered between Committee members and staff allowed for a broad and detailed exploration of energy issues.

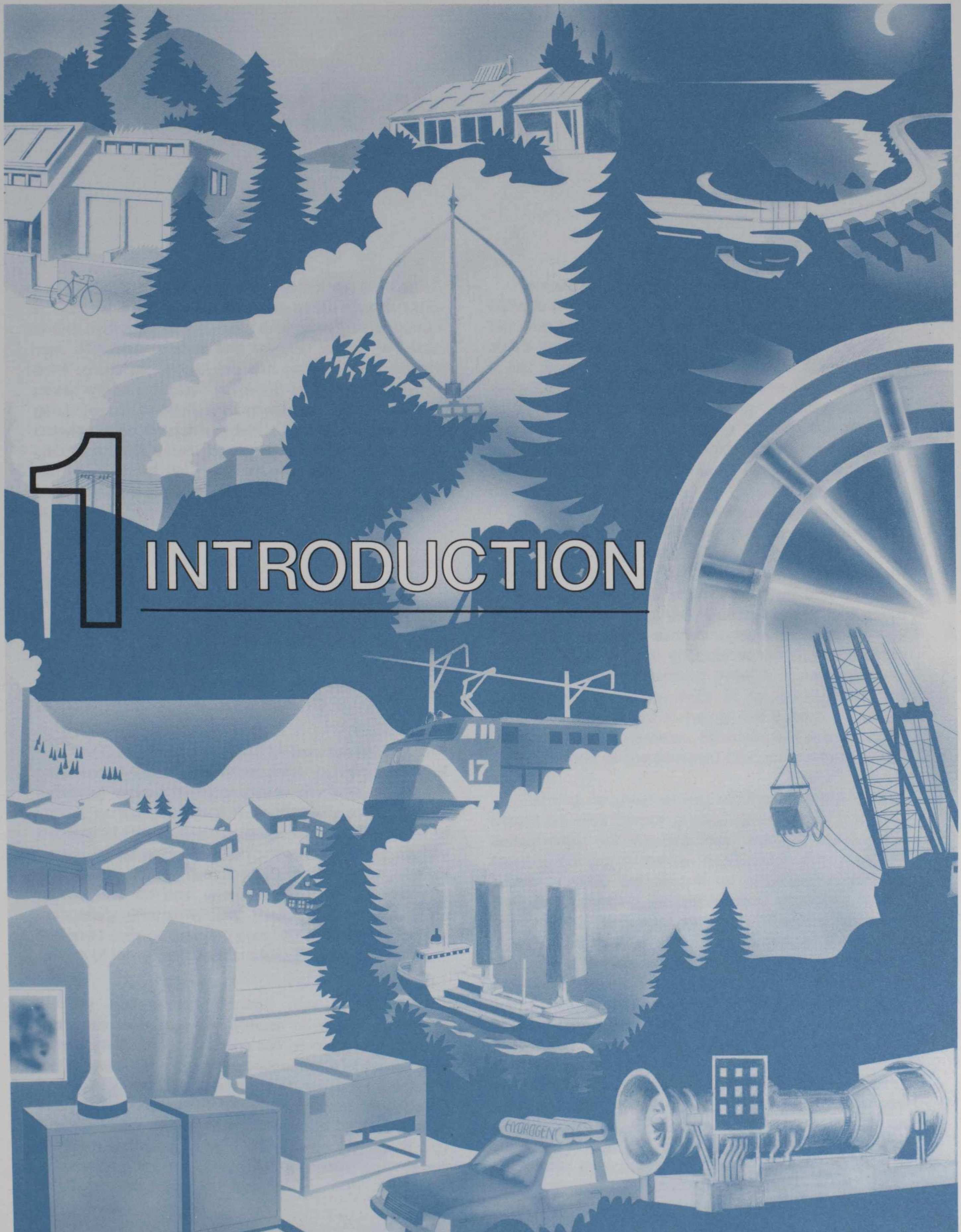
As elected representatives, Parliamentarians are entrusted with managing the public's affairs. This has never been an easy task, but recently it has become even more difficult as society is faced with increasingly complex and technical issues, not the least of which is how to deal with energy matters. Thus if Members of Parliament are to handle their legislative responsibilities effectively, especially with regard to technical matters, some new approach to help cope with this complexity must be considered.

We have found that the vehicle of a "Special Committee" has been an effective means of developing the expertise of Members in new fields. And to the extent that this style of committee operation allows Members to educate themselves in specialized areas, it also serves to expand Parliament's body of knowledge. This is because a Special Committee allows a small group of Members to study a subject in more detail than has typically been possible under the Standing Committee system. We found that a committee membership of seven was almost ideal for our purposes.

Beyond the fact that seven Members of Parliament have been given a unique opportunity to develop their thinking on the subject of alternative energy, our Parliamentary system benefits in another way. The knowledge garnered by the Committee's research staff also remains at the service of Parliament since that staff was drawn from the precincts of the Hill. This facilitates the transmission of new information to other Members.

We regard the establishment and operation of the Special Committees as an important test by the Government in strengthening the Committee system. We believe that our experience with a small specialized committee points the way to dealing with many of the complex issues facing Parliament today and promises to provide Members with more resources for and confidence in approaching such matters. We recommend that the Government consider building upon the experience of these Task Forces with a view to incorporating some features of their operation into the regular Committee system.

1 INTRODUCTION



Introduction

In fifty years Canada's energy system will be radically different. We foresee a system based upon electricity and hydrogen as the major energy carriers or currencies, with only minimal and selected use of hydrocarbons (crude oil, natural gas and coal) as fuels. Electric power will be generated in several ways, with the hydrogen produced primarily through the electrolysis of water. Drawing upon the sun's radiation and to a lesser extent upon the Earth's heat flow, our society will be able to satisfy much of its need for the low-grade thermal energy used in space and water heating and for industrial heat.

Our reasons for believing that Canada's energy system should be directed away from hydrocarbons in the long term are two-fold: first to counter the otherwise formidable environmental problems we see arising in the next century, especially if coal becomes a principal element in our energy supply; and second to preserve crude oil, natural gas and coal for such non-energy uses as the production of petrochemicals.

The Committee is troubled by past failures to anticipate many of the environmental consequences of exploiting various forms of energy. We wish to see this impact considered much more carefully in the future. Our lack of enthusiasm for coal as a principal supplier of energy in the next century, for example, arises directly from such environmental concern. We recognize of course that no new energy source or technology is completely environmentally benign but some can be preferred over others, and environmental impact should be one of the prime considerations in setting priorities.

We realize that Canada does not have the resources to pursue all avenues of alternative energy investigation, and that results can be diluted by attempting too much. But given the uncertainties inherent in any course of action, the Committee wishes to see Canada's energy options kept as broad as possible. Priorities in the alternative energy field will have to be assigned on the best estimates of today, and there are few energy sources and technologies which we would want to see totally ignored in this country.

In reviewing energy prospects, we cannot consider Canada in isolation from developments in other parts of the world. Global population now exceeds four billion and is expected to surpass six billion by the year 2000. It has been observed that anyone with a present life expectancy of 50 years may live to see a world inhabited by 10 billion people. Sustaining those numbers and improving the human condition beyond the abysmal state characterizing substantial regions of the world today will require a much expanded use of energy in developing countries.

Energy conservation (with conservation referring to both frugal and more efficient use) is a fundamentally important strategy which should carry forward far into the future. In fact, the Committee considers that restraining growth in energy demand will offer the best return in managing Canada's energy affairs throughout the remainder of this century at least. Many of the new technologies which we consider in this Report promise significant energy-conserving benefits. In the longer run, conservation becomes built in to our system and increasing efficiencies in energy use become more difficult and costly to achieve. At some point energy supply reasserts itself as the foremost concern in an expanding system.

Turning to other energy options, Canada should exploit biomass (carbon-containing material of plant and animal origin not including fossil fuels) as rapidly as is feasible, subject to certain reservations. Forest or cellulosic biomass will assume an important position in Canada's changing energy system, especially in the provision of transportation fuels. Thereafter, although biomass will continue to be a substantial provider of energy, we foresee its *relative* importance declining for environmental reasons and because of increasing pressure on the Earth's land base to feed the world's burgeoning population. Thus the Committee views biomass energy as playing its most significant role over the next few decades

Geothermal energy, the natural heat of the Earth, is a more enigmatic player in the energy game. In this century geothermal energy will have little impact on Canada's energy affairs. In the next century, the potential of this energy form hinges on the success of new approaches to its exploitation, something which is difficult to gauge today. Our conjecture is that geothermal energy will be a substantial contributor to Canada's energy system in the twenty-first century.

Wind energy will be a modest contributor in Canada's future energy mix. In according it this secondary importance domestically, we nonetheless see a substantial opportunity for Canada to develop an exportable wind energy technology. Unless seized upon quickly though, this opportunity will be lost since other nations are developing this technology as well.

Beyond saying that electricity should not be generated through the combustion of fossil fuels, the Committee is not able to state what methods will be used to produce the bulk of Canada's electric power in the next century. Obviously Canada will continue to develop its hydraulic resources but, equally clearly, hydro-electricity can satisfy only a part of future needs. Solar radiation will be exploited for electric power production but we see that use coming in specialized applications or settings. (The principal contribution of solar power will probably be in the supply of low-grade domestic, commercial and industrial heat.) Nuclear power, by means of the fission process or perhaps ultimately through the fusion reaction, is capable of providing electricity on an indefinitely large scale. Exploiting nuclear energy, however, is one of the more contentious political issues of today and whether or not Canada utilizes this source in a major way in the twenty-first century is a question which goes well beyond that of the adequacy of supply.

Recent discussions on energy matters in the industrialized nations have frequently been concerned with the relative merits of two policy paths. The *hard energy path* is described as a high-energy, nuclear, centralized and electricity-dependent route; the *soft energy path* is presented as a lower-energy, nuclear-free, decentralized and less electrified route. The Committee regrets this structuring of the debate into one characterized by only two choices — a "soft" or a "hard" energy alternative. It is misleading to the public to suggest that there is only one obviously correct path for Canada's complex energy system to follow, or to suggest that our energy future must be selected on an either/or basis. We do not debate the fact that the world's energy requirements must ultimately be met from sustainable sources. What is debatable are which sources will be exploited and to what extent, the length of time the restructuring of our energy system will require, and the route by which that restructuring will be achieved. These are highly complicated matters and their resolution will only be made more difficult by pursuing the debate in simplistic terms. Canada's energy choices will in part be governed by opportunity and in some cases by necessity. We must keep in mind too that Canada has a huge investment in its existing energy system, an investment from which the country will have to obtain as much return as possible. It is therefore our conclusion that Canada's energy system will be a mix of hard and soft technologies combined with a blend of centralized and decentralized sources as far as we can see into the future.

There will nevertheless be a fundamental recasting of our national energy system, the foundation for which will be laid over the next two or three decades. During this transitional phase, natural gas, coal, hydro-electricity and nuclear-electricity will be exploited on a larger scale than today, both because of projects presently under construction and because Canada must emphasize some of these sources in progressively reducing its dependence upon petroleum. The increased importance of natural gas and coal will be transient, however, and the significance of these commodities will in turn diminish in the next century as alternative forms of energy are brought into wider use.

Society can tolerate the increased use of some energy commodities over a limited period of time even if it is not prepared to exploit certain energy forms indefinitely. Canada can, for example, promote a technology such as fluidized bed combustion to reduce the environmental repercussions of burning coal. But the Committee is not prepared to recommend that coal be the central element of a Canadian energy system fifty years from now. As already indicated, we believe that the environmental price would become larger than society should be asked to pay. For parallel reasons we do not recommend the completely unrestricted use of biomass as a source of energy in the future. We have concluded that the environmental implications of such exploitation are not adequately understood.

It is one thing to say that Canada has a broad range of energy opportunities and that we should get on with the job of pursuing them. It is quite another matter to ascertain whether or not this country actually has the means and the will to capitalize upon these opportunities. Canada has not demonstrated that it possesses the research and development capability to accomplish a basic restructuring of its energy system. Canadians have not yet indicated that they are willing to pay the cost of pursuing new energy options to commercialization, and Canada's resources of professional and skilled manpower are not so extensive that one can be complacent about our ability to get the job done. In short, the Committee considers that Canada is not adequately prepared to accomplish what Canadians are now beginning to agree should be done.

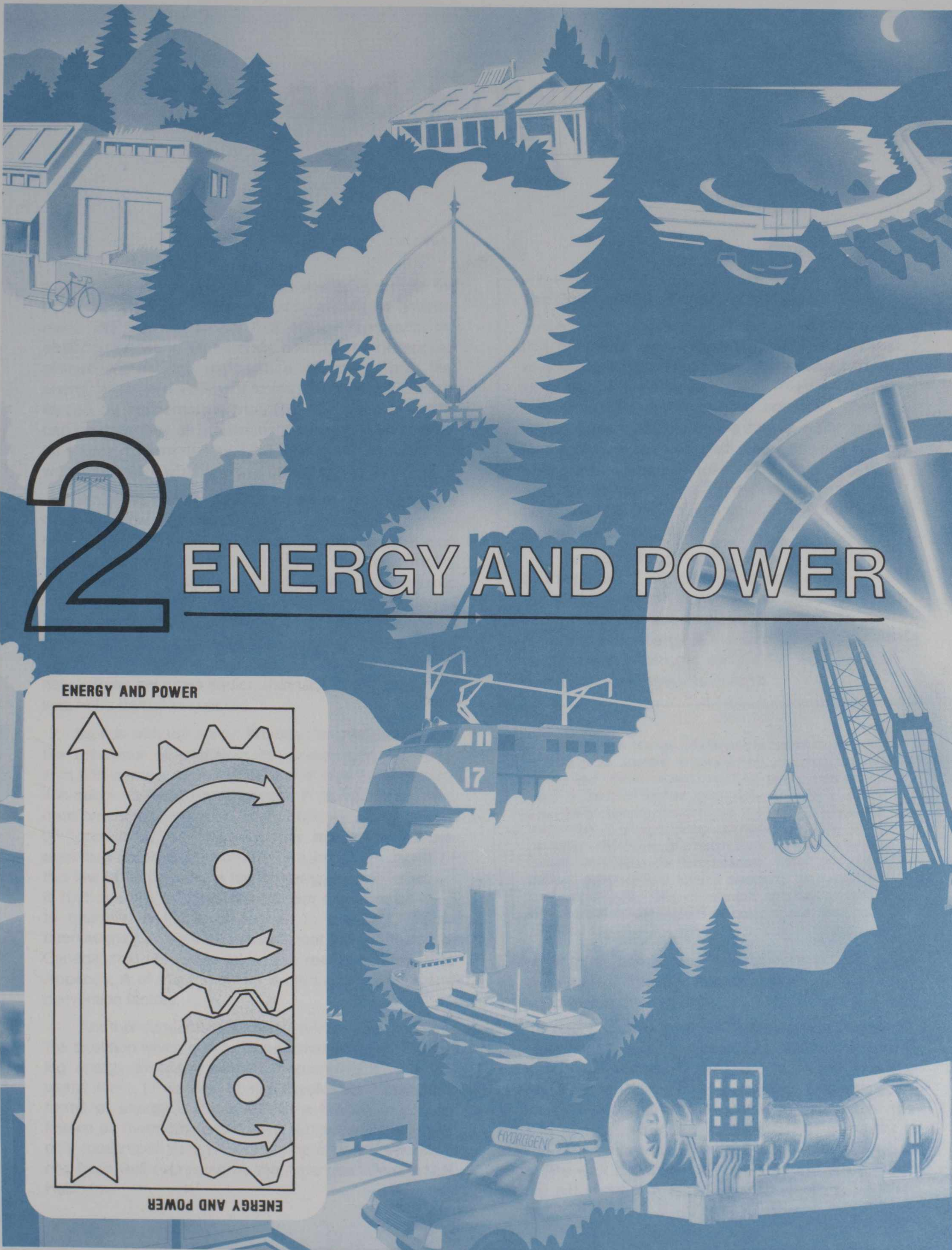
We do not lay the blame for this unreadiness at the feet of Canada's scientists and engineers — indeed, the Committee was frequently impressed with what is being accomplished with meagre resources. We do fault the management and sometimes erratic support of R&D in this country. The energy initiatives put forward in this

Report add up to a major effort in restructuring our national energy system — we do not think it can be accomplished given the way energy R&D is pursued in Canada today. Canada's unimpressive record in commercializing the fruits of research is another cause for concern. Simply calling for more funds for alternative energy development will not be sufficient.

The Committee has therefore concluded that a new approach to managing development in the alternative energy sector is required. We recommend that a Ministry of State for Alternative Energy and Conservation be established under the Ministry of Energy, Mines and Resources. We further recommend that the new alternative energy corporation, Canertech, report to the proposed Minister of State when it becomes an independent Crown corporation. To promote the broad development of hydrogen as an energy currency in Canada, we recommend that a Canadian Hydrogen Commission be established, also reporting to the proposed Minister of State.

Canada is not in an energy crisis. The Committee does, however, feel a strong sense of urgency about changing energy policy for a number of reasons, not the least of which is Canada's vulnerability to external developments in the petroleum sector (a vulnerability which could lead to an "oil crisis"). We further feel a sense of urgency because Canada is being left behind in the alternative energy field even though it has a lot to offer and in some new technologies holds a temporary advantage. Canada must respond to the alternative energy challenge more quickly or be placed in the paradoxical position of having a wealth of energy potential but a shortage of energy options because of a failure to capitalize upon that potential.

2 ENERGY AND POWER



Energy and Power

Man does not understand what energy is despite the fact that it is intrinsic to every part of his environment. We learn in school that energy represents the ability to do work, that literally nothing can be accomplished without the expenditure of energy and that energy exists in a variety of forms which can be characterized by mathematical formulae. We discover that it can be described as gravitational potential energy, elastic energy, radiant energy, heat energy and so forth, but we cannot state what energy actually *is*.

While this state of affairs may seem disconcerting, it does not represent any difficulty in what we are considering here. The United States could not have put a man on the moon if accomplishing that feat had meant understanding the force of gravity. What was required was a mathematical expression describing the action of gravity so that the proper flightpath of the Apollo spacecraft could be computed. Since Isaac Newton had obliged NASA by formulating his law of gravitation nearly three centuries earlier, that lack of understanding was not a barrier to success.

So it is with our study. We need only to understand the behaviour of energy in its various manifestations. Man has learned, for example, that energy is conserved; it is neither created nor destroyed in being transformed from one type to another. Thus, while we speak loosely of "consuming" energy, we really mean that we are *exploiting* it for some purpose. An important result of this law of nature — the law of energy conservation — is that one unit of measurement can therefore be used to quantify all forms of energy. In the SI (Système International) scheme of measurement being adopted in Canada, that unit is the *joule*. The reader is referred to Appendix A of this Report for a discussion of units and conversion factors.

Another fundamental energy relationship concerns the direction which energy transformations take. Exploiting energy invariably results in changing it to a less useful form. (This idea of the "usefulness" of various forms of energy is dealt with in a branch of physics known as thermodynamics — a subject which we need only touch upon here.) Although the concept is subtle, it has been well expressed by the American scientist M.K. Hubbert.

The Equivalence of Energy and Mass

A profound extension to the law of conservation of energy was provided by Albert Einstein who showed theoretically that there is an equivalence between energy and mass. This equivalence was embodied in his famous equation: energy equals mass multiplied by the square of the velocity of light ($E = mc^2$). Einstein's equation is normally applied in circumstances which are far beyond man's everyday range of experience and only becomes relevant, for example, in examining the subject of nuclear energy.

We recognize that life on Earth is sustained by the output of an immense fusion reactor — the sun. Solar radiation dominates all other forms of energy delivered into the Earth's surface environment and that energy is the product of hydrogen nuclei fusing within the sun's core, in a process which converts mass into energy.

> ...not only is energy continuously transformed from one form to another in processes occurring on the earth, but these transformations occur irreversibly from a form of higher availability to one of lower availability. During the process the energy, while not destroyed, is progressively degraded in terms of its potential usefulness, and finally ends up as heat at the lowest environmental temperature. From this state there is nowhere else for the energy to go except by low-temperature, long-wavelength thermal radiation into the still colder regions of outer space. (Hubbert, 1974, p. 8)

Expressing the idea another way, there is no such thing as a perpetual motion machine because there are energy losses in any process.

In many situations we are interested in measuring how fast energy is being or can be delivered, for example at a power station. Power refers to the rate at which energy is being dissipated or converted. Since all types of energy are measurable in joules, it follows that the rates of all types of energy transformations are measurable in a common unit and the SI unit of power is the *watt*. One watt is defined as the delivery of one joule of energy per second. A 500 megawatt electrical generat-

Measuring Energy and Power

In the science of mechanics, energy was originally defined in terms of work, which is the product of a force acting through a distance. In SI notation, the unit of energy is the joule and is defined as a force of 1 newton acting through a distance of 1 metre, or

1 joule = 1 newton-metre.

Other forms of energy such as heat were originally considered to be independent quantities and thus independent units of measurement were defined to quantify them. Now that we know that the various forms of energy are equivalent, however, we can use conversion factors to go from one type of measurement to another. Before the SI scheme was adopted, the energy content of such commodities as crude oil, petroleum products, natural gas and coal was normally expressed in British thermal units (Btu) while quantities of electrical energy were described in kilowatthours (kWh). The appropriate energy conversion factors are

1 Btu = 1,054 joules = 1.054 kilojoules, and

1 kWh = 3,600,000 joules = 3.6 megajoules.

Power is a measure of how fast energy is being or can be delivered. Thus power equals energy divided by time. The SI unit of power is the watt, which is defined as

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}.$$

When work is being done at the rate of 1 joule per second, the power involved is 1 watt. Since all types of energy are measurable in joules, the *rates* of all types of energy transformations are measurable in watts. In the past, power was typically expressed in Btu per hour, watts or horsepower, so we require the power conversions

1 Btu per hour = 0.293 watt, and

1 horsepower = 746 watts.

When power is generated at a constant rate, the amount of energy produced in a given time is

energy = power x time.

In other words, 1 joule = 1 watt-second. To take a familiar example, we pay our electricity bills on the basis of the number of kilowatthours of electrical energy we have used over the billing period. To calculate the energy represented by one kilowatthour, we multiply power by time, or

1 kWh = 1,000 watts x 3,600 seconds (in one hour)

= 3,600,000 watt-seconds

= 3.6 megajoules.

ing station is one which is capable of delivering 500 million watts of electrical power.

Since the joule and the watt are small measures of energy and power, we will be working with multiples of these units. Five prefixes in the SI scheme cover most of the quantities used in this Report, as shown in the following examples.

SI PREFIX	SYMBOL	VALUE	EXAMPLE
kilo	k	10^3 (thousand)	kilovolts (kV)
mega	M	10^6 (million)	megatonnes (Mt)
giga	G	10^9 (billion)	gigawatthours (GWh)
tera	T	10^{12} (trillion)	terawatts (TW)
peta	P	10^{15} (quadrillion)	petajoules (PJ)

If the reader will keep in mind these five multipliers, then he will understand references to an electrical transmission line in kilovolts, to Canada's annual coal production in megatonnes, to Quebec's sale of electrical energy to the United States in gigawatthours, to world electrical generating capacity in terawatts, and to Canadian energy demand in petajoules.

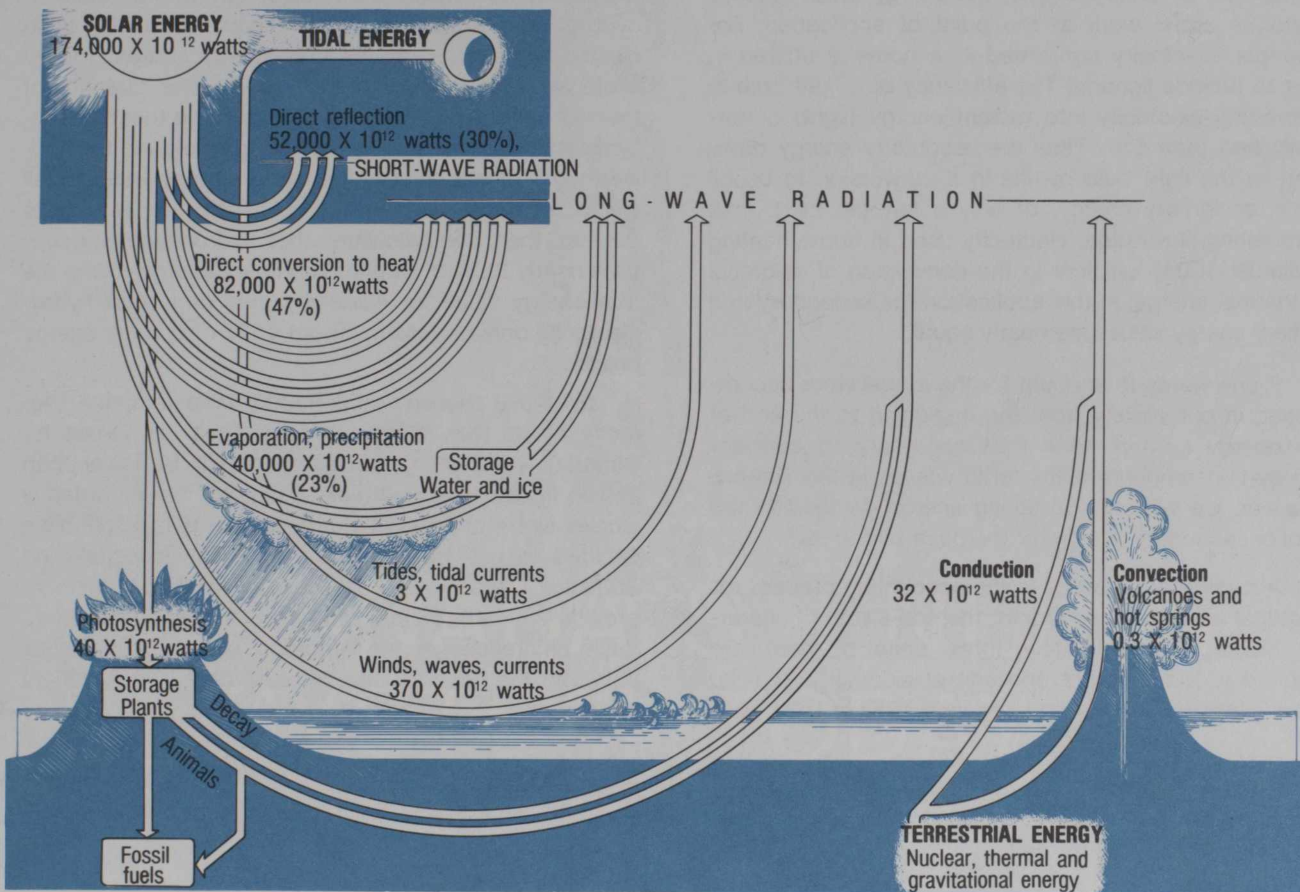
Let us now consider the Earth's natural energy budget or the manner in which energy flows through our planet's surface environment. Since we are looking at rates of energy flow, we are concerned with measuring power. And, because the amounts of power involved are very large, the unit which we will employ is the terawatt (10^{12} watts or trillions of watts).

Energy inputs to our environment come from three sources: (1) solar radiation intercepted by the Earth; (2) tidal energy derived from the combined gravitational fields of the moon and sun; and (3) geothermal (or terrestrial) energy reaching the Earth's surface from its hot interior. Energy losses from the Earth can be considered in one of two categories. First, approximately 30% of the incoming solar radiation is directly reflected by the atmosphere into space as short-wave radiation. Second, the remaining solar energy, together with the geothermal and tidal energy, undergoes a sequence of irreversible degradations in our environment, reaching an end stage as heat at the lowest local temperature. In this state it is radiated from the Earth into space as long-wave thermal radiation.

Figure 2-1 is a generalized representation of the energy flow through the Earth's surface environment. As can be seen from the illustration, solar radiation dominates this flow, being estimated at a power of 174,000 x 10^{12} watts. The terrestrial energy flow is more than three orders of magnitude smaller at an estimated power of 32 x 10^{12} watts. Even smaller is the input of tidal energy at 3 x 10^{12} watts. In other words, the relative power inputs in units of terrawatts are:

solar radiation	174,000
geothermal power	32
tidal power	3

Figure 2-1: THE EARTH'S ENERGY BUDGET



Source: After Hubbert, 1974, p. 11.

By a huge margin, the largest source of energy available to the Earth is sunshine.

The obvious question then is how does this natural flow compare with society's energy needs? Accepting the estimate that the annual global demand for primary energy now exceeds 300 exajoules (300 x 10^{18} joules), we can roughly calculate that man is today converting energy for his own use at an average rate of nearly 10 x 10^{12} watts, or 10 terawatts. Clearly the world is not running out of energy in any absolute sense. *What is in question is the continuing availability of inexpensive, easily accessible energy in forms that society finds environmentally acceptable and convenient to use.*

Man has the following options to derive the energy required to sustain his society. He can intercept the energy continuously and inexhaustibly flowing through his natural environment as outlined in Figure 2-1; he can continue to draw upon the finite amount of energy stored in fossil fuels; or he can convert mass into energy via the processes of nuclear fission and, potentially, nuclear fusion.

Turning from nature to the flow of energy in an industrial society such as Canada's, we find it necessary to consider energy at several stages of use. Energy commodities at the point of production are referred to as *primary energy*. Crude oil, raw natural gas, coal, hydro-electricity and nuclear-electricity are the familiar primary energy commodities in Canada. Hydro-electricity and nuclear-electricity are used directly by consumers, as is most of Canada's natural gas production. Some primary energy is converted into other forms before being consumed. Petroleum products, electricity derived from the combustion of coal, oil or gas, and coke produced from coal are examples of primary energy conversions.

Energy delivered to the point of use is typically referred to as *secondary energy* or *end-use energy*. Since energy is invariably consumed in conversions and transmission or transportation, the secondary energy supply in a region or country is necessarily smaller than the primary energy supply (apart from energy imports, exports and changes in stocks).

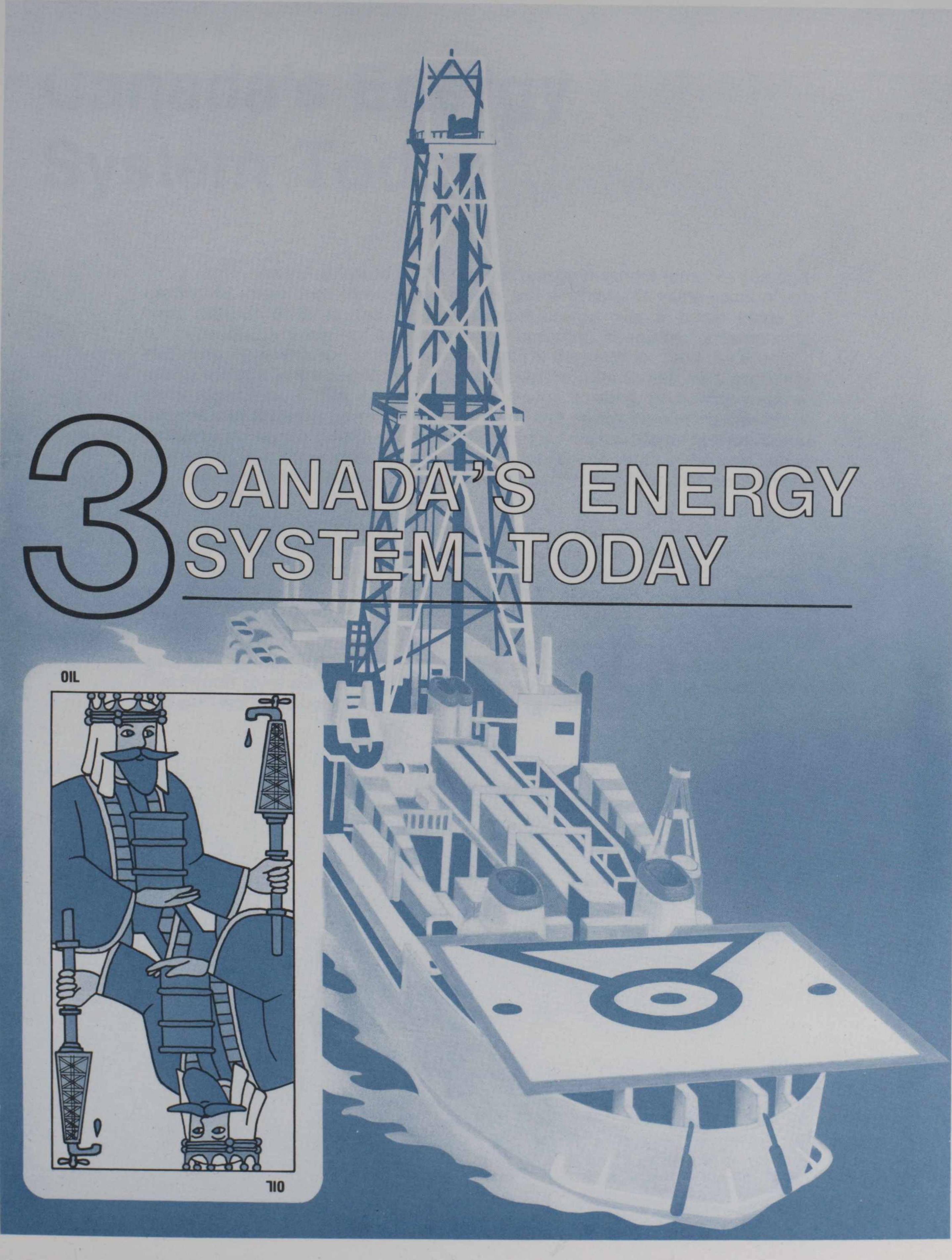
Some workers carry the accounting a step further to the level of *tertiary energy,* the energy which actually performs useful work at the point of application. For example, electricity consumed in a home is utilized in part to provide lighting. The efficiency of a light bulb in converting electricity into radiant energy (light) is normally less than 5%. Thus the secondary energy delivered to the light bulb results in a conversion to useful work, or tertiary energy, of only a few per cent. In a contrasting illustration, electricity used in home heating is almost 100% efficient in the conversion of electrical to thermal energy; in this application the secondary and tertiary energy values are nearly equal.

If one wants to account for the actual work accomplished in our society from the beginning to the end of the energy system, then it is necessary to consider energy consumption at the tertiary level. In this Report, however, we will only be taking energy demand to the level of secondary energy, or the point of end use.

A complication arises in the accounting process for electrical energy. At a modern, thermal-electric generating station, approximately three units of heat are required to manufacture one unit of electricity (that is, the efficiency of energy conversion is 35% or less). At a hydro-electric station, the energy contained in the falling water may be converted into electricity with an efficiency in excess of 90%. How then should a country value electrical energy — by its true energy content (3,600 kilojoules to the kilowatthour), or by the quantity of thermal energy required to generate it at a thermal-electric station (approximately 10,500 kilojoules to the kilowatthour)? If one adopts the higher energy value for all electrical generation including hydro, as is EMR's custom, then one calculates that hydro-electricity supplies nearly 25% of Canada's primary energy. Using the true energy value for electricity, one finds that hydro-electricity only represents about 11% of primary energy production.

We have chosen in this Report to value hydro-electricity by its true energy content. Thus our values for Canada's total energy consumption will be lower than EMR's figures and hydro-electricity will be accorded a smaller share of Canada's primary energy mix. We have decided to use true energy values, based usually on Statistics Canada data, because we consider them to provide a clearer picture of our national energy system. Such differences in the reporting of energy statistics point out the need for care in using data from a variety of sources.

3 CANADA'S ENERGY SYSTEM TODAY



Canada's Energy System Today

An industrialized nation requires energy in various forms — gasoline, heating oil, diesel fuel, pipeline quality gas and electricity to name some of the most obvious ones. It also requires thermal energy over a broad range of temperatures, whether for taking a bath, operating a smelter or generating electricity. Given this spectrum of requirements or demands for "end-use energy", energy systems in the developed world have become quite complicated, especially since World War II. The complex web of energy sources, conversion devices, transmission systems, energy carriers or fuels, and energy-consuming devices or installations may be collectively referred to as the *national energy system.* Canada's energy system reaches into the most remote communities in the land and in the post-war period became such an integral part of our lives that we normally thought little about it.

But the 1970s were not normal times and we have been forced to reassess the manner in which our society uses energy. That reassessment has led to two basic conclusions: the rate of growth in the demand for energy in Canada must be decreased, and our energy system must ultimately be shifted from one dominated by fossil fuels to one which runs on sustainable sources of energy.

While it is easy to state that these changes must take place, it is quite another matter to determine the route by which this will be accomplished. This Report gives our vision of Canada's energy path to the future. To see where that path leads, we begin with where the system stands today.

Canada's Energy Use in a Global Context

Canadians have been called the world's worst energy gluttons. While this is not true in a strict sense, there being several countries which consume energy even more voraciously than we do on a per capita basis, Canada is so close to the top that this distinction is not particularly comforting. Figure 3-1 presents the per capita consumption of commercial energy in selected countries, based upon United Nations data.

If Canada's energy use is measured in terms of energy consumption per dollar of economic output (Gross Domestic Product), as is illustrated in Figure 5-5 in the chapter Energy and the Economy, the international comparison is equally distressing. Most other industrialized nations typically require only 60 to 80% as much energy to generate each dollar of Gross Domestic Product. How did Canada come to be in such an unfavourable position and what are the implications of this situation?

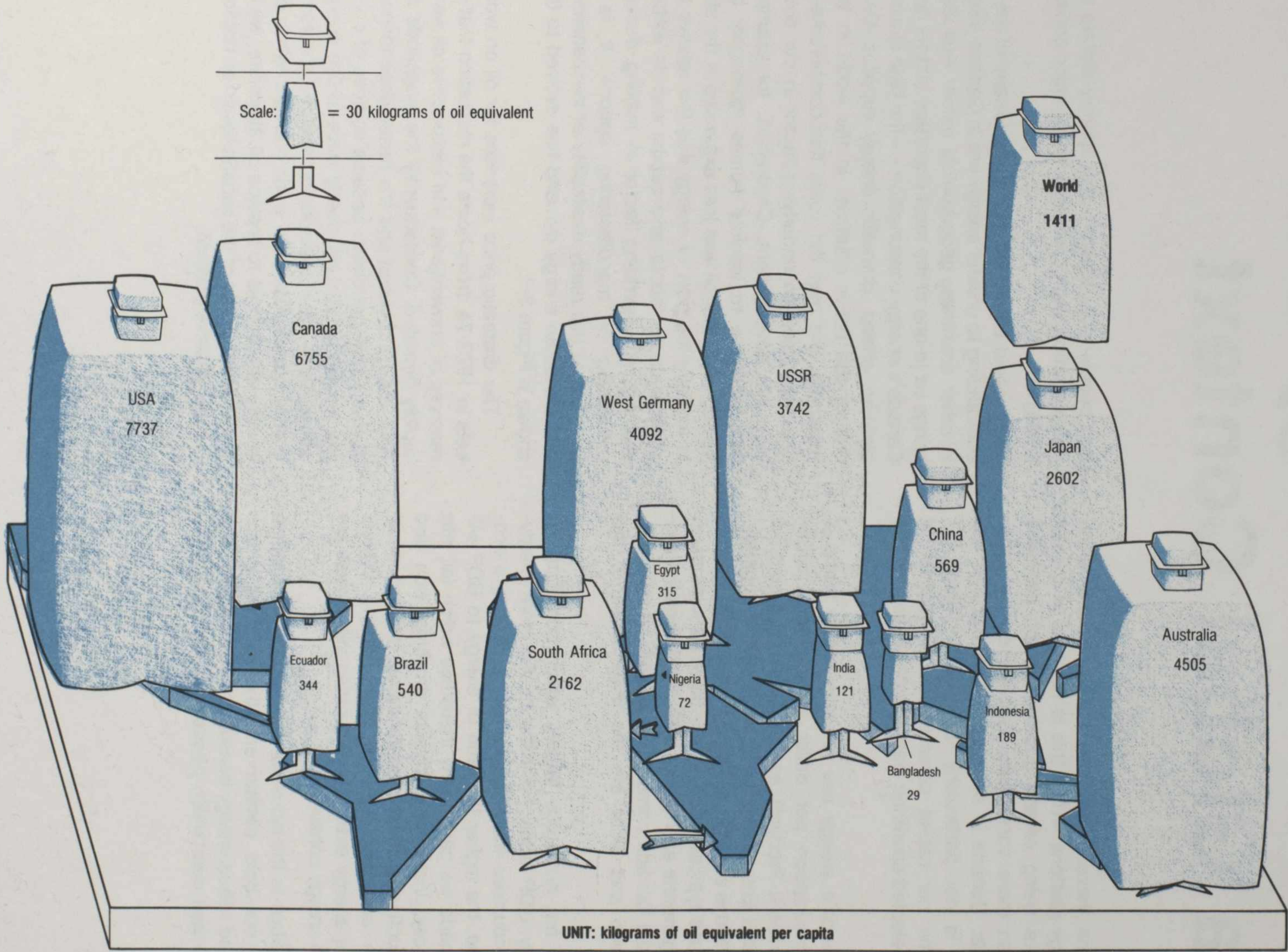
There are numerous factors which contribute to high energy/GDP ratios. For instance, the more energy-intensive industries there are forming a country's economic base, the higher the ratio of energy to GDP will be. In Canada we have many industries which fall into this category, including aluminum smelting, iron and steel production, cement manufacturing, petrochemical production and resource extraction, among others. Indeed, the energy extraction industries themselves are substantial energy consumers.

In addition to the industrial makeup of the Canadian economy, our cold climate and the resultant space heating load raises energy consumption still higher. The large distances over which goods must be transported and people must travel in this country dictate that our transportation sector will also be a major consumer of energy.

It could be argued though that many of the factors contributing to greater energy use in Canada also prevail in other countries, geographical extent excluded. This brings us to one of the most important factors governing Canada's energy consumption — the past availability of plentiful, cheap, domestic energy supplies. Canada is one of the richer countries in the world in terms of resources and over the years this comparative advantage has been an underlying factor in our social and industrial development. Consumers, for example, had little incentive to insulate homes thoroughly because buying more fuel oil was less expensive in the short run. In industry the cost of energy was low relative to other costs such as labour and capital and its efficient use was not an overriding factor in making decisions on processing or manufacturing options. It is largely because of this ready availability of inexpensive energy that Canadian energy demand has evolved to the state shown in Figure 3-1.

The dramatic price increases for oil on world markets in 1973-74 drove home the realization that our own reserves of conventional and inexpensive oil were being rapidly depleted. Consequently the magnitude of Canada's energy demand and the heavy dependence of our system upon petroleum became sources of concern. In the future Canada will clearly have to use energy more efficiently in the manufacturing sector if it is to maintain a competitive position in world markets. When choosing energy alternatives to replace oil, therefore, we must be mindful of the cost of the substitutes so as not to worsen our competitive position.

Figure 3-1: 1978 PER CAPITA CONSUMPTION OF COMMERCIAL [(a)] ENERGY IN 15 SELECTED COUNTRIES



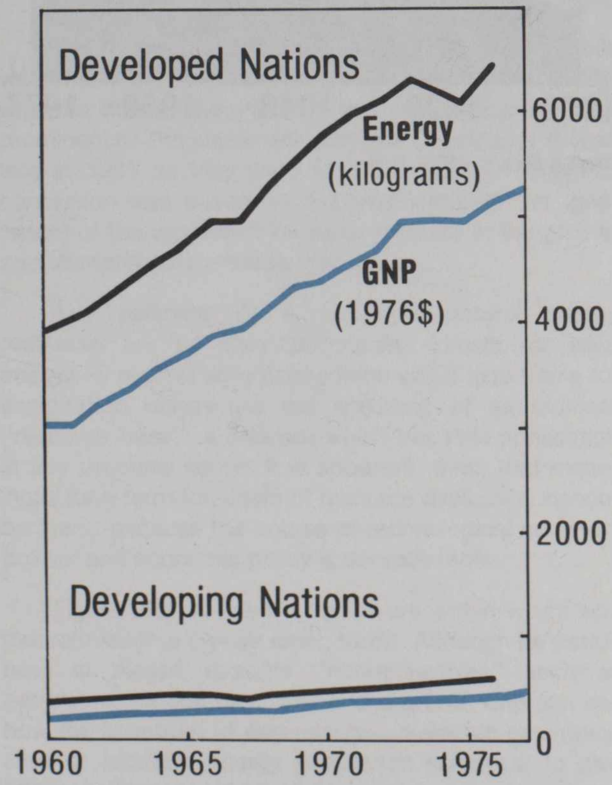
[(a)] Commercial energy refers to energy which enters into trade. Data on non-commercial energy use are scarce and imprecise.

Source: After United Nations, 1980.

In a more general sense, the industrialized world must also be concerned with its need for energy relative to the developing world. Figure 3-2 shows very clearly that the gap in per capita energy demand between these two parts of global society has widened over the last two decades. At the same time, oil has risen to a dominant position in satisfying world requirements for energy (Figure 3-3). Industrialized nations, with their diversified energy systems, have better prospects for oil substitution than do developing countries which, as a group, depend even more heavily upon petroleum. It is apparent from this perspective that a much better balance must be achieved in the global use of energy, both regionally and by energy source.

The degree to which the distribution of energy consumption varies across the world's population is clearly indicated in Figure 3-4. The total demand for primary energy worldwide in 1975 was estimated at 8.2 terawatts, summed over the year (that is, 8.2 TW-years). The *rate* of energy consumption in a world then populated by almost four billion people therefore averaged out

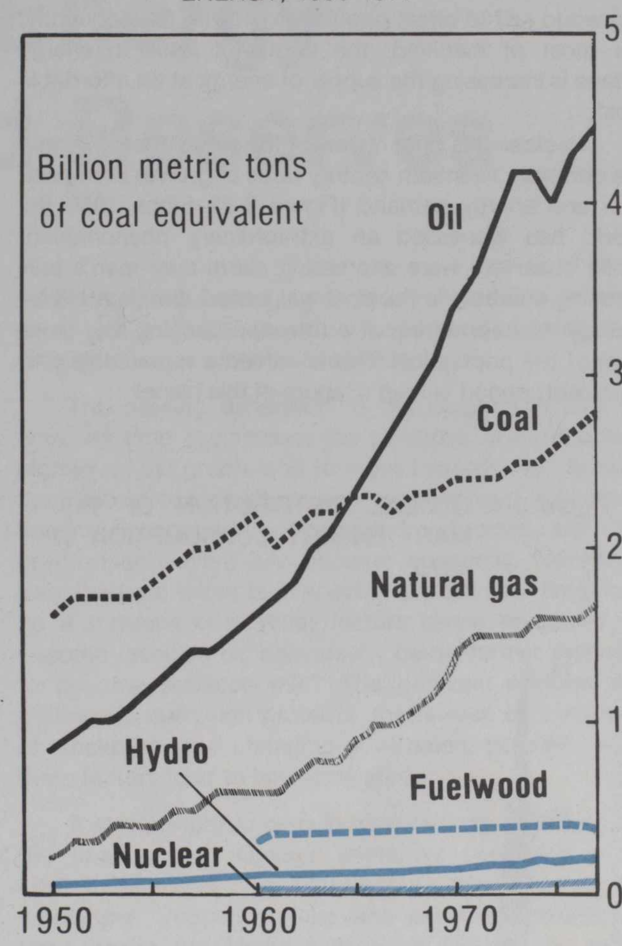
Figure 3-2: PER CAPITA GNP AND DEMAND FOR ENERGY IN THE DEVELOPED AND DEVELOPING NATIONS, 1960-1977



Note: Per capita demand for energy is measured in kilograms of coal equivalent per person.

Source: Sivard, 1979, p. 11.

Figure 3-3: WORLD PRODUCTION OF PRIMARY ENERGY, 1950-1977



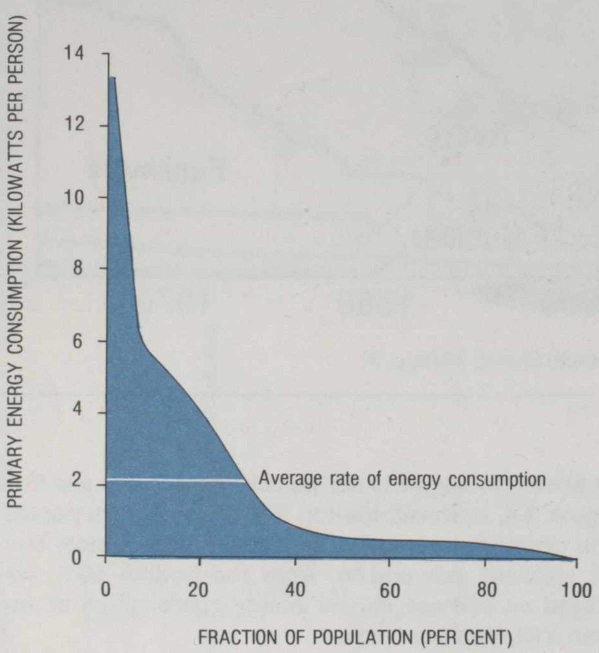
Source: Sivard, 1979, p. 7.

to about 2.1 kilowatts per person. As one can see from Figure 3-4, however, the top 5% of the world's population consumed energy at an average rate of more than 10 kilowatts per person, while the bottom 50% displayed an average rate of energy consumption of less than a kilowatt per capita.

The world's population is presently estimated to be growing at a rate of very nearly 2% per year, sufficient to double it in 35 years. Even allowing for some slackening in the rate of growth, man's numbers appear almost certain to be about 50% larger in the year 2000 than they are today. And most of that expansion will occur in regions amongst the lowest in per capita energy use today. Thus the concern with conserving energy in the developed world is not shared by the majority of the world's people. Just to maintain the present per capita use of energy over the coming 20 years will require increasing the global supply of energy by more than 50%. There is no conceivable way in which the conservation of energy in industrialized society can approach the requirement for new energy supplies in the developing world just to offset population growth. Consequently, for most of mankind, the dominant issue in energy affairs is increasing the supply of energy at an affordable cost.

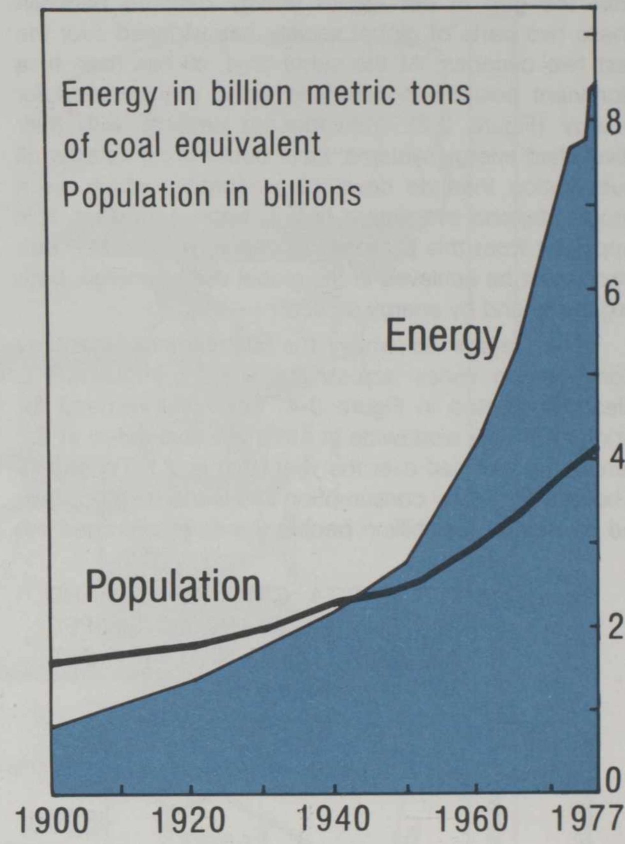
To close this brief review of the world energy scene, we compare twentieth century rates of growth in population and energy demand (Figure 3-5). Since 1950 the world has witnessed an extraordinary phenomenon: while observers were expressing alarm over man's burgeoning numbers in the post-war period, the demand for energy was escalating at a rate approaching *four times* that of the population. This is indeed a remarkable (but transient) period in man's tenure of this planet.

Figure 3-4: GLOBAL DISTRIBUTION OF PRIMARY ENERGY CONSUMPTION IN 1975



Source: Sassin, 1980, p. 120.

Figure 3-5: THE GROWTH IN WORLD POPULATION AND ENERGY DEMAND, 1900-1977



Source: Sivard, 1979, p. 6.

Conventional Energy Resources and Reserves

1. THE RESOURCE/RESERVE SPECTRUM

To understand what is meant by energy availability in Canada requires an appreciation of the terms *reserves* and *resources*. Consider the following quote from the 1926 *Book of Popular Science* which reflected a widely held view of the time:

> ...it is apparent that the supply of petroleum will soon be exhausted, and even now gasoline is becoming expensive. New and advanced methods of production may add to our supply somewhat, but unless new oil fields are discovered, the end of this commodity is not far off. We must look elsewhere for fuel for automobiles. Distillates from vegetable products can be made that will work well in gas engines and the hope of the future appears to lie in this direction. *(The Book of Popular Science,* Grolier, N.Y., 1926, p. 570)

The authors further predicted that the automobile was destined to play a diminishing role in American life, with the horse returning to a well-deserved position of prominence. The statement contains elements of fact as true in 1981 as they were in 1926, but the erroneous conclusion was based on a misinterpretation (or ignorance) of the distinction between reserves in the ground and ultimately recoverable resources.

Any estimate of a country's natural energy resources — be they petroleum, forests, or wind energy — must specify cost criteria and a time frame for exploitation unless we are speaking of an ultimate "resource base", a concept which has little application in any practical sense. It is apparent, then, that meaningful long-term forecasts of resource availability cannot be made because the course of technological advance, politics and economic policy is unpredictable.

Figure 3-6 provides a framework within which any natural resource can be categorized. Although its usefulness is biased towards "nonrenewables" such as petroleum, natural gas, coal and uranium, one can see how the spectrum of potential hydro-electric generation sites or biomass energy production schemes, to give two examples, could be assigned places on an adaptation of the diagram. Looking at natural gas for instance, it is apparent that all such deposits can be assigned to one or another quadrant of the figure, with currently-producing fields belonging to the "reserves" quadrant. Other gas resources are either known and uneconomic, or undiscovered, whether economic or not.

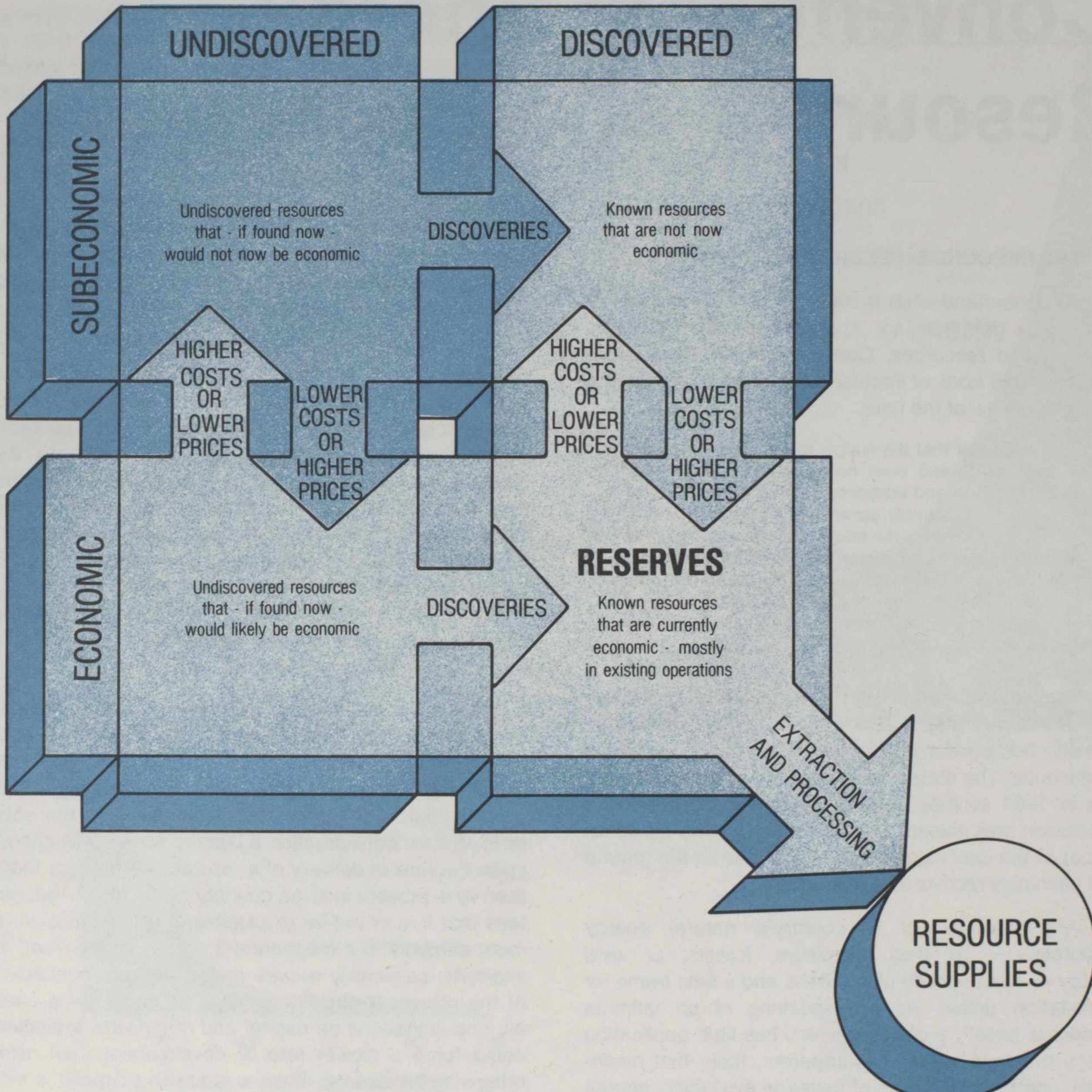
The missing dimension in the diagram is that of time. As time progresses, the positions of all deposits plotted on the graph tend to move towards the "extraction and processing" arrow: subeconomic resources become economic; undiscovered resources are discovered and eventually become economic. Nevertheless, the path taken by a specific deposit over time may be a tortuous one. What factors cause resources to become reserves or, conversely, cause former reserves to become subeconomic? The principal reasons are shifting consumption patterns, the release or formation of stockpiles, and changing government policies — all three factors tend to be interrelated.

It is important to bear in mind two constraints upon the reserve and resource estimates presented here. First, reserve estimates apply only to present economic conditions. Second, supply and demand projections, while useful, are highly speculative beyond the short term. A third consideration relates to physical limitations upon the rate of delivery of a resource — the fact that a reserve is present in large quantity by no means guarantees that it is or will be producible at a rate sufficient to meet demand. The creation of a new oil sands plant, for example, can easily require a decade from conception of the project to the first production of synthetic crude oil, and limitations on capital and manpower availability could force a slower rate of development than might otherwise be desired. Even a producing deposit is subject to rate-related constraints — crude oil is extractable from a reservoir at a rate determined by the viscosity of the oil, the characteristics of the reservoir rocks and well spacing.

2. HYDROCARBON RESOURCES

Hydrocarbons are organic compounds consisting of carbon and hydrogen, and these compounds may exist as gases, liquids or solids. Crude oil, natural gas and coal are essentially mixtures of hydrocarbons of varying degrees of complexity and containing varying amounts of impurities such as sulphur.

Figure 3-6: THE FLOW OF RESOURCES OVER TIME



Source: After Cranstone, McIntosh and Azis, 1978, p. 2.

A. LIQUID HYDROCARBONS

For the purpose of this discussion the term *liquid hydrocarbons* includes conventional crude oil, synthetic crude oil and natural gas liquids. Table 3-1 is a compilation of recent estimates of Canadian reserves and resources of liquid hydrocarbons. Figure 3-7 shows the evolution in Canada's reserves position since 1955 for conventional liquid hydrocarbons (that is, including conventional crude and natural gas liquids). Our reserves of conventional crude peaked in 1969 at 1,665 million cubic metres (about 10.5 billion barrels) and have since been in decline.

Canada's proven reserves of conventional crude oil are strongly concentrated in the Province of Alberta. If these reserves could be produced and delivered to markets at a rate equal to domestic demand, they would be sufficient to meet all of Canada's petroleum needs for about eleven years at the current rate of consumption (about 300,000 cubic metres per day). In fact, this could never actually take place as there are physical limitations which dictate a maximum rate of production and there is no crude oil delivery system in Atlantic Canada. Other conventional oil resources are estimated to be close to four times the level of reserves and are, once again, strongly concentrated in Western and Arctic Canada, notwithstanding recent discoveries on the Grand Banks of Newfoundland.

Table 3-1: CANADIAN LIQUID HYDROCARBON RESERVES AND RESOURCES

	Volume (millions of cubic metres)[a]
Conventional Proved Reserves of Crude Oil and Natural Gas Liquids	
British Columbia	32
Alberta	1,101
Saskatchewan	119
Manitoba	6
Eastern Canada	1
Mainland Territories	29
TOTAL	1,288
Unconventional Recoverable Upgraded Oil Resources[b]	
Lloydminister (heavy oil)	127–365
Cold Lake *in situ* (oil sands)	2,384–4,767
Athabaska Mining (oil sands)	4,291
Athabaska *in situ* (oil sands)	6,356–22,247
TOTAL	13,158–31,670
Conventional Oil Resources[c]	
Western Canada	1,589
Mackenzie-Beaufort	1,096
Eastern Arctic	604
Eastern Canada (including offshore areas)	826
Mainland Territories	79
TOTAL	4,194

(a) 1 cubic metre = 6.29 barrels.
(b) Range in estimates results from uncertainty regarding the recovery factor attainable using *in situ* recovery technology.
(c) Includes remaining reserves, discovered resources and undiscovered potential at the 50% probability level (1976 estimate).

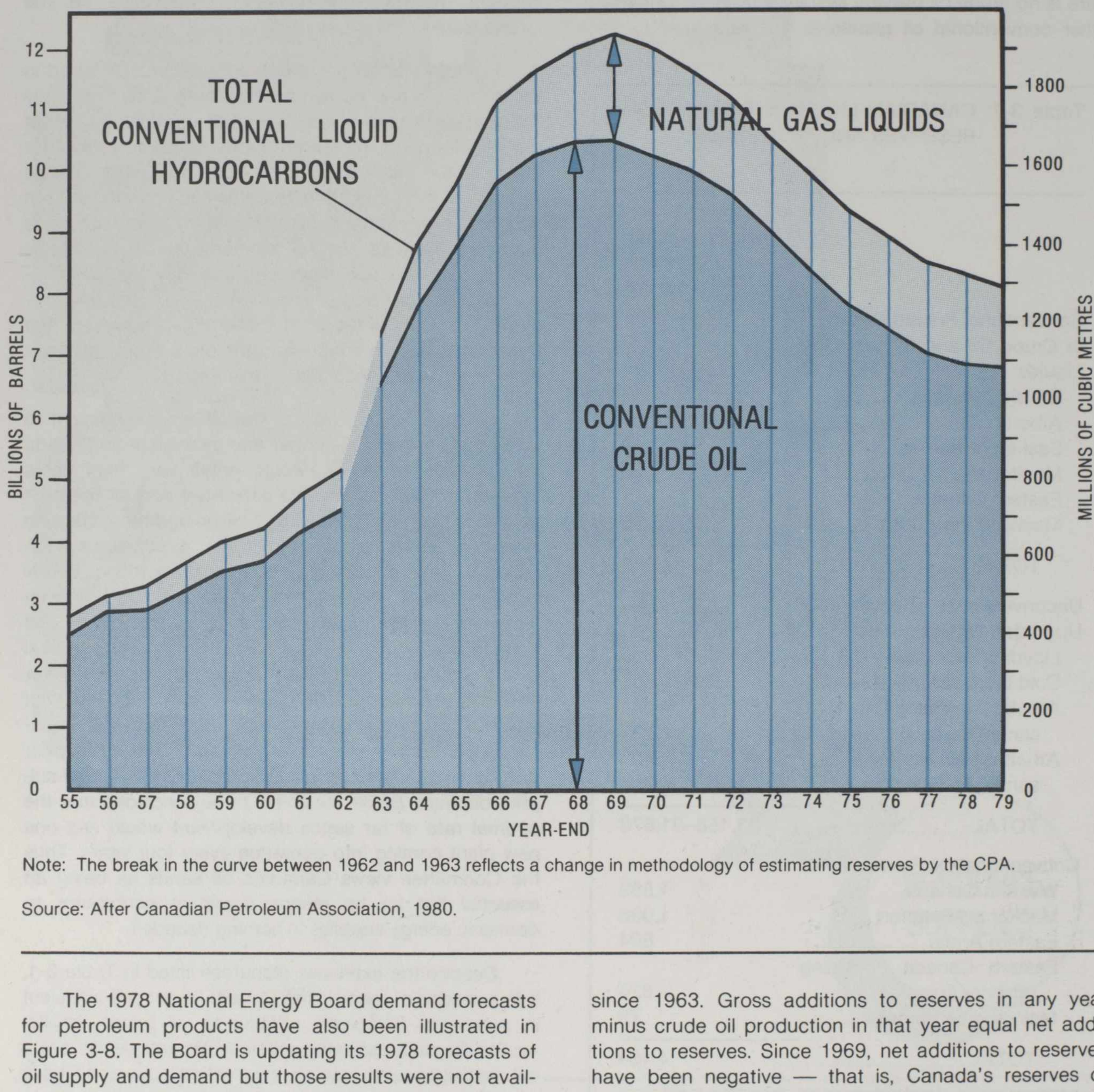
Source: Canada, Department of Energy, Mines and Resources, 1980b; and Canadian Petroleum Association, 1980.

Canada's largest hydrocarbon resource is found in the heavy oils and tar sands of Western Canada (mostly Alberta) — a resource sufficient, theoretically, to meet our requirements at current rates of consumption for close to 400 years, depending upon how much can be recovered. It is plain, then, that this country need not run short of conventional or synthetic oil for a very long time if political barriers can be overcome and if Canada is prepared to develop resources and pay the costs — economic, social and environmental — of that development. The Committee is of the opinion, however, that these costs *are* untenable and therefore proposes alternatives which are described in this Report.

Massive development of the oil sands, sufficient to sustain a petroleum-oriented energy system in Canada for decades to come, would entail very high costs indeed. In 1980 dollars, the estimated cost of the next tar sands plant has passed $10 billion and the impact on Alberta's economy of establishing a series of such plants in rapid succession could be devastating. Shortages in skilled and professional people together with restrictions in the supply of specialized equipment and materials would make it very difficult to construct several plants simultaneously. These facilities also require water in large volumes (which becomes contaminated with bitumen and cannot be returned directly to the Athabasca River), and release significant quantities of sulphur dioxide to the atmosphere in processing the high-sulphur bitumen. Some observers have concluded that the optimal rate of tar sands development would see one new plant coming into operation every four years. Thus the Committee views Canada's oil sands as being an essential but by no means dominant contributor to domestic energy supplies in coming decades.

Despite the extensive resources listed in Table 3-1, it is a matter of record that Canada is not self-sufficient in petroleum. Problems relating to oil prices, capital availability and technological innovation as well as political decisions and lagging exploration successes have contributed to a decline in production in recent years and, as indicated in Figure 3-8, this trend is likely to continue for some time to come. The lower, shaded area in the illustration indicates future crude oil producibility from known reserves (in 1978) of conventional oil and of synthetic oil from the two operating tar sands plants. Actual production is not likely to drop into this region because these reserves are sure to be augmented and because present conditions suggest that we will continue to extract crude oil at a rate near Canada's maximum productive capacity.

Figure 3-7: CANADA'S RESERVES OF CONVENTIONAL LIQUID HYDROCARBONS, 1955-1979



Note: The break in the curve between 1962 and 1963 reflects a change in methodology of estimating reserves by the CPA.

Source: After Canadian Petroleum Association, 1980.

The 1978 National Energy Board demand forecasts for petroleum products have also been illustrated in Figure 3-8. The Board is updating its 1978 forecasts of oil supply and demand but those results were not available at the time of preparation of this Report. Forecasts prepared since 1978 by EMR suggest that future Canadian demand will fall below the 1978 NEB base case, and that domestic supply will actually lie between the NEB base and high forecasts. If the EMR projections prove nearer the mark, then Canada's petroleum shortfall over the 1980s will be less than that suggested in the 1978 NEB report.

The role that price plays in influencing reserves is reflected in Figure 3-9, which illustrates Canada's success in adding to its reserves of conventional crude oil since 1963. Gross additions to reserves in any year minus crude oil production in that year equal net additions to reserves. Since 1969, net additions to reserves have been negative — that is, Canada's reserves of conventional crude oil have fallen throughout the period. This decline was sharpest in 1973-1974 when reserves fell at the rate of about 0.5 billion barrels per year. With rising oil prices, however, drilling was encouraged and more producing wells were brought in. Drilling activity reached its highest level ever in Canada in 1980 and gross reserve additions very nearly offset domestic production. Nonetheless, the Western Canada Sedimentary Basin is a mature oil-producing region and Canada must look to its frontier regions or to the oil sands for major production increases in the future.

Frequently Used Terms in the Petroleum Industry

The petroleum industry uses a specialized vocabulary and we have drawn together here some of the more commonly used terms. These definitions are not always consistent from source to source and in some instances have changed with time.

FOSSIL FUEL—Combustible geologic deposits of carbon in organic form and of biological origin. These deposits include crude oil, natural gas, oil shales, oil sands and coal.

PETROLEUM—Often defined as naturally-occurring liquid hydrocarbons. Sometimes the definition is extended to include refined products in the liquid state; occasionally it is used to further encompass natural gas, bitumen and kerogen (a solid hydrocarbon found in oil shale).

(CONVENTIONAL) CRUDE OIL—A mixture mainly of pentanes and heavier hydrocarbons recoverable at a well from an underground reservoir, and which is liquid at the conditions under which its volume is measured or estimated.

SYNTHETIC CRUDE OIL—A mixture mainly of pentanes and heavier hydrocarbons that is derived from crude bitumen and which is liquid at the conditions under which its volume is measured or estimated. The output from the Athabasca oil sands comprises synthetic crude oil production in Canada today.

CONDENSATE—A mixture mainly of pentanes and heavier hydrocarbons recoverable at a well from an underground reservoir, and which is gaseous in its virgin reservoir state but is liquid at the conditions under which its volume is measured or estimated. Condensate is often understood to be included in "crude oil" and we follow that usage in this Report.

PENTANES PLUS—A mixture mainly of pentanes and heavier hydrocarbons which is obtained from the processing of raw gas, condensate or crude oil.

As used in this Report, the term *OIL* includes conventional and synthetic crude, condensate and pentanes plus. If we wish to exclude synthetic crude from this grouping, we denote the remaining three as *CONVENTIONAL OIL.*

CRUDE BITUMEN—A naturally-occurring mixture, mainly of hydrocarbons heavier than pentane, that in its natural highly-viscous state is not recoverable at a commercial rate through a well.

TAR SANDS—Sands impregnated with a heavy crude oil, tar-like in consistency, that is too viscous to permit recovery by natural flowage into wells.

HEAVY OIL DEPOSITS—Oil deposits transitional in character between the heavier tar sand type of bitumen deposit and conventional crude oil. The crude is highly viscous and either does not flow or flows at very low rates under normal conditions.

Tar sands and heavy oil deposits are usually jointly referred to as *OIL SANDS,* a terminology which we follow.

NATURAL GAS LIQUIDS (NGL)—A product intermediate between natural gas and crude oil, and which constitutes a family of hydrocarbons extracted as liquids during the production of natural gas. NGL includes ethane, propane, butanes or pentanes plus, or a combination thereof.

LIQUEFIED PETROLEUM GASES (LPG)—A subgroup of the natural gas liquids, consisting principally of a mixture of propane and butanes, which are gaseous at atmospheric pressure but liquid at slightly higher pressures. These are familiar as "bottled gas".

The commodities mentioned thus far — crude oil, synthetic crude oil, condensate, pentanes plus, propane, butanes and ethane — comprise the *LIQUID HYDROCARBONS.*

ASSOCIATED GAS—Gas in a free state in a reservoir and found in association with crude oil, under initial reservoir conditions.

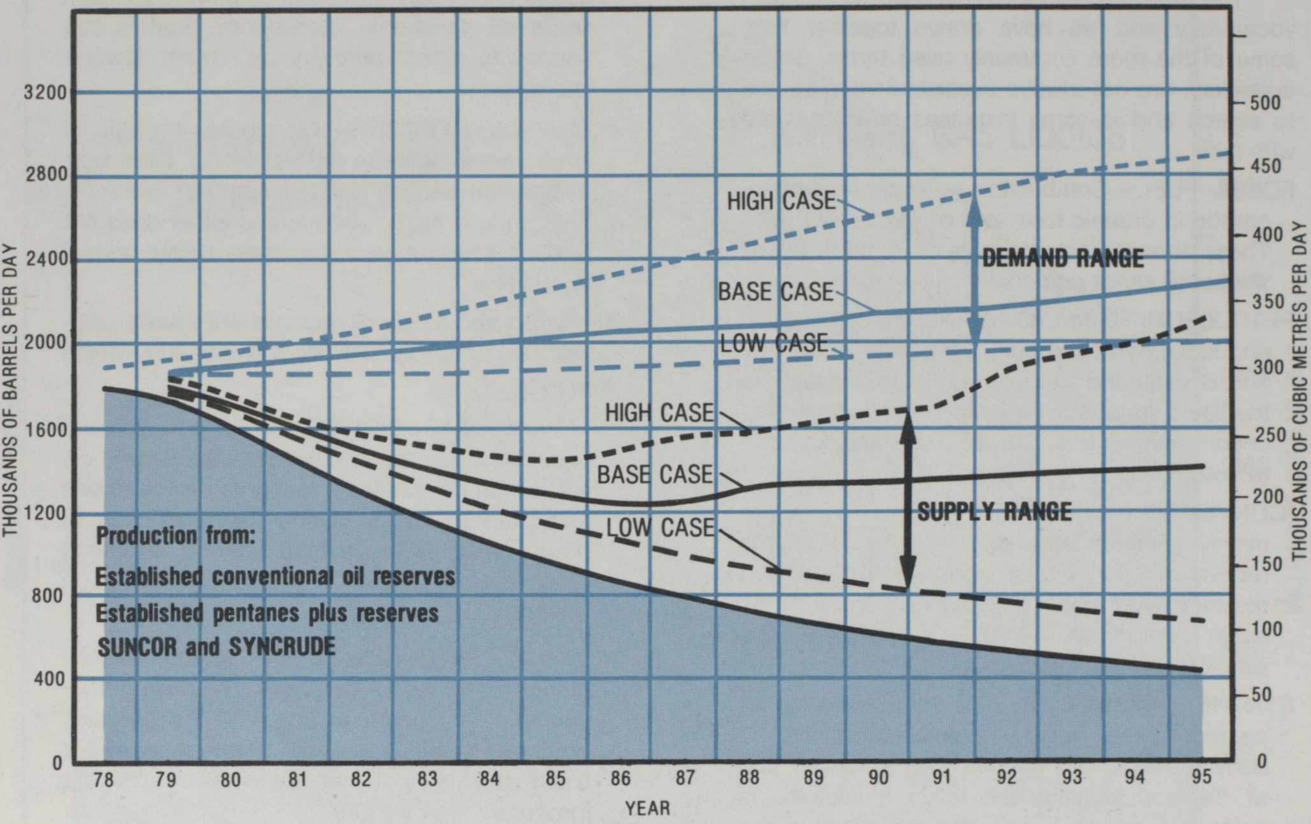
NON-ASSOCIATED GAS—Gas in a free state in a reservoir but not found in association with crude oil, under initial reservoir conditions.

SOLUTION GAS—Gas that is dissolved in crude oil under reservoir conditions and which evolves as a result of pressure and temperature changes.

RAW GAS—Natural gas in its natural state, existing in a field or as produced from a field and prior to processing.

MARKETABLE NATURAL GAS—Raw gas from which certain compounds have been removed or partially removed by processing. Marketable gas is often referred to as "pipeline gas" or "sales gas", and is primarily composed of methane.

Figure 3-8: RANGE OF OIL PRODUCIBILITY AND DEMAND FORECASTS, 1978 NATIONAL ENERGY BOARD REPORT



The lower, shaded area of the graph represents reasonably assured future production from known conventional reserves and from the two operating plants in the tar sands. The upper supply curves are producibility forecasts based on optimistic, base case and pessimistic assumptions for future additions to conventional reserves and to nonconventional production capacity. Similarly, the demand curves represent high, low and base case projections.

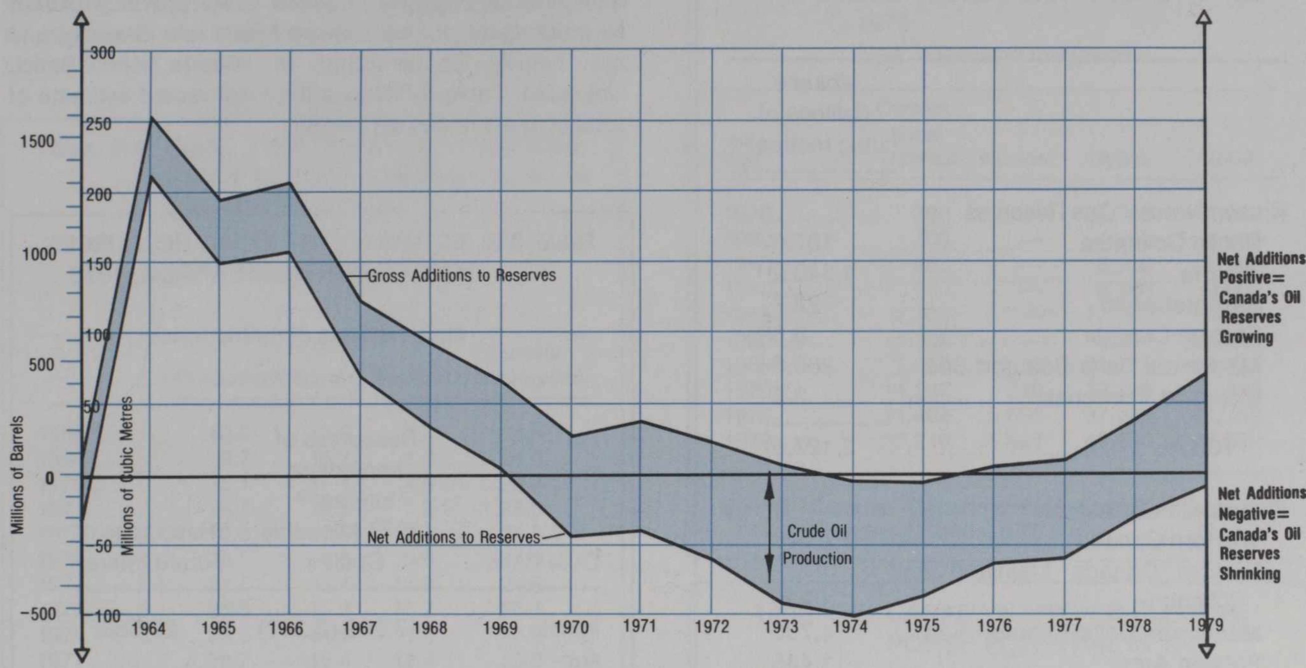
Source: After Canada, National Energy Board, 1978.

B. NATURAL GAS

As shown in Table 3-2, Canada's natural gas reserves and resources are extensive. Figure 3-10, which displays Canada's reserves of marketable natural gas since 1955, indicates an almost continual expansion in our reserves position. As is the case with crude oil, the resource is strongly concentrated in Western Canada, particularly in the Province of Alberta. If all known natural gas reserves in Canada could be produced and delivered to the Canadian market at a rate sufficient to meet domestic requirements, the supply would last for some fifty years at current rates of consumption (about 45 billion cubic metres per year), and additional resources could add about 180 years to this total. Of course, such numbers must be used cautiously, bearing in mind that Canada will continue to export gas; that new domestic markets will be established in Quebec and the Maritime Provinces; and that new reserves will be discovered. Nevertheless, it is apparent that in the context of Canadian energy demand, the national resource base for natural gas is substantial indeed.

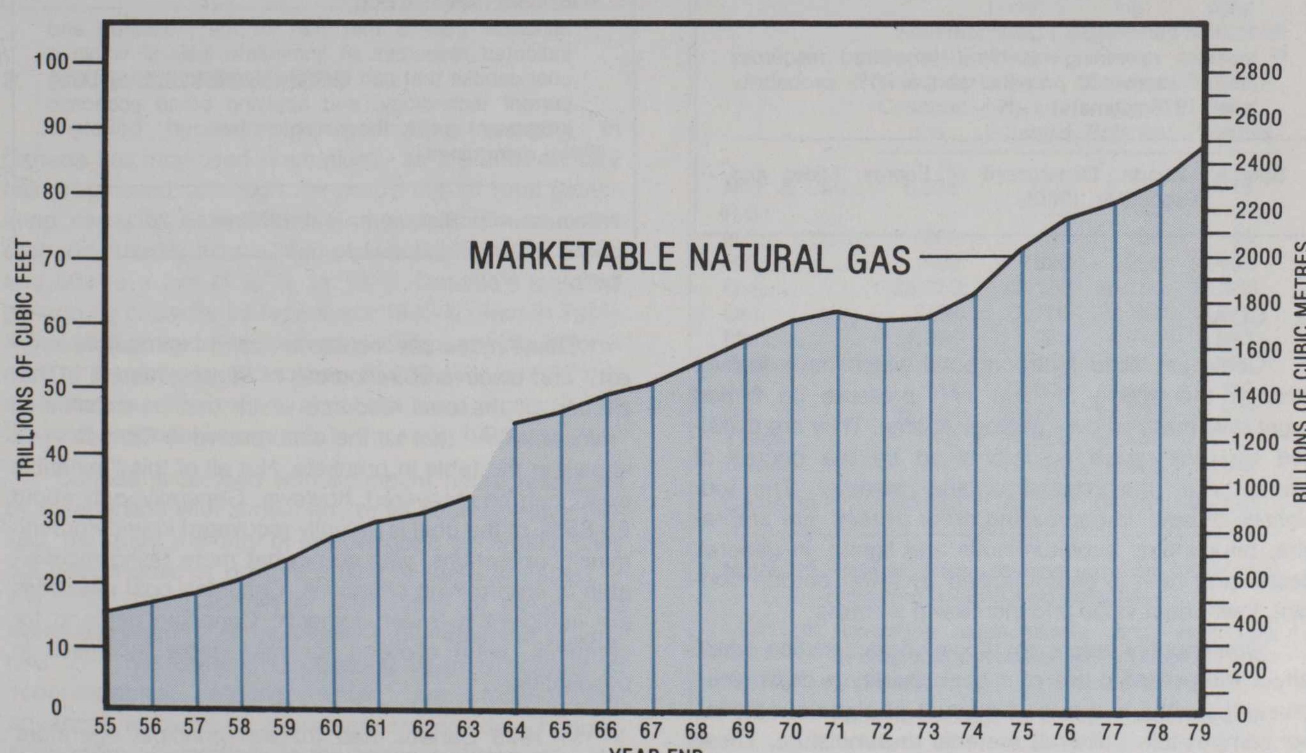
Canada is in a position to make a major substitution of natural gas for crude oil in meeting its domestic energy requirements and in backing imported crude out of the Eastern Canadian market. Extending the distribution system for natural gas into Eastern Quebec and the Maritimes in Eastern Canada and onto Vancouver Island in Western Canada are matters of high priority. Only after sufficient reserves have been set aside to supply a truly national distribution system should gas be allocated to the export market.

Figure 3-9: GROSS AND NET ADDITIONS TO CANADA'S CONVENTIONAL CRUDE OIL RESERVES, 1963-1979



Source: After Canadian Petroleum Association, 1980.

Figure 3-10: CANADA'S RESERVES OF MARKETABLE NATURAL GAS, 1955-1979



Note: The break in the curve between 1963 and 1964 reflects a change in methodology of estimating reserves by the CPA.

Source: After Canadian Petroleum Association, 1980.

Table 3-2: CANADIAN NATURAL GAS RESERVES AND RESOURCES

	Volume (billions of cubic metres)[a]
Known Natural Gas Reserves	
British Columbia	187.0
Alberta	1,640.2
Saskatchewan	22.7
Eastern Canada	8.5
Mackenzie Delta-Beaufort Sea	260.6
Mainland Territories	8.5
TOTAL	2,127.5
Natural Gas Resources[b]	
Western Canada	2,748
Eastern Canada Mainland and Offshore	1,235
Mackenzie Delta-Beaufort Sea	1,700
Eastern Arctic	1,445
Mainland Territories	275
TOTAL	7,403

[a] 1 cubic metre = 35.3 cubic feet.
[b] Includes remaining reserves, discovered resources and undiscovered potential at the 50% probability level (1976 estimate).

Source: Canada, Department of Energy, Mines and Resources, 1980b.

C. COAL

Coals are solid hydrocarbons which have formed through the action of heat and pressure on buried vegetative material over geological time. They are classified by *rank* which is determined by the degree of alteration of the original organic material. The four classes of coal, in decreasing order of rank, are anthracite, bituminous, subbituminous and lignite. In general, decreasing rank is characterized by lower carbon content, lower heat value and increasing softness.

Coal quality refers to those characteristics which affect the potential use of a coal. Quality is determined primarily by the nature and amount of organic material, noncombustible (mineral) material and moisture. These characteristics govern the use to which the coal can be put, whether for power generation, metallurgical coke or chemical feedstock.

Canada is fortunate to possess abundant coal resources of all ranks except for anthracite. Economically significant deposits occur in every province except Newfoundland, Prince Edward Island and Quebec, and are heavily concentrated in Alberta and British Columbia. Table 3-3 shows the most recent estimate of total coal resources in Canada.

Table 3-3: ESTIMATES OF COAL RESOURCES AND RESERVES IN CANADA, 1978

Unit: Millions of metric tons.

Coal Rank	Resources of Immediate Interest[a] (1977 Mineable Coal)[b]	Resources of Future Interest
lignitic	17,209 (3,207)	27,586
sub-bituminous	132,000 (7,328)	l98,000
bituminous	98,787 (5,556)	[c]

[a] Includes mineable coal.
[b] Mineable coal is that part of the measured and indicated resources of immediate interest within a coal deposit that can be considered for mining using current technology, and applying broad economic judgement only to the mining method.
[c] Not determined.

Source: After Bielenstein *et al*, 1979, p. 15, 23.

These resources include those of "immediate interest" and discovered resources of "future interest". That portion of the coal resource which can be considered "mineable" — that is, the coal reserve in Canada — is shown in the table in brackets. Not all of this "mineable coal" can be recovered, however. Generally, only about 65-85% of the coal is actually recovered in underground mining operations, with somewhat more being recoverable in strip-mining situations. Canadian coal resources are sufficient to meet domestic Canadian demand for centuries, even allowing for reasonable increases in production.

In 1979 Canada had thirteen principal operators producing coal from 21 coal mines. Between them they produced an estimated 33.2 million tonnes of coal, mostly bituminous grades. Table 3-4 shows that coal production in Canada has more than doubled since 1970, with the level of coal exports increasing to roughly match imports (thermal and metallurgical coal has traditionally been imported into Ontario from the Eastern United States).

Table 3-4: COAL PRODUCTION, IMPORTS, EXPORTS AND CONSUMPTION IN CANADA, 1968-1978

Unit: Millions of metric tons.

	Production	Imports	Exports	Domestic Consumption
1968	10.0	15.5	1.3	24.8
1969	9.7	15.7	1.2	24.0
1970	15.1	17.1	4.0	26.8
1971	16.7	16.5	7.0	25.6
1972	18.8	17.5	7.7	25.8
1973	20.5	14.8	10.9	24.9
1974	21.3	12.4	10.8	24.8
1975	25.3	15.3	11.7	26.1
1976	25.5	14.6	11.8	28.2
1977	28.7	15.4	12.4	30.9
1978	30.5	14.1	14.0	31.7

Source: After Aylesworth and Weyland, 1980, p. 2.

3. HYDRAULIC RESOURCES

Installed hydro-electric generating capacity in Canada has increased dramatically as the 20th century has progressed, although the proportion of total generating capacity represented by hydraulic sources has dropped steadily from a high of over 90% in the 1940s and 50s to a low of 57% in 1979. Canada's installed generating capacity by type since 1920 is given in Table 3-5. Although hydro-electric generating capacity is forecast to increase by more than 15,000 MW by 1991, it nevertheless will remain at about the same proportion of the total electrical energy mix in the early 1990s.

Canada is blessed with abundant hydro resources by comparison with almost any other country. Nevertheless, the great majority of undeveloped generating sites are uneconomic at present; many of these are small or low-head. The question of how many of these sites eventually become economically exploitable and at what rate they are developed depends upon a number of imponderables, among which are technological advances in hydraulic power generation, the changing economics of electricity in the national energy mix, and technical and political changes relating to nuclear fission. A further constraint lies in the environmental impact of extensive hydro development. The impact of

Table 3-5: INSTALLED ELECTRICAL GENERATING CAPACITY IN CANADA, 1920-1979

Unit: Electrical megawatts.

Year	Conventional Thermal	Nuclear	Hydro	Total
1920	300	—	1,700	2,000
1930	400	—	4,300	4,700
1940	500	—	6,200	6,700
1950	900	—	8,900	9,800
1955	2,100	—	12,600	14,700
1960	4,392	—	18,657	23,049
1965	7,557	20	21,771	29,348
1970	14,287	240	28,298	42,825
1975	21,404	2,666	37,282	61,352
1979	27,216	5,866	43,990	77,072

Source: Canada, Department of Energy, Mines and Resources, 1980a, p.70.

Table 3-6: CANADA'S HYDRO-ELECTRIC POWER POTENTIAL IN 1980

Unit: Electrical megawatts.

		Undeveloped Power Potential		
	Actual Operation and under Construction	Remaining Theoretical Hydro Potential	Remaining Technically Developable Potential	Economically & Technically Developable Potential
Nfld. & Lab.	6,535	7,000	6,272	4,776
P.E.I.	—	—	—	—
N.S.	360	160	100	50
N.B.	900	620	556	460
Que.	25,750	42,160	30,750	18,838
Ont.	7,138	7,770	6,152	2,072
Man.	4,796	7,023	4,945	4,945
Sask.	567	2,395	1,711	1,161
Alta.	718	18,800	11,440	4,357
B.C.	12,134	29,400	25,827	17,575
Yukon	68	11,000	10,440	5,043
N.W.T.	47	14,900	6,000	4,163
CANADA	59,013	141,228	104,193	63,440

Notes: [a] Projects in the planning stage are included in remaining undeveloped potential.

[b] Remaining economically and technically developable potentials are installable capacity in megawatts.

[c] Pumped storage and tidal power are not included.

Source: Canada, Department of Energy, Mines and Resources, 1980c.

the construction of many new hydro schemes upon inland fisheries, recreational and other land use and local climate will require careful study in the years to come.

Current estimates suggest that a further 104,000 megawatts of hydraulic power is technically feasible to develop, more than double the capacity exploited today. Of this amount, perhaps 63,000 megawatts is economically developable. The present distribution of existing and potential hydro-electric power development in Canada is summarized in Table 3-6. It is apparent that the ultimate potential of this energy source is quite limited by comparison to many other energy forms, and that Canada's hydraulic resources will have been largely exploited by the middle of the 21st century.

4. URANIUM RESOURCES

Canada has extensive uranium resources. Uranium mining is underway in Ontario and Saskatchewan, and significant additional deposits are known in these Provinces and in Newfoundland, New Brunswick, Quebec, British Columbia and the Northwest and Yukon Territories. Table 3-7 gives the most recent published estimate of Canada's mineable uranium resources. Discoveries since 1979 have added significantly to these totals and rising prices will result in the conversion of more uranium resources to reserves. Figure 3-11 shows that Canada's uranium production capability far exceeds forecast domestic requirements, explaining our major export position in this energy commodity.

Table 3-7: CANADA'S MINEABLE URANIUM RESOURCES IN 1979

Unit: Thousands of metric tons of elemental uranium.

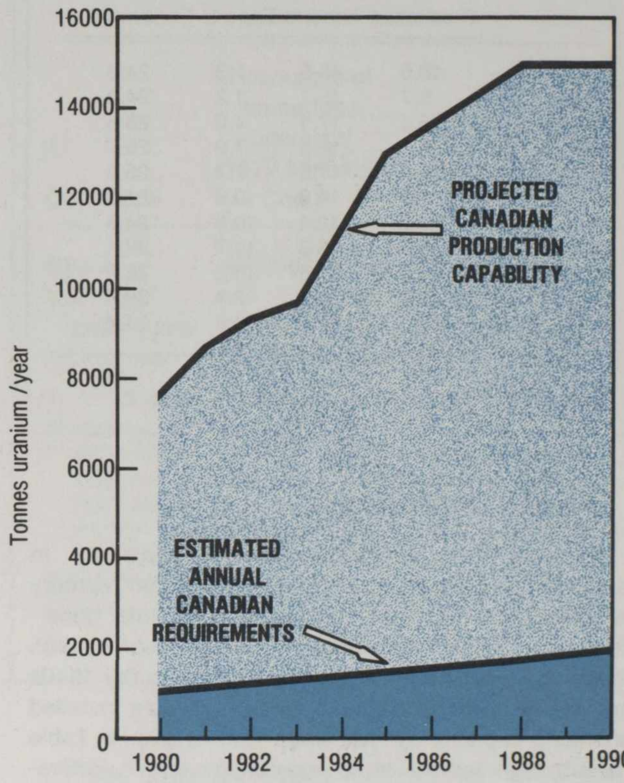
Mineable at Uranium Prices of	Uranium Contained in Mineable Ore[a] Measured	Indicated	Inferred
Up to \$130/kg of Uranium[b]	73	157	238
\$130 to \$200/kg of Uranium[b]	4	25	90
TOTAL	77	182	328

[a] The uranium recoverable from the ore will be somewhat less because of milling losses.

[b] The dollar figures refer to the market price of a quantity of uranium concentrate containing 1 kilogram of elemental uranium.

Source: Canada, Department of Energy, Mines and Resources, 1980g, p. 5.

Figure 3-11: PROJECTED CANADIAN URANIUM PRODUCTION CAPABILITY COMPARED WITH ESTIMATED ANNUAL URANIUM REQUIREMENTS



Source: Canada, Department of Energy, Mines and Resources, 1980g, p. 13.

Energy Flows in Canada

1. ENERGY SUPPLY, DEMAND AND TRADE

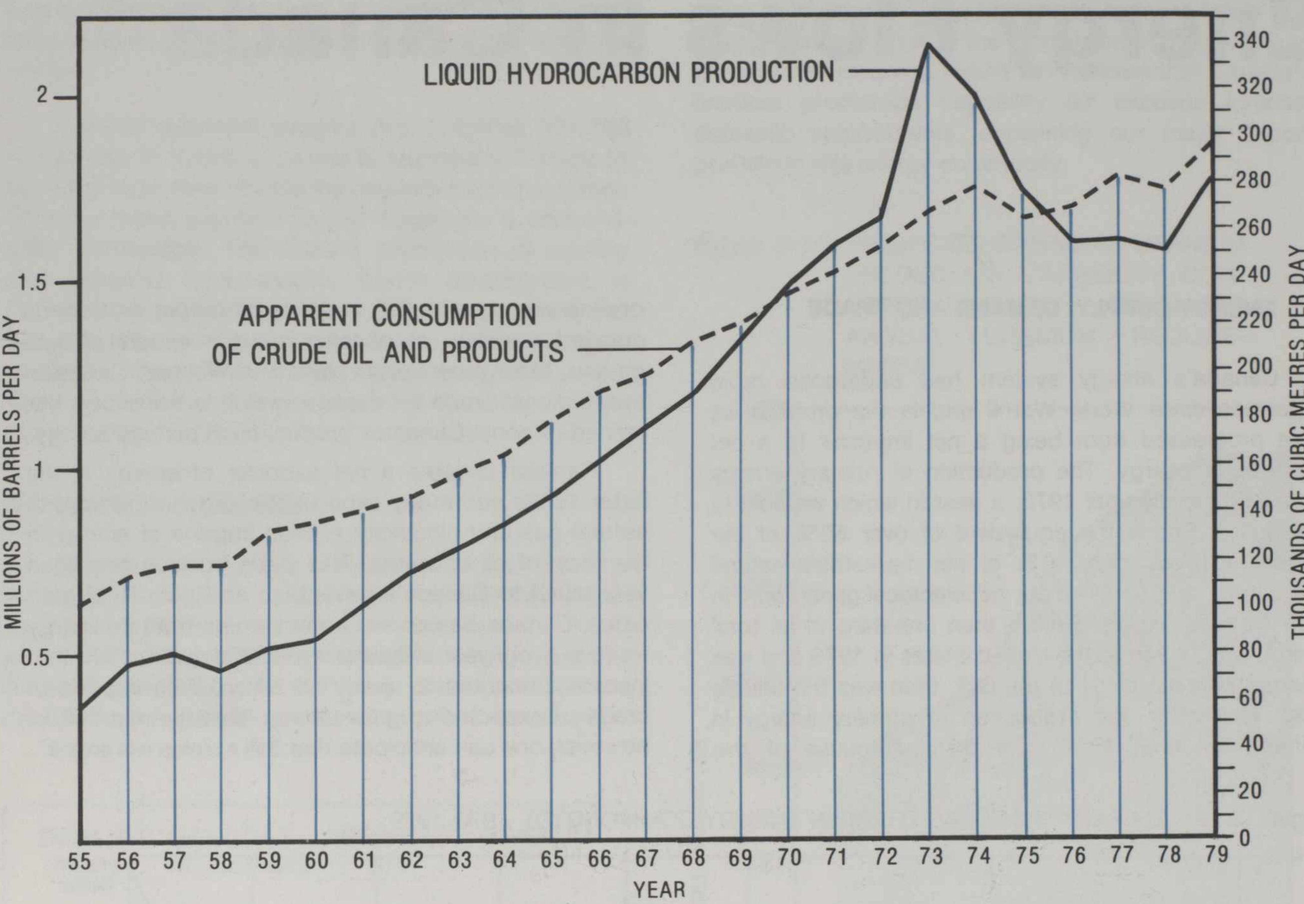
Canada's energy system has undergone rapid expansion since World War II and in the process we have progressed from being a net importer to a net exporter of energy. The production of primary energy increased rapidly until 1973, a year in which we sold to the United States the equivalent of over 60% of our petroleum production, 40% of our marketable natural gas output, and 6.4% of our net electrical generation. In fact, Canada exported more than one-third of its total energy production to the United States in 1973 and was a larger supplier of oil to the U.S. than was the Middle East. Thereafter, the production of primary energy in Canada fell until 1977. The principal cause of this decline was a reduction in crude oil output as Canada pursued a policy of phasing out the export of light crudes. Most recently, an upturn in Western Canadian conventional crude production (which is transitory) has helped to boost Canada's production of primary energy.

Canada became a net exporter of energy in the latter 1960s and today exports of energy in the form of natural gas and electricity exceed imports of energy in the form of oil and coal. This trade position has been very much to Canada's advantage as Figure 3-12 indicates. Canada has shown a net income from its energy trade in every year since the late 1960s and in 1979 that income amounted to nearly $4 billion. With imports of crude oil expected to grow until at least the mid-1980s, however, one can anticipate that this surplus will shrink.

Figure 3-12: CANADA'S DOLLAR TRADE IN ENERGY COMMODITIES, 1970-1979

Source: After Canada, Department of Energy, Mines and Resources, 1980e, p. 8.

Figure 3-13: CANADA'S PRODUCTION AND CONSUMPTION OF PETROLEUM, 1955-1979



Source: After Canadian Petroleum Association, 1980.

The trends in Canada's domestic supply and demand of oil and gas are displayed in Figures 3-13 and 3-14. The first illustration shows liquid hydrocarbon production (crude oil and gas liquids) plotted against Canada's apparent consumption of crude oil and products. In the early 1970s we were net exporters of oil, with sales to the United States peaking in 1973. After a modest upturn in production in 1979, domestic oil output slipped in 1980 and Canada faces a widening gap between supply and demand as the 1980s progress.

In contrast, Figure 3-14 shows how Canada's output of natural gas has outpaced domestic demand, sustaining our substantial sales of gas in the U.S. market. This excess productive capacity in natural gas has been the principal factor behind Canada's positive trade balance in energy commodities throughout the 1970s.

2. THE CONVENTIONAL ENERGY MIX

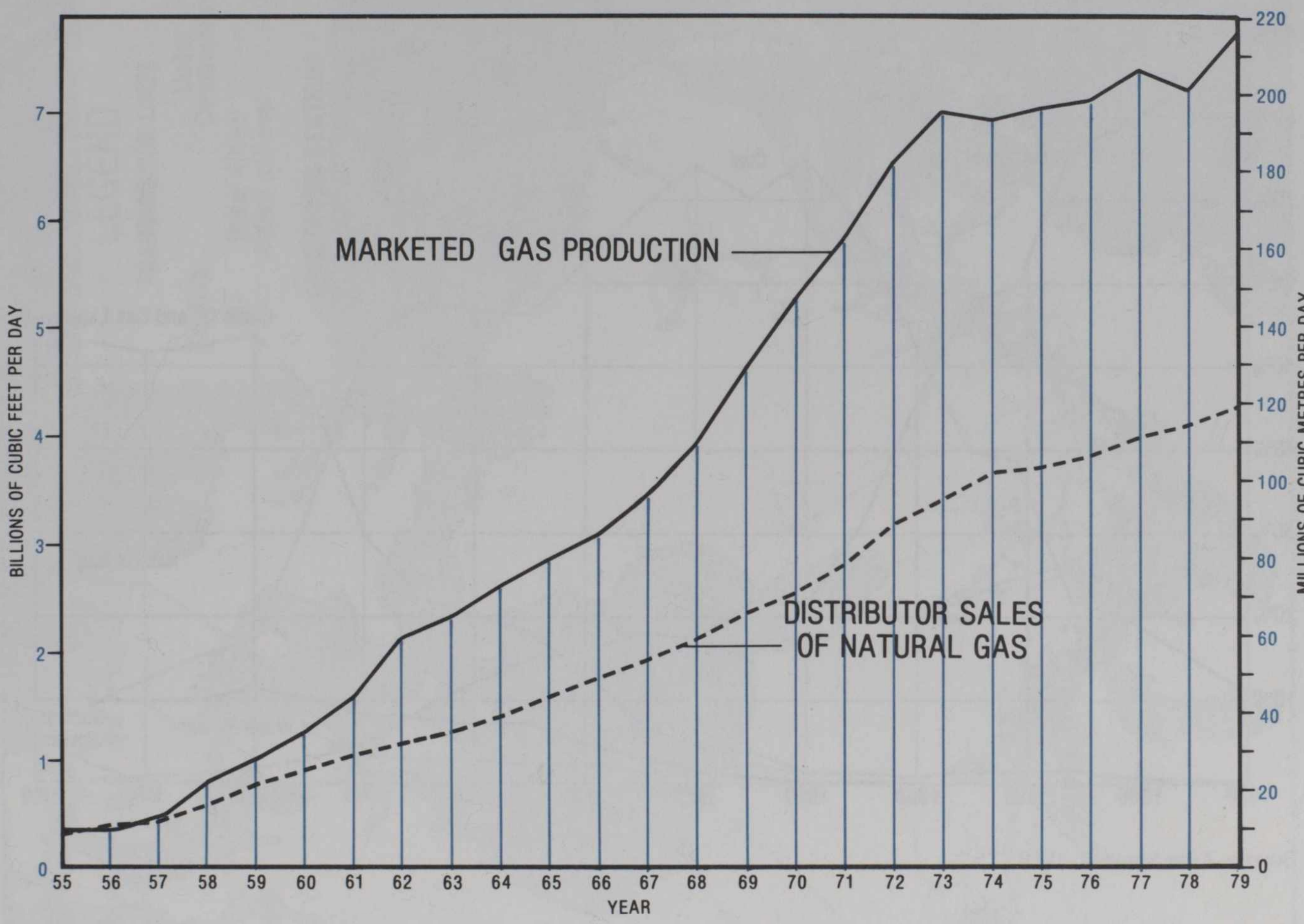
As well as appreciating the growth in Canada's energy system, it is also important to follow the evolution in the energy mix — the relative contributions that have been made by each primary energy form. That evolution is depicted in Figure 3-15 which shows the contributors to Canada's primary energy supply since 1871.

First fuel wood and then coal dominated our energy system. Crude oil and natural gas have risen in tandem since World War II to displace coal, with oil established as our most important energy commodity over the last quarter-century.

In a time span of less than two decades, during the 1940s and 1950s, oil's share in Canada's energy mix expanded from approximately 20% to more than 50%. That share was subsequently maintained for 15 years but now has begun to contract. We expect oil to continue to lose ground to the other major components of Figure 3-15, namely natural gas, primary electricity and coal.

While Figure 3-15 suggests that substantial changes can be brought about in an energy system rather quickly, that interpretation is not entirely correct. Oil penetrated Canada's energy mix at a time when our

Figure 3-14: CANADA'S PRODUCTION AND CONSUMPTION OF NATURAL GAS, 1955-1979



Source: After Canadian Petroleum Association, 1980.

energy system was much smaller and less complex. Today, the inertia to change is far greater because the system is large and entrenched. Oil also found ready acceptance because it possessed obvious advantages over other energy forms. Now we are being forced to consider some options which are not as appealing. One can safely predict that it will prove much more difficult to get off oil than it was to get on it.

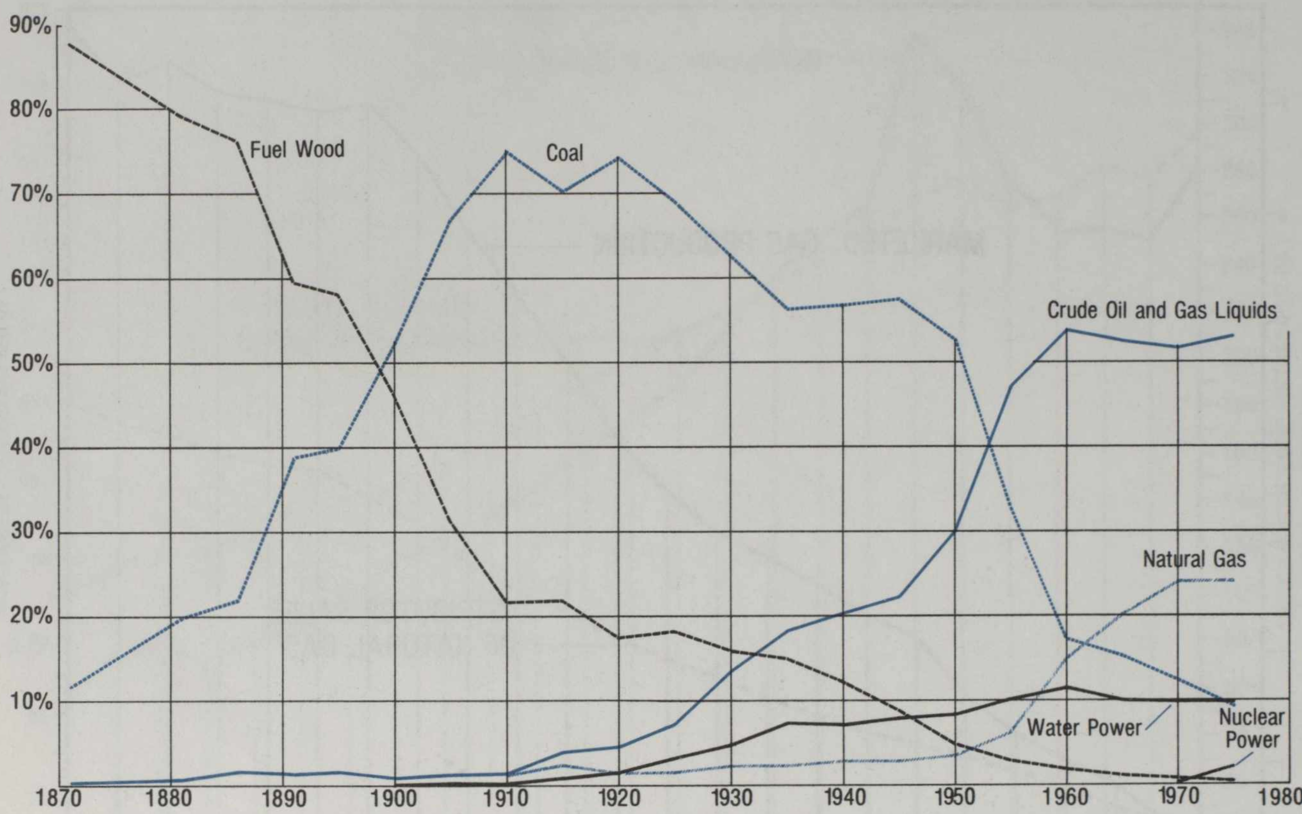
3. ENERGY LIFELINES

Energy moves across Canada in an extensive system of pipelines and transmission lines, supplemented in places by truck, rail, water and air transport. These energy distribution systems are so fundamental to the economy and so important to the well-being of Canadians that they may be thought of as energy "lifelines". We tend to appreciate their significance, however, only when they are disrupted. None of these systems is truly nationwide in extent, and lack of service by pipelines or the electrical grid to a region may represent both a problem in conventional energy supply and an opportunity for the penetration of alternative energy forms.

Hydro-electricity and nuclear-electricity together satisfy about 13% of Canada's primary energy requirements. Hydro and nuclear generating stations comprised 65% of Canada's installed electrical generating capacity at the end of 1979, with the remaining capacity made up of coal-, oil- and gas-fired stations. The use of electricity is spread over all sectors of the economy and most populated regions of the country. Such widespread use has been made possible by the construction of a complex transmission system.

Over 90% of the electricity used in Canada is generated and distributed by provincially-owned public utilities. In many locations interprovincial transmission lines have been built to service areas of adjacent provinces and to spread the benefits of reliability inherent in larger electrical systems. In all there are twenty-two

Figure 3-15: THE PRIMARY ENERGY MIX IN CANADA SINCE 1871



Source: After Steward, 1978.

separate provincial interconnections in excess of 100 kV, with two more proposed or under construction. Canada's main transmission lines are illustrated in Figure 3-16.

In addition to the interprovincial links, there are more than 100 transmission lines between Canada and the United States, which provide over 8,000 megawatts in power transfer capability. About one-half of the international transfer lines connect Ontario to utilities in New York and Michigan. The remainder of the lines link New Brunswick with Maine, Quebec with New York and Vermont, Manitoba with North Dakota and Minnesota, and British Columbia with Washington. Several new high voltage lines (from Ontario to New York and from Manitoba to the North-Central States) are in the planning, licensing or construction stages. These new lines will add a further 3,240 megawatts of transfer capability.

At the present time, the largest addition being made to Canada's electrical network is the extensive system for transmitting power from the James Bay Project to southern markets. This system involves five parallel 735 kilovolt AC lines, the first of which was completed in September 1979. The remaining lines are due to be finished by October 1984. A single 500 kV AC line between the Fraser Valley in B.C. and Calgary is the other major transmission line under construction today.

Canada has an oil pipeline system for moving domestically-produced oil to refining centres from British Columbia to Quebec, and for bringing imported oil into Montreal via the United States. Neither Vancouver Island nor any of the country east of Montreal is connected to this distribution network. Figure 3-17 shows existing and proposed pipelines.

The Trans Mountain Pipeline consists of 1,156 km of pipeline between Edmonton and Vancouver, with connections to the Westridge Marine Terminal (in Vancouver) and to the American border where it joins pipelines serving four refineries in Washington State. This pipeline system has a pumping capacity of 410 thousand barrels per day (65,180 m^3/d) and a storage capacity of 4.35 million barrels (692,000 m^3).

The major cross-Canada pipeline delivering western oil to eastern refineries and consumers is the Interprovincial Pipe Line. This system runs 3,700 km across the Canadian prairies, through the United States south of Lakes Huron and Michigan to Sarnia, Toronto and Mon-

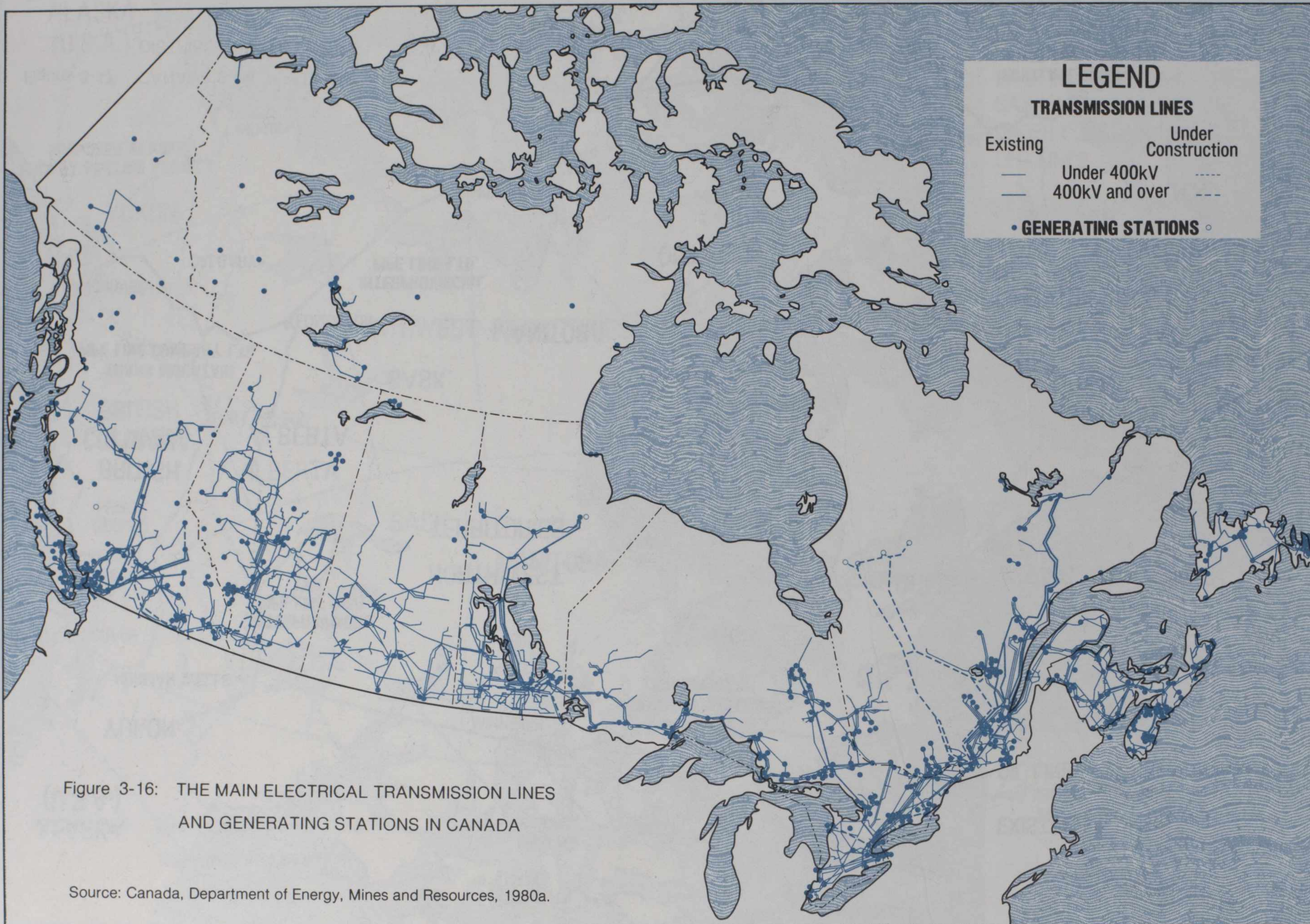


Figure 3-16: THE MAIN ELECTRICAL TRANSMISSION LINES AND GENERATING STATIONS IN CANADA

Source: Canada, Department of Energy, Mines and Resources, 1980a.

Figure 3-17: CANADA'S OIL PIPELINE DISTRIBUTION SYSTEM

Source: Canada, National Energy Board, 1980.

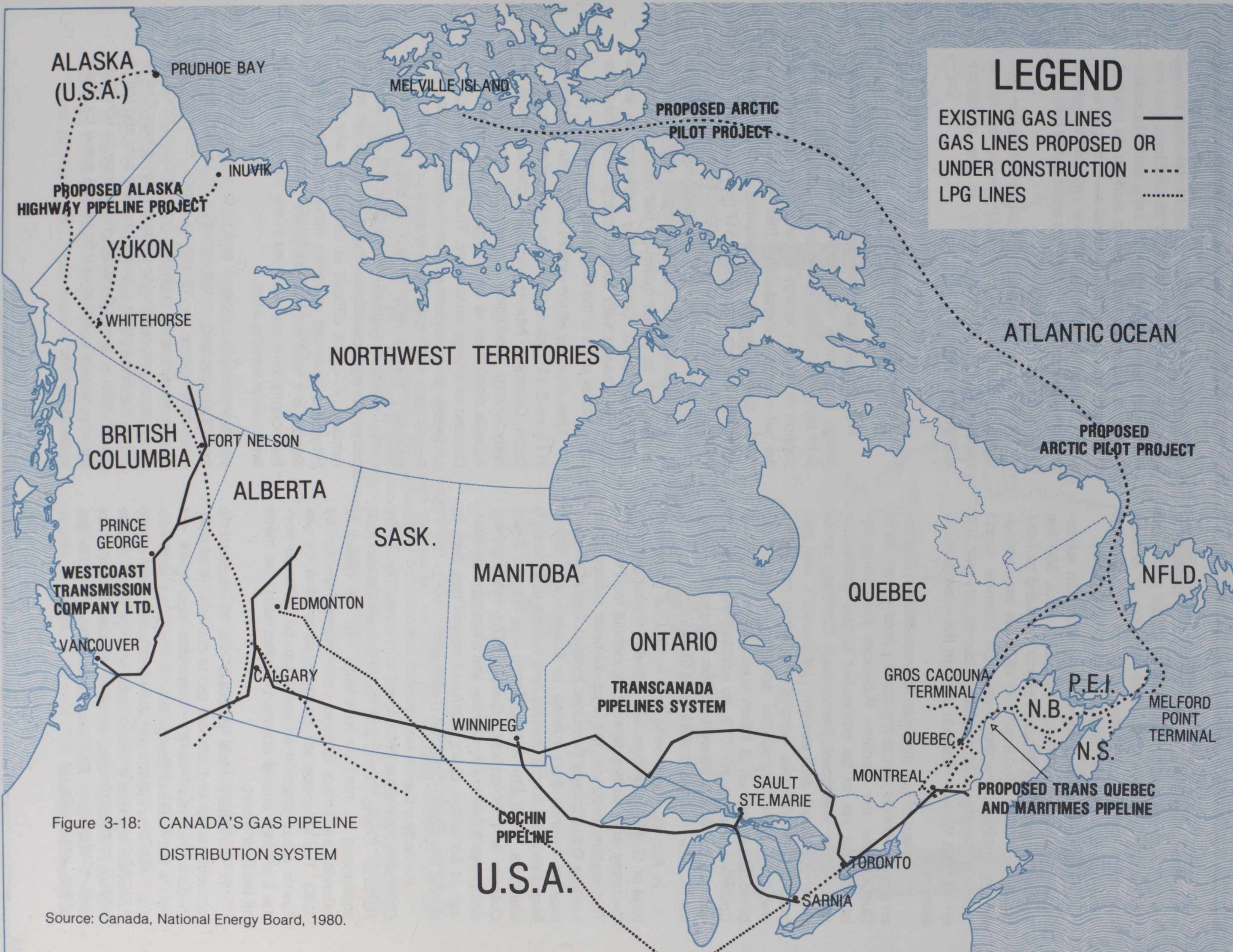


Figure 3-18: CANADA'S GAS PIPELINE DISTRIBUTION SYSTEM

Source: Canada, National Energy Board, 1980.

treal, with a lateral line to Buffalo. It has a capacity to pump 1,528 thousand barrels/day (243,000 m^3/d) and for the last few years has been running at or near capacity. The storage capacity of this large pipeline system is about 16.25 million barrels (2.6 million m^3).

The third pipeline system serving Canadian refineries is the Portland-Montreal Pipe Line. This 380 km pipeline has a design capacity of 550 thousand barrels/day (87,440 m^3/d) but since mid-1976 has been operating very much below this level since Montreal began receiving roughly 300 thousand barrels/day (47,700 m^3/d) from Western Canada through the Interprovincial extension.

A system of gas pipelines delivers Western Canadian gas to markets across the country from Vancouver to Quebec, but the Maritime Provinces and Vancouver Island have yet to be connected to this distribution system. The Westcoast Transmission Company serves British Columbia and western U.S. markets with gas from British Columbia, Alberta, the Yukon and Northwest Territories. This system delivered a total of 146 billion cubic feet (4.13 billion cubic metres) to British Columbia markets in 1979. In addition the system is licensed to export 869 million cubic feet per day (24.59 million cubic metres) to the United States.

In Alberta, the Alberta Gas Trunk Line operates a total of 10,836 kilometres of pipeline to collect gas from the many small wells scattered throughout the Province. This system feeds into the large-diameter system operated by TransCanada PipeLines Limited. TransCanada's pipeline extends from Alberta to Quebec with lateral lines stretching to the international border at Emerson, Manitoba; Sault Ste. Marie, Sarnia and Niagara Falls, Ontario; and Philipsburg, Quebec. The total system comprises 9,344 km of pipeline and transports an average of 85 million cubic metres of natural gas daily to almost two million Canadian customers.

Recently a license was granted to extend the TransCanada system beyond Montreal to Quebec City. In the National Energy Program the Federal Government announced its intention to ensure that the system is extended still further to serve the Maritime Provinces by 1983. The extension will be designed to allow for gas flow in either direction so that it can be delivered from the Maritimes should commercial discoveries be made off the East Coast.

In the future, new pipelines will be required to connect frontier and offshore gas to markets. To accommodate this need several proposals have been put before the National Energy Board. The "Dempster Lateral" would be used to transport Mackenzie Delta gas to Canadian markets in conjunction with the larger Alaska Highway Natural Gas Pipeline System, which has already been given Canadian approval to carry U.S. gas to American markets.

The Arctic Pilot Project seeks permission to deliver Arctic gas to southern markets in liquified form, and the Polar Gas Project is designed to bring both Mackenzie Delta and Arctic gas to sourthern markets via pipeline. The recent gas find off Sable Island could be connected to the mainland by pipeline, but no proposal for such a line has yet been made. This must await better definition of the gas reserves available.

Existing and proposed natural gas distribution systems are illustrated in Figure 3-18. Proposed distribution systems include those presently in the regulatory approval process.

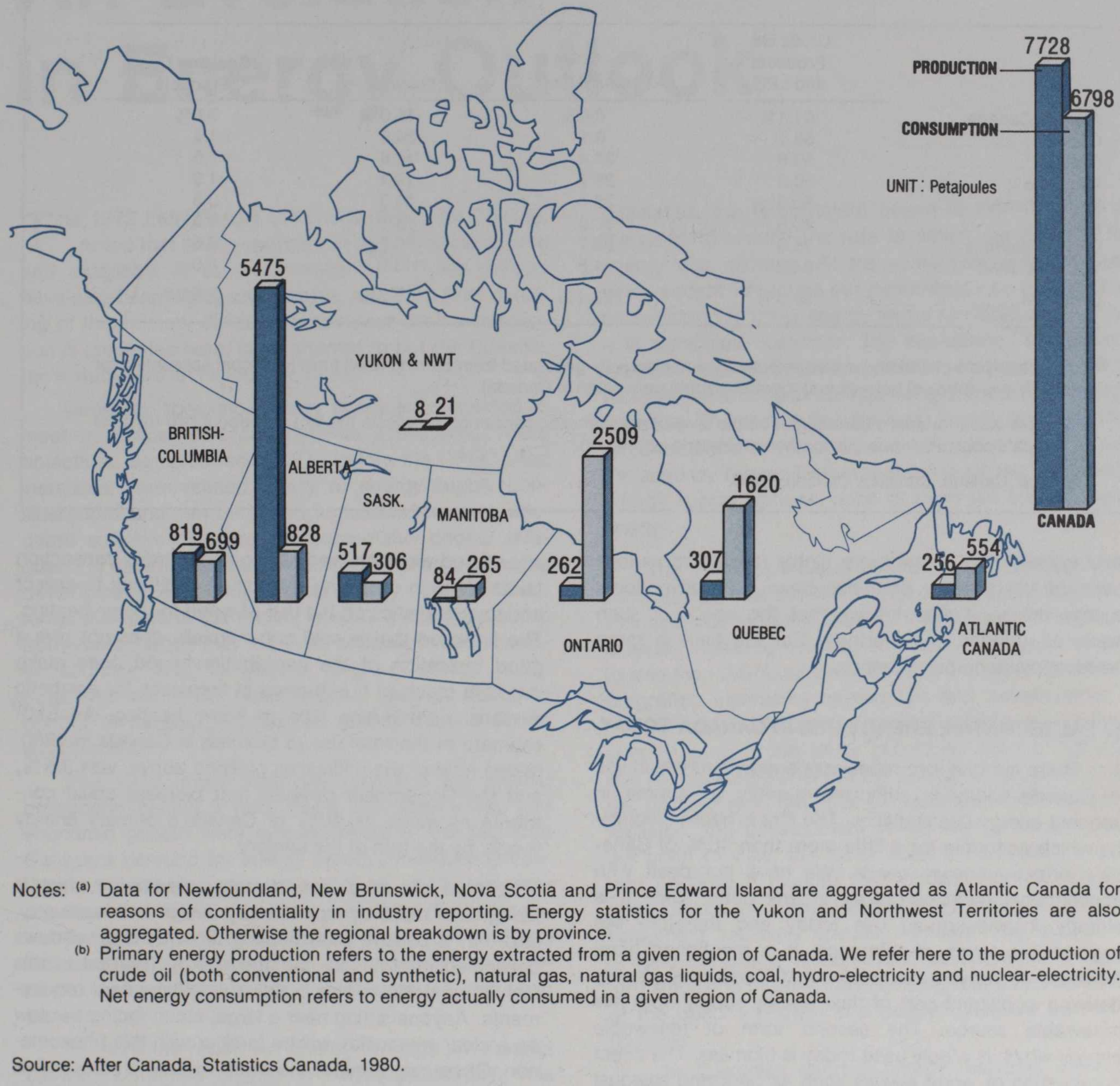
4. REGIONAL CONSIDERATIONS

Not yet revealed in our discussion are the regional energy imbalances which exist in this country. Figure 3-19 brings this situation into focus, displaying the production of primary energy in Canada by region against the net energy demand within that region, for the year 1978. Saskatchewan, for example, had a primary energy production that year of 517 petajoules and a net energy demand of 306 petajoules. Even allowing for conversion losses, Saskatchewan produced from within its own borders substantially more energy than it required for its needs (although not necessarily in the appropriate form). Consequently Saskatchwan was a region of Canada with surplus energy which could be sold in other parts of the country and abroad.

Now consider all the regions of Canada represented in Figure 3-19. Only in the western part of the country—British Columbia, Alberta and Saskatchewan—does primary energy production exceed net energy demand. Alberta dominates as an energy supplier; Ontario and Quebec as energy consumers. Thus the prevailing flow of energy in Canada's system is from west to east. Based upon 1978 data, Alberta alone produced 71% of Canada's energy while consuming only 12%. In contrast, Ontario accounted for less than 4% of Canada's primary energy production but 37% of its net energy demand. It is not difficult to understand why the two Provinces have had opposing views on energy pricing. Neither is it hard to understand why different regions of the country view opportunities in the alternative energy field in such varying ways.

Moreover, this regional energy imbalance is greater than that indicated in the statistics of primary energy production alone — Western Canada contains two energy resources, in addition to conventional crude oil and natural gas, which are presently being exploited at only a fraction of their potential, namely coal and the oil sands. This region of Canada will continue to dominate the supply side of the domestic energy scene for many years to come.

Figure 3-19: PRIMARY ENERGY PRODUCTION AND NET ENERGY CONSUMPTION BY REGION IN CANADA DURING 1978



Notes: (a) Data for Newfoundland, New Brunswick, Nova Scotia and Prince Edward Island are aggregated as Atlantic Canada for reasons of confidentiality in industry reporting. Energy statistics for the Yukon and Northwest Territories are also aggregated. Otherwise the regional breakdown is by province.

(b) Primary energy production refers to the energy extracted from a given region of Canada. We refer here to the production of crude oil (both conventional and synthetic), natural gas, natural gas liquids, coal, hydro-electricity and nuclear-electricity. Net energy consumption refers to energy actually consumed in a given region of Canada.

Source: After Canada, Statistics Canada, 1980.

The simple statement that Canada still satisfies about half of its energy requirements with liquid hydrocarbons (crude oil and natural gas liquids) also hides some startling regional variations. These variations are highlighted in Table 3-8 which gives the degree to which the regions of the country depend upon the various forms of conventional energy. Looking at Atlantic and Northern Canada's overwhelming dependence upon oil, it is not surprising that these regions of Canada show some of the strongest interest in alternative energy and oil substitution.

When one further considers that Canada's national distribution systems for crude oil and natural gas do not yet extend into the Maritimes, concern regarding the region's vulnerability to events abroad in the oil sector is quite understandable. With the potential to exploit alternative energy forms also varying substantially from region to region, it is clear that an alternative energy

Table 3-8: PERCENTAGE CONTRIBUTIONS OF THE VARIOUS ENERGY FORMS TO NET DOMESTIC ENERGY CONSUMPTION IN CANADA BY REGION DURING 1978

	Crude Oil, Products and LPG	Natural Gas	Electricity[a]	Coal and Coal Products
Atlantic Canada	81.1%	0.0%	15.0%	3.9%
Quebec	68.1	6.1	24.4	1.4
Ontario	50.6	27.4	14.6	7.5
Manitoba	50.3	29.7	18.1	1.9
Saskatchewan	50.5	38.6	10.3	0.6
Alberta	40.5	50.8	8.3	0.3
British Columbia	55.0	23.7	20.6	0.6
Yukon & NWT	84.3	1.8	13.9	0.0
CANADA	56.5%	23.1%	16.8%	3.6%[b]

[a] Includes hydro-electricity, nuclear-electricity and electricity generated from burning fossil fuels (with coal accounting for roughly two-thirds of non-nuclear thermal-electric generation in Canada).

[b] This low value for coal's contribution at the level of net domestic consumption reflects the fact that about two-thirds of Canada's coal requirement is for thermal-electric generation.

Source: Canada, Statistics Canada, 1980.

strategy will have to be more highly tailored to various parts of the country than has been our conventional energy policy. It also follows that the needs of such areas as Atlantic and Northern Canada have a more pressing claim on our attention.

5. ALTERNATIVE ENERGY USE IN CANADA TODAY

There are only two renewable energy sources in use in Canada today in sufficient quantity to appear in national energy use statistics. The first is hydro-electricity, which accounts for a little more than 10% of Canada's primary energy needs. We have not dealt with conventional hydro-electricity in any detail since it is already in widespread use today and therefore lies beyond our terms of reference. It is mentioned here, however, to remind the reader that Canadians already derive a significant part of their energy supply from this renewable source. The second form of renewable energy which is widely used today is biomass. The direct combustion of wood wastes such as bark and sawdust for process heat and steam in the forest industry accounts for over 3% of Canada's primary energy consumption. It has been suggested that this figure could double over the next few years simply by making increased use of waste wood within the forest products industry.

It is estimated that there are now approximately 100,000 wood stoves being purchased and installed annually in Canada, although the total number of wood stoves is not known with any accuracy. Many consumers heat their homes with wood cut from small, individually-owned woodlots and, as no commercial transaction takes place in obtaining this fuel, it is difficult to collect accurate statistics on the use of wood for home heating. The firewood that is sold commercially does not give a good indication of the contribution wood does make because much of it is burned in fireplaces for aesthetic reasons, contributing little to home heating. An EMR estimate of the total use of biomass in Canada in 1980, taking note of the difficulties outlined above, was 3.5%, and the Department believes that biomass could contribute as much as 10% of Canada's primary energy supply by the turn of the century.

There is a third form of renewable energy which is being used more by luck than by design in this country, and that is passive solar heating. South-facing windows collect solar radiation and the energy trapped in this fashion contributes to a building's daytime heat requirements. Anyone sitting near a large, south-facing window on a clear winter day will be familiar with this phenomenon. Of course, at night the same window is responsible for a certain amount of heat loss. In terms of net contribution however, it is estimated that 1.5% of Canada's primary energy consumption in 1980 was in the form of passive solar heat. As is the case with domestic use of wood this is only a rough estimate, there being no simple way of obtaining precise data.

In total then, renewable energy sources supplied something more than 15% of Canada's primary energy needs in 1980, if one includes hydro-electricity. The contribution from biomass and solar alone totalled perhaps 5%.

An Evolution in Energy Outlook

The 1973 EMR Report, *An Energy Policy for Canada,* noted that energy policies were "complex, diverse and incapable of simple formulation." These policies have also been highly changeable, making a brief detailing of their history difficult. Nonetheless such a description is presented here, in an attempt to put the Committee's study into an historical context.

Generally speaking, energy policy is formulated to meet a number of broad national aspirations. These objectives, as perceived in 1973 before the OPEC price increases, were related totally to energy supply considerations and can be stated as follows: ensuring adequate supplies of energy at competitive prices; safeguarding national security; encouraging energy resource development; exporting surplus energy supplies under terms that benefit the nation; acquiring energy supplies from abroad when they are more economic than domestic sources; and, in general, aligning energy policy objectives with other national goals such as Canadian control of its energy industries and protection of the environment.

The 1973 review was optimistic and the general philosophy behind it maintained that energy use and economic growth were closely linked — the fact that Canada's demand for energy would consequently continue to increase was accepted as an inescapable consequence of our continued prosperity. Furthermore, the potential of the oil sands and frontier oil and gas indicated we could indeed have abundant, reasonably-priced energy to maintain a high rate of economic growth.

In 1976 the report *An Energy Strategy for Canada* showed a marked change in EMR's philosophy. This report was written during what was described as an energy crisis and is thus imbued with a pessimism which was not evident in 1973. Our proven reserves of oil and low-cost gas had begun to decline while demand continued to increase. Our exports of oil were declining but imports were increasing and Canada was faced with rising import compensation payments. Drilling results in Canada's frontier regions were disappointing and extracting oil from the tar sands was proving to be more expensive than previously anticipated. In light of such difficulties, the Government began to look seriously at the need to reduce the rate at which our demand for energy was growing. At the same time, policies were being sought to reduce our dependence on imported oil by switching to other energy forms available domestically in significant quantities. The expression "energy self-reliance" was introduced by the Government in 1976 to indicate its approach to improving the nation's energy situation. The notion that low-cost energy was essential for Canadians to maintain their standard of living was replaced by the realization that although we have many energy supply options, none of them will supply cheap energy.

The 1976 report also outlined a number of policies designed to meet the stated objectives. These measures included moving domestic oil prices towards international levels; reducing the rate of growth in energy demand to less than 3.5% annually through energy conservation programs; increasing exploration and development in frontier areas of Canada (with Petro-Canada subsequently to aid in this task); promoting interfuel substitution to reduce the share of our energy needs satisfied by oil; building new gas and oil pipelines; and increasing research and development in the energy sector. From our point of view, this latter point is particularly important because it marked the first time that funding for conservation and renewable energy research and development received special mention. The subject of funding for energy research and development is important since it is through such funding that implementation of the options chosen in a policy statement are made possible.

The Canadian effort in energy research, development and demonstration (RD & D) at the federal level which should have helped to achieve some of the above objectives was unimpressive throughout the 1970s, and there was no significant increase in real annual expenditures despite the rising concern over energy supplies which had developed from 1974 to the end of the 1970s. Figure 3-20 shows the evolution of Federal Government energy RD & D budgets from 1974 to 1979, in current and constant dollars. Provincial government expenditures are not included in Figure 3-20.

An Evolving Federal View of Energy Strategy in Canada

Foreword, *An Energy Policy for Canada - Phase 1*, 1973

The attainment of many of our national goals is dependent on our continued access to low-cost supplies of energy: the growth in our standards of living, as individuals and as nations; the improvement in the quality of life, in the choices available to us.

At the international level we have heard expressions of concern about the availability and cost of energy in the future. In Canada we have had the good fortune to be endowed with substantial supplies of all five main sources of energy: coal, oil and gas, hydro power and uranium. But with our climate, and with the transportation demands imposed on us by our vast land-area, our demand for energy is also substantial.

Foreword, *An Energy Strategy for Canada: Policies for Self-Reliance*, 1976

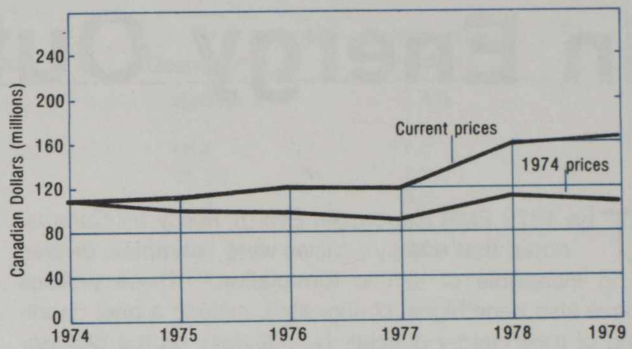
While our proved reserves of oil and low-cost gas continue to decline, Canadian demands for these energy forms continue to increase. The growing gap between our energy demands and our ability to supply them from domestic reserves suggest that we could become increasingly dependent on the rest of the world, and the Organization of Petroleum Exporting Countries in particular, for our future oil supplies. This prospect carries with it economic and political risks which the Government of Canada views with concern.

We have, within Canada, the people, the equipment, the expertise and the potential energy resources to reduce substantially our dependence on imported oil. We can do this by reducing the rate at which our energy requirements grow in the future, by substituting those energy forms which are in relatively abundant supply in Canada for those that are not, by accelerating the search required to find new oil and natural gas — to convert the potential of our undiscovered energy resources to proved reserves from which our needs can be supplied. All of these options will be expensive, but all must be pursued...

The National Energy Program 1980, p. 9

...Canada's energy problem is not only manageable, but its solution can draw from many options. Canada has the diversified energy resource base to support a relatively quick and clean shift away from world oil. Canada also has the time to make the transition to an economy that is more efficient in its use of energy, and more dependent upon renewable energy sources.

Figure 3-20: EVOLUTION OF FEDERAL GOVERNMENT ENERGY RD&D BUDGETS IN CURRENT AND 1974 DOLLARS



Source: After International Energy Agency, 1980b, p. 114.

In 1979 the total Federal expenditure on energy RD&D amounted to slightly more than $162 million, broken down in general terms as follows (IEA, 1980b):

Conventional Nuclear	$103.6 million (63.8%)
Fossil Fuels..........................	16.5 million (10.2%)
New Energy Sources	21.7 million (13.4%)
Energy Conservation	12.5 million (7.7%)
Nuclear Fusion.....................	2.9 million (1.8%)
Supporting Technologies....	5.1 million (3.1%)
TOTAL	$162.3 million

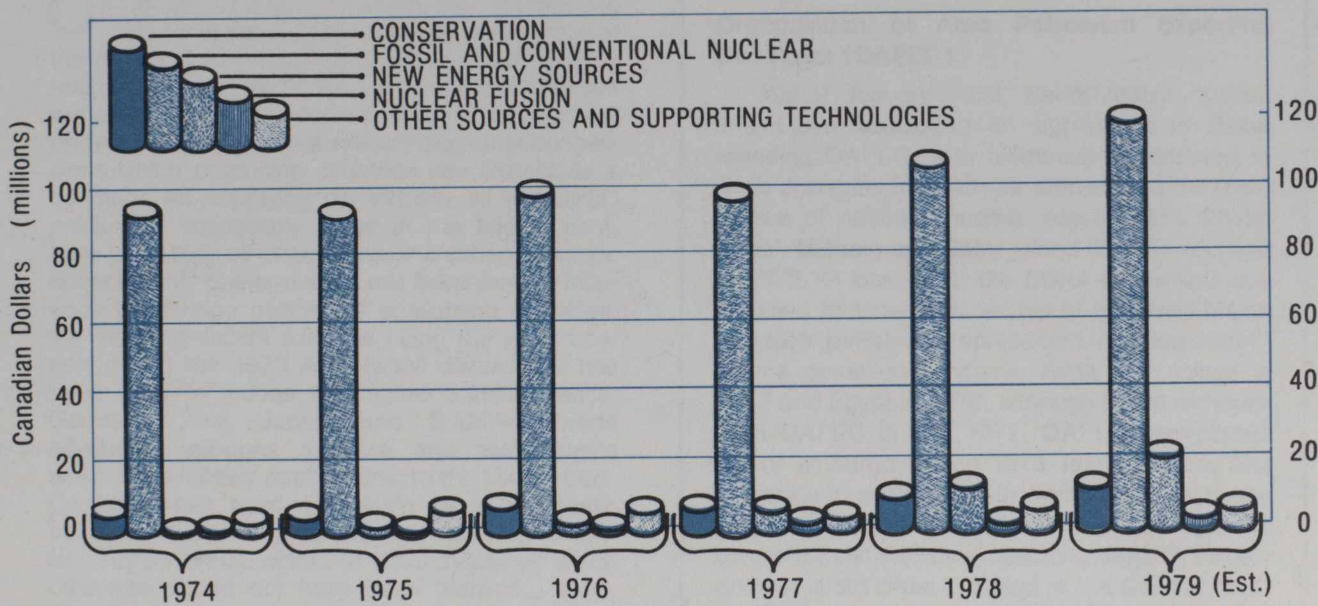
This amounted to only 15.5% of total Federal expenditure on RD & D and represented a decline of 4.5% from 1978 in real terms. Clearly a re-examination of funding for energy RD & D in this country is in order. We will not be able to exercise our various energy options if sufficient support for their development is not forthcoming.

The 1980 National Energy Program is the most recent statement of the Federal Government's view of Canada's energy situation. Perhaps one of the most significant aspects of this statement is an increased emphasis on reducing our energy demand as well as increasing the use of alternative energy sources.

The 1980 program states that our commitment to developing nuclear technologies will continue but the overall emphasis on energy RD & D will shift towards finding alternatives to gasoline, increasing the efficiency of energy use and developing new energy sources. It is in the context of such a shift in emphasis that this Committee was established and it is in this atmosphere that our report will be considered.

The following illustration (Figure 3-21) is included to show the relative emphasis which has been placed in recent years on renewable energy technologies and conservation. Again provincial funding is excluded from the totals. Funding for RD&D in these areas is beginning to expand and the Committee urges increased and sustained support so that recommendations contained in this Report may be acted upon.

Figure 3-21: EVOLUTION OF FEDERAL GOVERNMENT ENERGY RD & D BUDGETS IN MAJOR ENERGY TECHNOLOGY AREAS



Source: After International Energy Agency, 1980b, p. 113.

The Problem With Oil

Oil is not merely an economic commodity. It is a source of enormous political leverage in the hands of the major oil producing nations. Any realistic assessment of the cost of oil must include not only the price in dollars and cents, but also the price in terms of political, military and other concessions which producing countries can extract as a condition for supplying oil. Virtually all the OPEC producers, particularly those in the Middle East, have used their oil at one time or another to pursue noneconomic objectives. Oil has been used to influence the foreign policies of consuming countries, the most significant example being the Arab boycott during the 1973 Arab-Israeli dispute. Oil has been used to induce the United States, France, Germany, Italy, Japan, and Brazil to trade advanced weapons systems and technologies which have military applications, to the Middle East. Oil has been used to obtain other economic concessions including assistance in building refineries, petrochemical plants or other industries which otherwise would not have been granted.... (U.S. Senate Committee on Energy and Natural Resources, 1980, page 29.)

Organization of Petroleum Exporting Countries (OPEC)

Prior to the formation of OPEC in 1960, control of the world petroleum business lay primarily in the hands of the major oil companies and price changes were arranged through a distributors' cartel. With the aim of preventing oil price reductions and improving their negotiating position, a number of oil-producing countries held discussions concerning a united pricing and production policy, culminating in the formation of OPEC on 10 September 1960, in Baghdad. The founding five countries were Saudi Arabia, Kuwait, Iran, Iraq and Venezuela. Today the membership of OPEC stands at thirteen: Saudi Arabia, Kuwait, Iran, Iraq, the United Arab Emirates (whose oil-producing members include Abu Dhabi, Dubai and Sharjah), Qatar, Libya, Algeria, Nigeria, Gabon, Ecuador, Venezuela and Indonesia. OPEC's estimated crude oil production in 1980 was 26.8 million barrels/day, or 45% of world crude liftings of 59.7 million barrels/day.

Organization of Arab Petroleum Exporting Countries (OAPEC)

On 9 January 1968, Saudi Arabia, Kuwait and Libya concluded an agreement in Beirut founding OAPEC, with membership restricted to Arab countries in which oil represented the main source of national income. Algeria, Abu Dhabi, Dubai, Bahrain and Qatar joined in 1970 and Iraq in 1972. In late 1971, the Beirut agreement was modified to allow membership of any Arab nation in which petroleum represented an "important" source of national income. Syria then joined in 1972 and Egypt in 1973, although Dubai withdrew from OAPEC in late 1972. OAPEC precipitated the oil embargo of late 1973, leading to the first explosion in world price. In April 1979, Egypt was suspended from OAPEC membership but, for consistency in statistical reporting, Egypt's oil production is still often included in the OAPEC total. OAPEC's crude oil output in 1980 was approximately 19.6 million barrels/day, about 33% of world production.

The world petroleum market is susceptible to manipulation for a variety of reasons. OPEC controls almost 70% of global conventional crude oil reserves and one member alone, Saudi Arabia, holds approximately 27% of the total. This small group of nations also possesses the greatest capacity to expand production in the short term. With OPEC accounting for a little less than half of the world's oil output while holding more than two-thirds of its reserves, it is apparent that other oil-producing countries are compelled, at least in relative terms, to overproduce their oil resources. The oil producers in the Middle East could, on average, sustain current levels of output for nearly half a century; the United States and Canada have little more than a decade of oil left at the current rate of production with their present proved reserves. In a world in which oil is the dominant energy commodity, now accounting for about 45% of primary energy consumption, this is a degree of resource concentration holding profound implications.

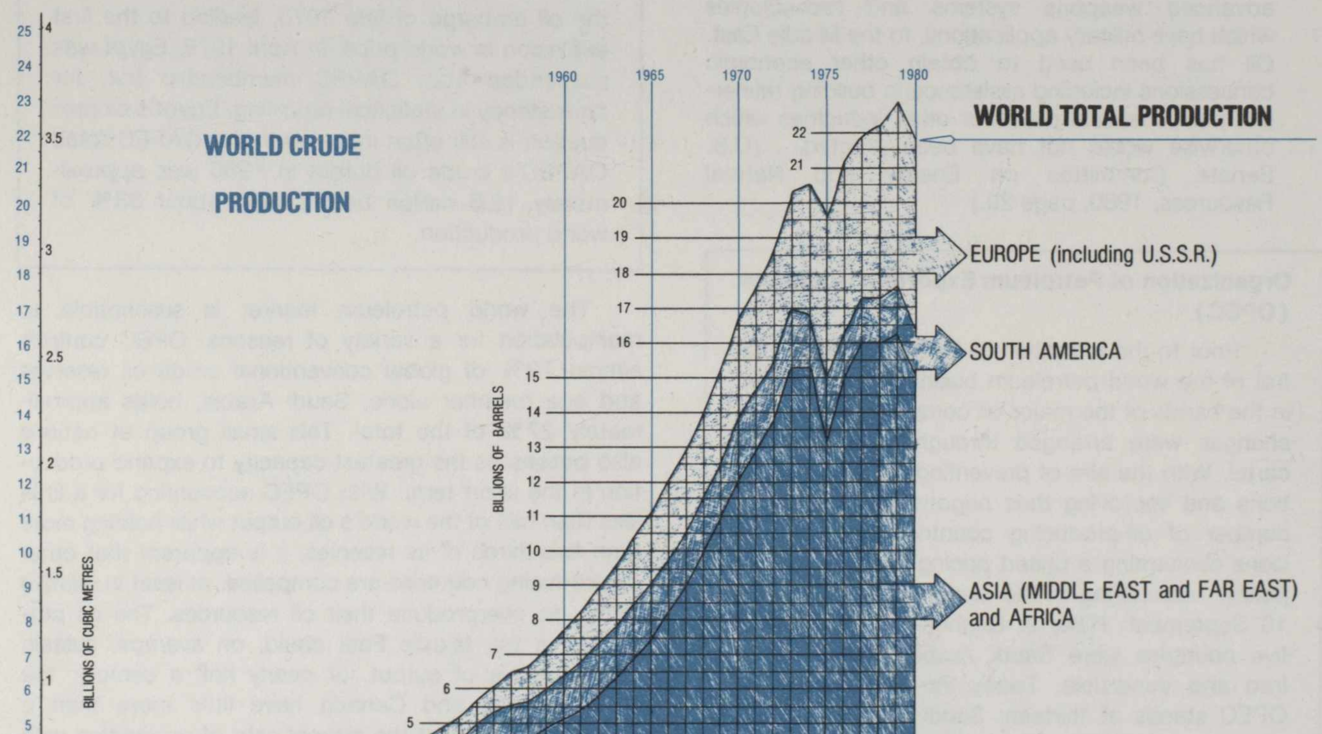
Oil is an essential component of the energy system in every industrialized nation and fuels all conventional military machines. Over half of the oil involved in international trade passes through the Strait of Hormuz at the entrance to the Gulf of Arabia, at a rate of about 18 million barrels per day. In a typical 24-hour period, 70 to 80 ships use the Strait, including the world's largest supertankers. Roughly 90% of Japan's total oil requirements are shipped via this narrow passage, as are 60% of Western Europe's oil imports and about 30% of U.S. imports. The invasion of Afghanistan brought Soviet military forces to within 550 kilometres of the Strait, adding to the anxieties of the oil-importing nations.

In a number of other ways, OPEC is moving to strengthen its ability to control the world petroleum market. During the 1970s, host governments nationalized most of OPEC's oil fields, relegating the petroleum companies to the role of operator. The oil-producing countries are also moving more towards direct sales via government-to-government transactions. Prior to the 1973 embargo, more than 75% of the oil extracted by OPEC was marketed by the major oil companies; by 1979, the figure had dropped to less than 50%. The ability of the oil companies to act as a buffer between consuming and producing countries — notably to re-route supplies in the event of emergencies — is consequently being lost.

OPEC also is seeking to extend its control through diversification into downstream petroleum activities such as refining and shipping. Such diversification allows OPEC to earn more revenue for each barrel of oil produced (thereby diminishing the need to expand production), and allows producers to extend their influence in the marketing process. Some European refiners have even agreed to process crude while allowing the producing country to retain title to the oil throughout the refining process. This also grants the producing country more power to control the destination of its petroleum exports.

This concentration of power in the hands of OPEC has paralleled the decline of the United States in world oil affairs. At the end of World War II, the U.S. was not only the world's largest producer, but its output exceeded that of all other countries combined. As recently as

Figure 3-22: WORLD CRUDE OIL PRODUCTION BY REGION, 1930-1980



Source: DeGolyer and MacNaughton, 1980, p. 4; and Auldridge, 1980, p. 78-79.

1963, the United States still accounted for more than half of all the crude oil that had ever been produced. Today the United States is the world's third largest producer, with the Soviet Union standing first and Saudi Arabia second. The decline of American influence in international petroleum affairs is indicated in Figure 3-22, which outlines world oil output by region since 1930. With U.S. crude output having peaked in 1970, American influence on the world petroleum scene has declined rapidly over the past decade.

While other parts of the world, most notably the North Sea and Mexico, have risen in prominence as oil-producing regions, OPEC will continue to be the dominant influence in the petroleum market for many years to come. Reducing dependence on foreign petroleum should thus be an overriding concern of national policy in the countries of the Western World. This situation also drives home the consequences of allowing one nonrenewable energy commodity to dominate an energy system.

4 CANADA'S ENERGY SYSTEM TOMORROW

Guiding the Development

We have seen what Canada's energy system looks like today but how should it be structured tomorrow? Certainly, the fact that we presently depend so heavily on hydrocarbons for primary energy means that if we get off this energy source by substituting alternatives, the energy mix of tomorrow will have to be radically different. But how will it be different? What should the guiding principles be in developing a new energy system and what emphasis should be placed on the options available to us?

The Committee believes there are a number of principles which should be embodied in Canadian energy policy.

(1) We should make every effort to reduce energy demand by practicing *conservation.*
(2) In the long term, energy should be derived primarily from *renewable* and/or *inexhaustible sources of energy.*
(3) The production of the primary energy we require should be achieved *with as little environmental disruption as possible.*
(4) We must achieve greater *diversity* in Canada's energy mix.
(5) We must recognize *regional differences* in energy resources and in energy requirements.
(6) We must address *strategic concerns* in formulating energy policy.
(7) We must adequately consider the *social implications* of bringing about major changes in Canada's energy system.

In proposing energy policy for the "foreseeable future", the Committee divided the future into the short term (1980-1990), medium term (1990-2000) and long term (beyond the year 2000). While energy development over the next 20 years is easier to predict than in the long term, and thus tended to claim our attention, it is clear that some of the recommendations we are making may require a half-century or more to be fully achieved. Although the fundamental reshaping of Canada's energy system will not be accomplished in this century, the process of reshaping should be well underway by the dawn of the 21st century. The Committee has been faced therefore with making recommendations that not only improve Canada's energy position in the short term but which also are compatible with the long-term evolution we are trying to promote in this complex system.

We have not deluded ourselves into thinking that our conclusions and recommendations represent the final word in energy policy. For this reason we have tried to develop a strategy which will be flexible enough to adapt to changing or unforeseen circumstances, even though this may delay the attainment of the objectives listed above. We know that conditions can change very rapidly — economic shifts such as changes in the relative prices of petroleum and its alternatives can occur at any time; the introduction of new technologies or new energy sources might dictate a revision of long-term goals; and political developments at the domestic or international level could make the achievement of long-term objectives effectively impossible.

1. CONSERVATION AND ENERGY EFFICIENCY

From an early moment in the Committee's existence it became apparent that encouraging energy conservation would have to be a major recommendation of this Report. Witness after witness extolled the importance of conservation practices by pointing out that conservation is the easiest and least expensive means of reducing the energy supply-demand gap. This, then, is a major goal of our alternative energy policy, because by simply reducing energy demand, we moderate energy supply constraints.

The Committee realizes that conservation has been promoted by a variety of groups and governments over the past decade and that this is not a new recommendation. Nonetheless, we wish to add our voice to those already advocating conservation and, in so doing, hope to make the message clearer and stronger. We want to help promote a sense of urgency that will motivate all Canadians to continue and expand their conservation efforts in all sectors of the economy.

Conservation practices should not bring about a reduction in our standard of living. The Committee does not see Canadians doing "less with less" but rather "more with less" or, at least, more with greater efficiency. For example, new television sets now consume much less energy during operation than did earlier models but the quality of the picture hasn't diminished — it has actually improved. This is due to technological innovation and serves to illustrate the philosophy the Committee wishes to advocate — do more with less. We believe that achievements of this type must be realized in all our private, commercial and industrial activities.

A conservation problem can be tackled in a variety of ways. Consider, for example, the objective of reducing the amount of heating fuel used to heat a home. One can turn down the heat or insulate the home. Of course, there is a limit to the amount of energy which can be saved by turning down the thermostat because discomfort would soon prevent anyone from allowing the temperature to fall too far. But the second option of retrofitting a home to make sure heat is not being lost because of poor construction can generate savings with no attendant discomfort. Ideally, one should insulate *and* turn down the thermostat, thus encouraging maximum energy savings.

This brings us to the second part of the title of this sub-section — energy efficiency. When most of the homes and industries, indeed nearly all of Canada's infrastructure, were being designed and built, energy efficiency was not a major factor taken into consideration. It made little sense to heavily insulate houses when the cost of that insulation took years to recover, fuel costs being so low. Similarly, it made no economic sense to invest a large amount in building an energy-efficient industrial complex when energy was cheap; the cost of building in that efficiency might never be regained in terms of the amount of money saved by spending less on energy. Thus, because energy was so cheap, energy inefficiency was actually built into our economy.

Now the tide has turned. Few see us ever again living in an age of inexpensive and plentiful energy. The Committee does not wholeheartedly share this pessimistic view, but we do realize that energy will become an increasingly valuable and expensive commodity for some decades to come. This is not to suggest that Canadians can look forward only to a steadily diminishing standard of living or to a continuous reduction in their quality of life. It does mean though that we have been forced to recognize that from now on, energy efficiency is perhaps the first and foremost factor which must be taken into consideration in building the Canada of tomorrow. We have been forced to take literally the old saying, "Waste not, want not!"

Taking a positive look at the Canadian energy situation, we see this energy inefficiency as a unique energy opportunity — the energy we waste every day is an energy resource which can be readily tapped. In other words, not only are we endowed with a considerable array of conventional and nonconventional natural energy resources but, since we spend more energy per dollar of GNP generated than other countries, we have a tremendous "conservation resource" which can be exploited as well. Therefore, by setting out to build energy efficiency into all aspects of every Canadian activity, whether it be industrial, commercial or social, we can save a very significant amount of energy. And by so reducing energy demand, we can bring our country that much closer to the goal of energy self-sufficiency in *all* energy forms.

The Committee believes, then, that energy efficiency must be built into all our endeavours starting now. We recognize that the conservation resource which can be tapped will diminish as time progresses and we weed out inefficiency but this does not mean conservation will become less important. It simply means it will become an integral part of the system and will make a continuous contribution towards keeping our energy demand down. The real energy crunch will probably occur during the next one to two decades. We are fortunate that the conservation resource is exploitable now, when we very much need it. It would be foolish to deny its importance and its potential.

2. RENEWABLE AND INEXHAUSTIBLE SOURCES OF ENERGY

Canada must place new emphasis on deriving its energy requirements from sustainable sources of energy. We must ultimately shift our dependence away from nonrenewable fossil fuels for the simple reason that their supplies are finite. As stated in Canada's Energy System Today, it is true that these supplies will not be exhausted for some time to come, and that depletion will occur more quickly for some forms than others, but the final result is inevitable. Society cannot go on indefinitely exploiting fossil hydrocarbons for energy. This Report considers some of the reasons why it is advantageous to begin the transition to sustainable energy forms sooner rather than later.

Renewable energy sources are those which are naturally replenished with or without human intervention. The winds and tides are examples of sources of energy which will be available in limited supply in perpetuity without human management, whereas biomass is renewable as an energy resource only if properly managed. Inexhaustible energy supplies are those such as solar or fusion which offer the promise of providing all the energy mankind is ever likely to require if they can be adequately and safely harnessed.

Moving Canada's energy system to phase out nonrenewables and to incorporate renewables and inexhaustibles will not be a simple task nor one which is achieved overnight. It will take commitment, a lot of hard work and money and, perhaps most important, time.

Certainly, if we hope to remould our economy with a minimum of disruption to the quality of life we have come to expect, we must get on with it as soon as possible. This means there will be an extended transitional period, several decades in duration, when neither the system we know today nor the one we envisage for the future will be in place. In this interim, we will have to continue and even augment the use of certain hydrocarbons while developing alternative energy sources and technologies to the point of commercialization. This is seen as necessary to "buy time", but *the ultimate goal of our alternative energy policy is to phase out the use of fossil hydrocarbons as sources of energy.*

The transition period will be a challenging time but one which offers unique opportunities for Canada. All nations will at some stage have to face the reality of getting away from using nonrenewable energy resources and if we develop the alternative technologies which will eventually be required by the rest of the world, our export opportunities will be unprecedented. Specific efforts which should be begun immediately are offered in the form of recommendations throughout this Report but they are concentrated primarily in the chapter on Alternative Energy Sources, Currencies and Technologies.

3. ENVIRONMENTAL CONCERNS

The exploitation of energy cannot be accomplished without having some effect upon the environment, but different energy options affect the environment in differing ways and degrees. Some forms of energy development are more ecologically benign than others and the Committee wishes to emphasize that its investigation has been pursued taking environmental concerns into consideration at all times. It would not make sense to formulate an energy policy which would solve energy problems but create serious environmental ones.

Many of our seemingly most intractable environmental problems arise out of our overwhelming dependence upon hydrocarbons as sources of energy. This is because both the fossil fuels themselves and their combustion products are pollutants when released into the biosphere.

Natural gas is the cleanest of the hydrocarbon fuels. Being a gas, it is easily dispersed when released to the atmosphere and, depending upon the completeness of combustion, produces predominantly carbon dioxide upon burning. Oil in its various forms is more polluting, being a complex, biologically toxic substance to begin with and releasing a variety of materials upon combustion, including hydrocarbons, particulates, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and heavy metals. Coal is yet again more polluting, producing a significantly greater quantity of the same types of pollutants derived from liquid hydrocarbons but also bringing about significant ecological damage during the mining process. Strip mining, acid mine wastes, particulate release during transportation and burning, erosion and occupational health hazards such as black lung disease all contribute to making coal the least environmentally acceptable type of fossil fuel.

Two of today's most disturbing environmental problems are acid rain and the accumulation of carbon dioxide in the atmosphere, and both of these phenomena result primarily from the combustion of fossil fuels. Thus environmental concern has been a major factor in causing the Committee to believe that a new energy system in Canada should be one which is not based principally upon the combustion of hydrocarbons.

A. ACID RAIN

Acid rain was once thought to be a problem of only local magnitude, such as the acidification of lakes in close proximity to mineral smelting operations. However, it has now been shown that acid rain is a widespread, even global, problem whose ecological effects may become most significant.

Acid rain is not new. In 1852, residents of Swansea, Wales complained about the effects "corrosive rain" caused by the local coal industry was having on their cattle and the vegetation of the region. It is, however, a growing problem with Europe, Scandinavia, Japan and North America all beginning to recognize its detrimental ecological, social and health effects. In 1979, the preliminary report of the joint Canada-U.S. group studying the Long Range Transportation of Air Pollutants (LRTAP) "identified acidic precipitation as the problem of greatest common concern at the present time."

The reason acid rain has made headlines only in the last few years is that scientists have just recently managed to accumulate enough data to begin to appreciate the geographical extent and the severity of the problem. Acid rain is not immediately or obviously damaging and, for this reason, it can be termed an insidious pollutant; ecological consequences only become apparent after enough acid has accumulated, over a considerable length of time, to bring about an observable effect. Many environmentally-concerned people believe that by the time damage becomes blatantly obvious, too much acid will have accumulated for ameliorative action to be taken at reasonable cost to prevent rapid environmental deterioration.

More is known about the effects of acid rain on some sectors of the environment than on others. For instance, a good deal is known about the effects of

Formation of Acid Rain

Acid rain is formed when rainwater is contaminated by acid. Pure water is a neutral compound and, as such, is neither acidic nor alkaline. However, even natural unpolluted rain is not pure water; it is really a dilute solution of carbonic acid — an acid which forms when atmospheric carbon dioxide dissolves into water vapour in the air.

Many compounds can become incorporated in rain drops and some of them, such as soil particles, can make rainwater more basic or alkaline. Other compounds such as sulphur dioxide and nitrous oxides — two of the combustion products of fossil fuels — can dissolve in rainwater and make it more acidic than normal.

Although all the intricacies of the various chemical reactions which take place in the atmosphere during the formation of acid precipitation are not completely understood at the present time, the end result is that the oxides of sulphur and nitrogen are converted to sulphuric and nitric acids respectively. These are *strong* acids which dissociate almost completely in water and have the ability to lower the acidity of rainwater significantly. In fact, the most acidic precipitation yet recorded fell in Scotland in 1974. It was roughly as acidic as vinegar or dilute acetic acid and over *one thousand times* as acidic as natural rain.

acidification of aquatic ecosystems (environments) but much less is known about its effects on terrestrial or land ecosystems such as forests or agricultural crops.

The direct effects of acid rain on human health have yet to be fully described. There is concern that the sulphur dioxide from which acid rain primarily derives can affect the health of people afflicted with respiratory problems. Acidic water passing through metallic pipes can increase copper and lead concentrations in drinking water and even some natural spring waters from areas which have been exposed to heavy acid rainfall have shown elevated levels of lead, copper, aluminum, mercury and cadmium. All these metals can affect human health but the extent of the effects and their associated health costs have yet to be quantified.

Acidic precipitation can also deleteriously affect human artifacts. It can greatly accelerate erosion processes, causing buildings, roads, paint, sculptures and so forth to be aesthetically and functionally damaged with prolonged exposure. The cost of these damages to the urban environment are estimated to exceed $5 billion annually in North America alone.

B. THE CARBON DIOXIDE QUESTION

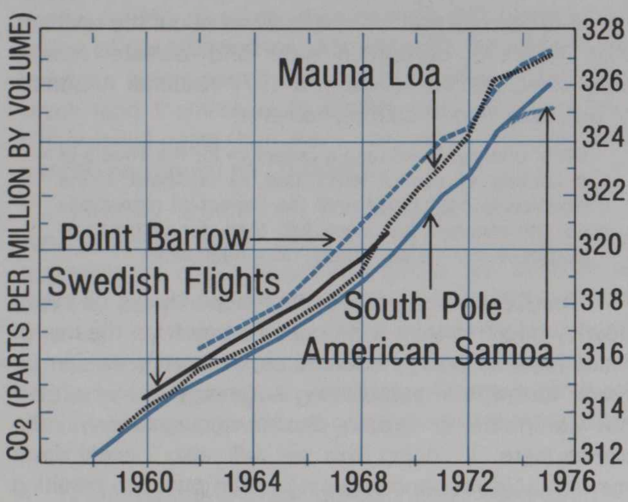
As more and more people discover that acid rain is not a new phenomenon, they begin to wonder why they haven't heard of it before now. There are a number of reasons for this but the dominant one is that in our society little effective long-range planning is done and most environmental problems are ignored until they are perceived as having reached serious proportions. This is precisely what the Committee hopes to avoid by planning an energy future which will not produce difficult ecological "surprises" that will have to be dealt with in an *ad hoc* fashion at some future date.

Thus, enter the "Carbon Dioxide Question". The term "question" as opposed to "problem" is used here because the repercussions of the well-documented and steady increase in the concentration of carbon dioxide in the Earth's atmosphere are, at present, contentious. But in the opinion of the Committee, this is no reason they should be ignored. On the contrary, this is even greater reason to investigate the phenomenon thoroughly and to plan an energy future which does not alter historical environmental balances, so that a potential problem of truly global proportions will not have to be grappled with 20 to 50 years from now. Certainly, a long-term perspective is called for in the case of the carbon dioxide question.

Much of the public has not yet heard about the carbon dioxide pollution phenomenon. But measurement of the concentration of CO_2 in the atmosphere made at a variety of locations, and over a time span dating back to 1958, have clearly and unambiguously demonstrated that the concentration of CO_2 in the atmosphere is rising at a rate of about one part per million (1 ppm is 1 milligram in 1 kilogram) per year (Figure 4-1). To put this figure into perspective, the concentration increased 13.8 ppm in the 15 years between 1962 and 1977 — an increase from 316.2 to 330.0 ppm or over 4%. Since 1850 and the beginning of the Industrial Revolution, the increase has been from around 290 to 330 ppm, or approximately 14%. If the trend of the last 20 years continues or accelerates, the CO_2 concentration could well reach 400 ppm by the year 2000 — a concentration which could begin to change the Earth's climate, perhaps irreversibly.

Historically, there is evidence that the atmospheric concentration of carbon dioxide has remained approximately constant for past ages because a balance existed between (1) the amount of CO_2 being turned into solid organic compounds annually through photosynthesis and the amount being released annually through both plant and animal respiration; and (2) the amount of CO_2 dissolving into or escaping from the oceans. However, it should be emphasized that this balance was achieved with a *small but steady net loss* of carbon from

Figure 4-1: THE CONCENTRATION OF CARBON DIOXIDE IN THE EARTH'S ATMOSPHERE



Source: After Kellogg, 1978, p. 15. Reprinted by permission of THE BULLETIN OF THE ATOMIC SCIENTISTS. Copyright © 1978 by the Educational Foundation for Nuclear Science, Chicago, Ill.

this dynamic cycle over millions and millions of years. The CO_2 which was removed from circulation and stored underground in the remains of once-living organisms is now termed fossil fuel. Thus, when we burn fossil fuels we release carbon which was taken up from the atmosphere by living plants and stored millions of years ago. When we cut down trees we aggravate the problem further because (1) this reduces total photosynthetic activity; (2) the trees release CO_2 when they are burned or decompose; and (3) their removal bares the soil's surface and allows the humus content of the soil to decompose, releasing even more CO_2 to the atmosphere.

Measurements have shown that the annual harvesting of forest biomass releases approximately the same amount of CO_2 as does the combustion of fossil fuels. This means that no great global dependence upon biomass for energy can be tolerated and that for the biomass which is used there must be a policy of *complete replacement.* Unfortunately, this seems to be an unlikely prospect because even without a large-scale commitment to biomass energy the size of the Earth's forests is rapidly diminishing.

It is perhaps difficult for many to think of carbon dioxide as a pollutant because it is a natural and essential component of our atmosphere. But it is not the gas itself which is the problem; it is its atmospheric *concentration* which is potentially environmentally disruptive. This is because there is an intimate relationship between the amount of CO_2 in the air and the Earth's temperature and climate.

The Greenhouse Effect

The atmosphere is composed of molecules we are all familiar with (oxygen, nitrogen, carbon dioxide, water vapour and so forth), but not everyone is aware that these molecules have the ability to absorb energy of certain wavelengths. Most atmospheric gases, including carbon dioxide, are transparent to the relatively short wavelengths of incoming solar radiation; thus much of the incoming energy passes through the atmosphere to be absorbed or reflected by the Earth's surface. At longer wavelengths — the wavelengths at which the Earth reradiates — CO_2 and water vapour are the two main energy-absorbing molecular species in the atmosphere.

When these molecules absorb energy, they cause general atmospheric warming, a phenomenon commonly called the "greenhouse effect" because it is roughly analogous to the warming of a glassed enclosure. A greenhouse is transparent to incoming solar radiation but it impedes heat loss (in this case by preventing convection) and consequently warms up. If the atmosphere warms because of increased energy absorption due to elevated concentrations of CO_2, the surface temperature of the Earth will also rise by means of heat transfer.

The oceans contain a tremendous amount of carbon and they have traditionally been called a sink for or absorber of CO_2, but it is now becoming apparent that the seas may not be the answer to reducing or even controlling the steadily increasing concentration of atmospheric carbon dioxide. (In 1980, the combustion of fossil fuels was expected to release the equivalent of 5.57 billion tonnes of CO_2 (Munn *et al,* 1980) and deforestation probably released an equivalent amount.) There seems to be little dispute that the world's oceanic reservoirs could absorb all the CO_2 man is ever likely to generate, even if he burns the Earth's entire fossil fuel resources. The question is one of time.

Various research techniques have indicated that the rate of turnover of the ocean's thermally stratified waters is very slow. The warm surface waters (some 100 to 200 meters deep) mix with colder deep waters with an exchange time in the order of a thousand years or so. Thus if the surface waters of the oceans did become saturated with carbon dioxide, the removal of elevated levels of atmospheric CO_2 could take an amount of time in the order of several human lifetimes.

What will the effects of this carbon dioxide accumulation be? Scientists indicate that if the air's concentration of CO_2 were to double, this would have the potential to raise the Earth's mean temperature by a few degrees Celsius. Few seem concerned about this possibility because they perceive such a change to be relatively minor. Indeed, it is difficult for Canadians, who commonly experience temperature changes of from 10 to 20 degrees Celsius within a matter of hours or days, to be convinced that a one to three degree change in the global mean temperature over a period of 20 to 70 years could be of any major significance. But such a modification could be most significant indeed. Increases in temperature would vary with latitude and although the increase at the equator might be insignificant for a two to three degree mean global rise, temperatures near the poles might increase by as much as 10°C. Thus it has been suggested that the melting of the polar ice caps could be triggered by a mean global temperature rise of only one to three degrees Celsius. In fact, from the peak of the last glacial period (20,000 to 16,000 years ago) to the peak of the warm interglacial period we are presently living in, the mean temperature of the ocean rose only 2°C and the mean global temperature rose only 5°C.

There are many arguments to counter the idea CO_2 will radically alter climate but on one point there is universal agreement. CO_2 accumulation in our atmosphere does pose a *potential* environmental or climatic threat.

Few predictions call for carbon dioxide to have significant climatic effects before the year 2000 but it should be noted that *there are no currently-known feasible methods to bring about a significant reduction in the amount of carbon dioxide already released should CO_2 accumulation prove to be a real problem with an unacceptable environmental impact.* This is most disturbing because the lead time for substituting alternate energy sources for fossil fuels is measured in decades; the cost of the transition is essentially incalculable; and each alternative should itself be examined for potential unacceptable environmental impacts.

Scientists do not know exactly what a warmer climatic regime would be like. Most agree that it would be wetter in general but some areas, such as the interior of North America, might become much drier. This could have extremely serious consequences in Canada if our grain-producing lands became too dry to support agriculture. In addition, shifting of the growing region north as temperatures moderate would not compensate for this loss as the northern soils are too infertile to support intensive agriculture. In any event, changing the length of the growing season and altering traditional precipitation patterns would almost certainly disrupt established agricultural practices. Man might eventually harvest even more food with a warmer and wetter climate but the confusion which would ensue following major changes could bring about a long sequence of lean years during adaptation. This is not a cheery prospect for a world which already has too many hungry people.

It is obvious that many questions about the relationship between carbon dioxide and climate remain unresolved. As the words of a 1977 National Academy of Sciences Report caution however:

> Unfortunately, it will take a millenium for the effects of a century of use of fossil fuels to dissipate. If the decision is postponed until the impact of man-made climate changes has been felt, then, for all practical purposes, the die will already have been cast.

The Committee believes that steps should be taken now to begin to take this country away from the use of fossil fuels as energy sources so that progress can be made forthwith in establishing an energy mix which will not contribute to carbon dioxide accumulation in the atmosphere. In doing this we will also benefit from curbing acid rain and reducing urban pollution resulting from the use of gasoline and diesel fuel in the transportation sector.

We recognize that Canada's contribution to the global output of CO_2 is small but a start at reducing carbon dioxide emissions has to be made somewhere. Canada has a wealth of alternative energy sources available for development and is thus admirably suited for demonstrating to the rest of the world that an economy can be run on energy sources other than hydrocarbons.

4. DIVERSITY IN ENERGY SUPPLY

People often make the misrepresentative statement that we are in an oil crisis. We are not — at least at the moment. But since so much of our energy is derived from petroleum and since we cannot meet demand with domestic supply, we are in a precarious position. This realization has hopefully taught us that overdependence on any one finite source of supply is shortsighted and foolhardy. Certainly the Committee has concluded that one important characteristic which should be aimed for in a new energy policy is a greater diversity in energy supply.

At present, Canada's energy future is not certain. For instance we do not know to what extent the political and economic climate in years ahead will permit the development of our oil sands resources or of our nuclear-electric potential. Nor do we know the speed with which the technology of some of the alternatives discussed in this Report will be commercialized. Similarly, we do not know when fusion technology will be demonstrated as technically and economically feasible. Reducing these kinds of uncertainties is important if adequate and appropriate investment in energy is to be realized.

Achieving a more diverse and flexible energy system will not be without its attendant problems and costs — diversification will require large investments of capital for the research, development and commercialization of the alternatives. For example, equipment and buildings which permit the use of a range of fuels and which lend themselves to flexible uses likely will have higher initial costs than more specialized fuel- and use-specific equipment and buildings.

Diversity should not, however, be regarded as a desirable objective in itself. We must avoid spreading our research and development efforts too thinly in an effort to develop a myriad of energy technologies some of which may not be practical or economic. Nor should we sacrifice the economics inherent in centralized plants and large-scale energy transmission systems when these can serve large populations and industrial activity at the least cost.

Perhaps the greatest difficulty encountered in constructing a more diverse energy system will be social adjustment problems. Adjustments in employment will be necessary as industries which produce inefficient or inflexible energy-consuming products are eliminated by economic and political pressures. Income effects and life-style changes are likely.

We feel, however, that the costs of a more diversified energy system will be small compared to the benefits. Environmental quality will be enhanced. Self-sufficiency will permit greater economic stability. Less uncertainty will encourage growth. The moderated influence of monolithic energy supply corporations may permit greater economic freedom for all of us. Furthermore, the flexibility of a diverse energy system will facilitate adjustments to sudden changes in world energy supply and price and promote more rapid adjustment in the domestic energy mix. Conservation will serve as a motivating force in seeking paths to diversification but supply constraints will also encourage us to diversify our energy mix.

Diversification of our energy system may be promoted by following a variety of paths simultaneously. These include the following:

- *Substitutability*: equipment design and the use of fuels which lend themselves to substitutability to reflect changes in prices and supply will be important.
- *Flexible design*: building construction and equipment design should allow for changes in seasonal applications and for changes in life-styles, and should be adaptable to improved technology.
- *Multi-component systems*: will be necessary to take advantage of changes in the availability of energy sources. For example, it may be desirable to have two or even three sources of heat in a house provided this is economically feasible.
- *Ease of retrofit*: design and construction should foresee the need to make fundamental changes to energy systems.

Canada must lay the scientific and policy groundwork to engender a more diverse supply and utilization of energy for the future to exploit the potential of its resources, to improve energy security and to gain experience in energy management. The Committee therefore believes that short- and medium-term energy strategy should avoid an overwhelming dependence on a few energy forms or technologies and emphasize instead the development of diverse energy alternatives.

5. REGIONAL CONSIDERATIONS

From a domestic point of view an alternative energy policy can and must take this country's vast regional differences in energy resources and energy demand into prime consideration. No one source, technology or currency is equally applicable to all parts of Canada and it would be foolish to once again paint Canada one energy colour. Just as a nation benefits from taking advantage of its best opportunities in trade with other countries, so can each region of Canada benefit by developing alternative energy sources and technologies which exploit its particular advantages.

We are not advocating that each region strive for total energy independence, since such independence may be neither feasible nor a wise use of capital resources. We do believe, however, that a better balance than exists today in the domestic supply of energy from region to region is a goal well worth striving for in promoting economic well-being across the country.

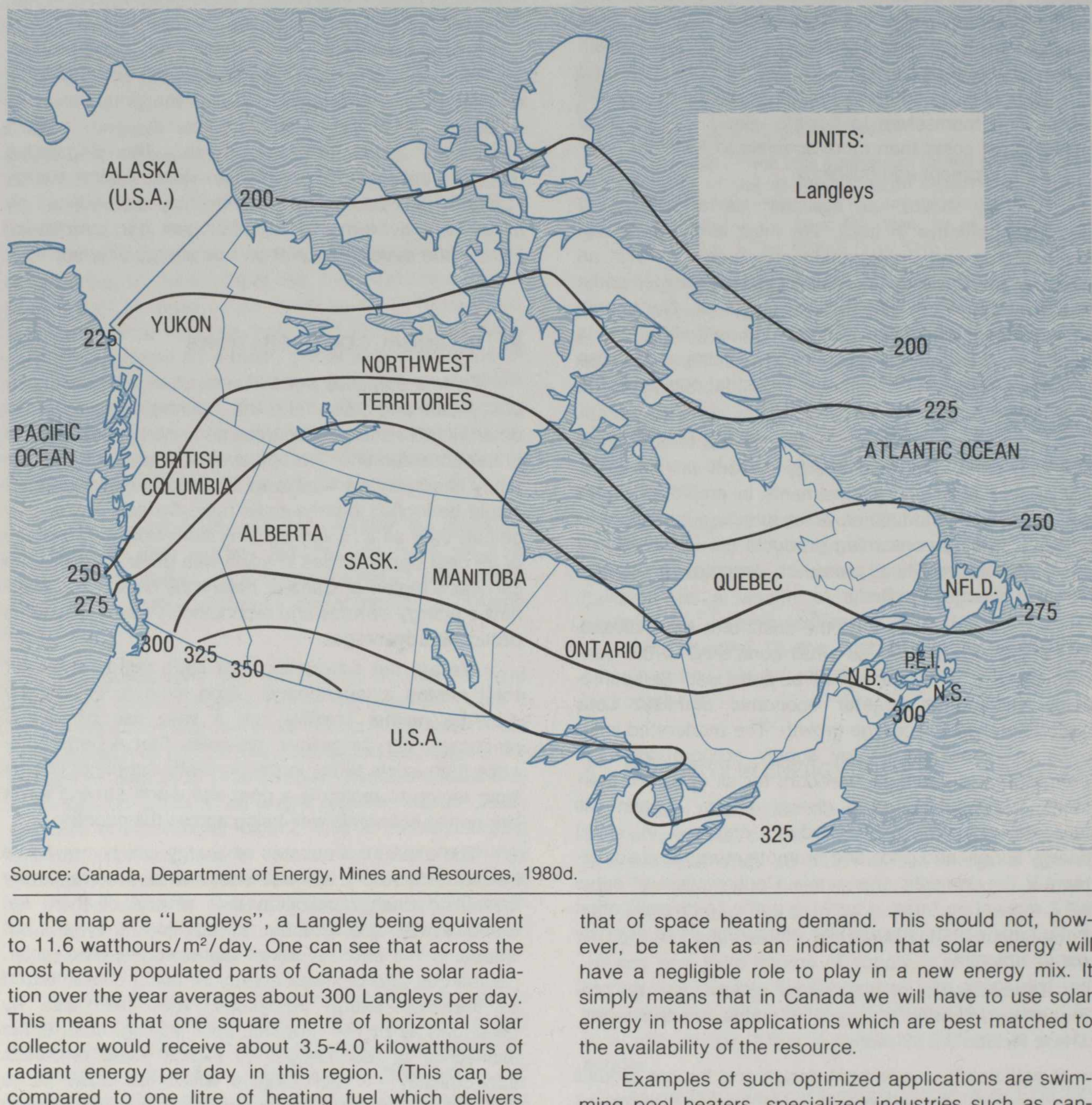
The alternative sources of energy which may figure in Canada's future are well suited to a new, regionally diversified energy policy in that several of them are found across the country. In addition, they are not limited in the strict sense of the word — wind, solar, geothermal and biomass energy all being characterized as immense energy resources. They may also be described as diffuse however, so a limiting factor is the availability of technologies to exploit these resources economically — technologies which will allow us to collect, concentrate and/or convert these resources to meet our energy requirements.

The following maps depict the availability of some of the renewable energy sources across Canada and each is accompanied by brief notes explaining the significant features of the resource.

A. SOLAR ENERGY

Figure 4-2 shows the mean daily solar radiation incident upon a horizontal surface in Canada. The units

Figure 4-2: MEAN DAILY SOLAR RADIATION IN CANADA, MEASURED ON A HORIZONTAL SURFACE AND AVERAGED OVER THE YEAR



Source: Canada, Department of Energy, Mines and Resources, 1980d.

on the map are "Langleys", a Langley being equivalent to 11.6 watthours/m^2/day. One can see that across the most heavily populated parts of Canada the solar radiation over the year averages about 300 Langleys per day. This means that one square metre of horizontal solar collector would receive about 3.5-4.0 kilowatthours of radiant energy per day in this region. (This can be compared to one litre of heating fuel which delivers about 10 kWh of energy.) Of course, only a portion of this energy will be captured by collectors as they vary greatly in their collection efficiency.

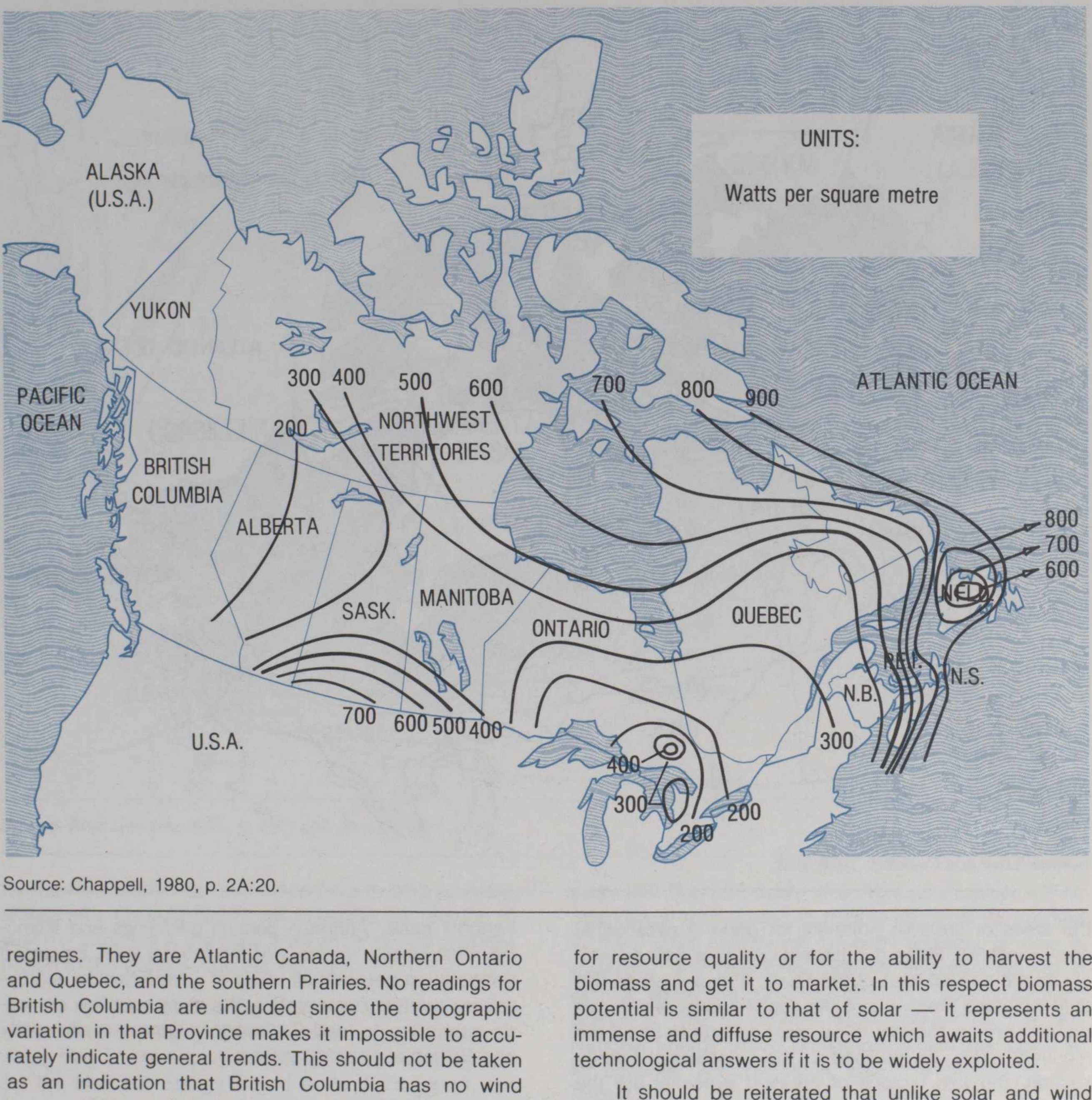
Canada compares favourably with most countries of the world in terms of *average* solar radiation received, but this average value is less important than the seasonal distribution of solar energy. We receive the majority of our solar energy during the long, sunny, summer days and considerably less during short winter days. Thus, unfortunately, the peak in energy supply is opposite to that of space heating demand. This should not, however, be taken as an indication that solar energy will have a negligible role to play in a new energy mix. It simply means that in Canada we will have to use solar energy in those applications which are best matched to the availability of the resource.

Examples of such optimized applications are swimming pool heaters, specialized industries such as canning, and greenhouses where crops can be started early to lengthen the growing season. The careful design of collectors, efficient seasonal storage systems, and passive solar structures, all taking the Canadian climate into account, will be necessary if increased and widespread use of solar energy is to be encouraged.

B. WIND ENERGY

The map showing wind energy densities in Canada (Figure 4-3) indicates the areas with the best wind

Figure 4-3: ANNUAL AVERAGE WIND ENERGY DENSITY IN CANADA AT 50 METRES ALTITUDE



Source: Chappell, 1980, p. 2A:20.

regimes. They are Atlantic Canada, Northern Ontario and Quebec, and the southern Prairies. No readings for British Columbia are included since the topographic variation in that Province makes it impossible to accurately indicate general trends. This should not be taken as an indication that British Columbia has no wind energy resource though. In fact, coastal B.C. is seen as one of the areas of greatest wind energy potential. Moreover, in mountainous parts of B.C. there are many sites where winds are funnelled in a way which makes them ideally suited for power generation.

C. BIOMASS

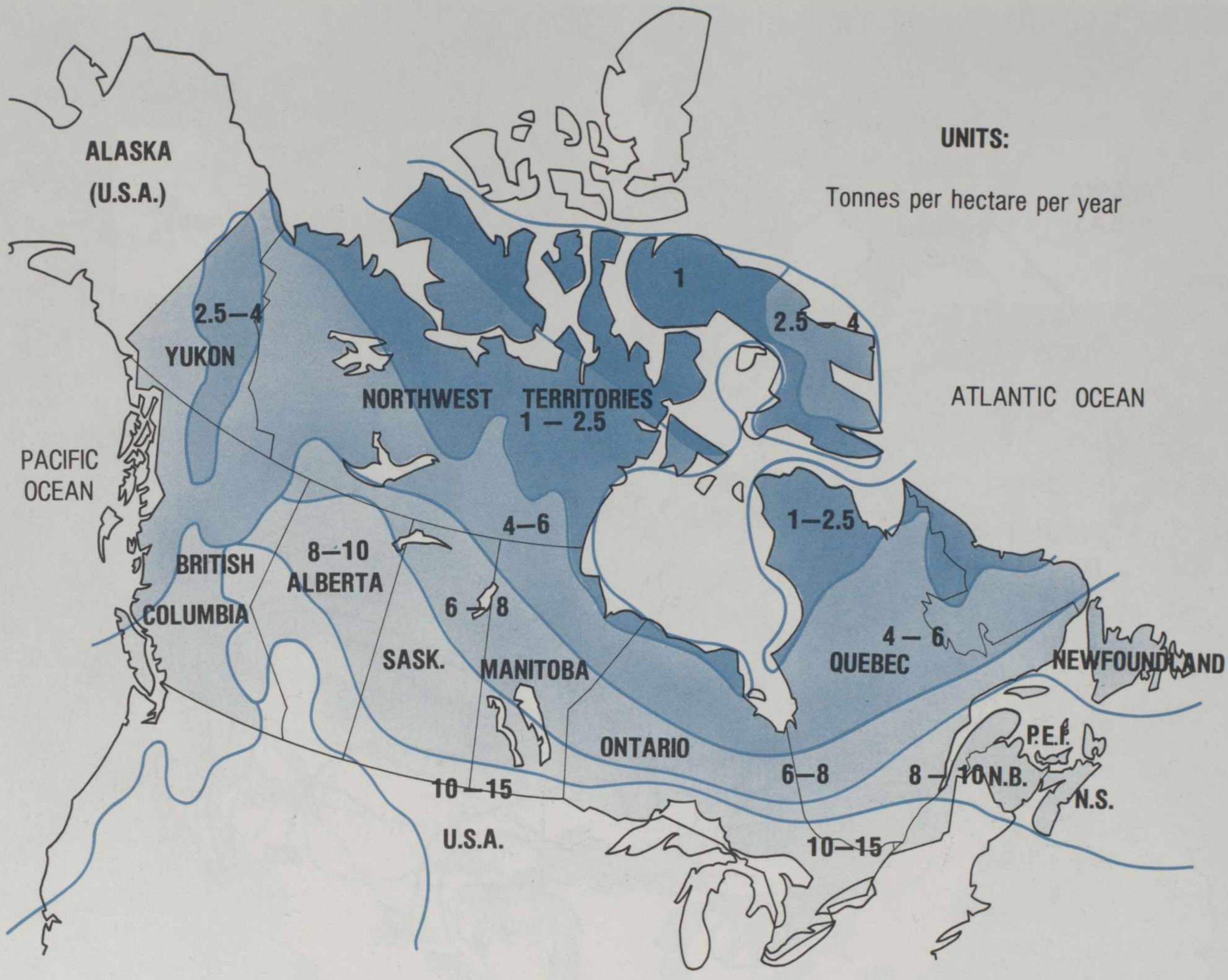
Figure 4-4 presents an estimate of the number of tonnes of biomass which are produced per hectare per year in Canada. This is a very generalized illustration and, while it indicates productivity, it in no way accounts for resource quality or for the ability to harvest the biomass and get it to market. In this respect biomass potential is similar to that of solar — it represents an immense and diffuse resource which awaits additional technological answers if it is to be widely exploited.

It should be reiterated that unlike solar and wind energy, the exploitation of biomass potential requires careful management of the resource. The sun will always shine and the wind will always blow regardless of how we try to exploit them, but when an area is harvested for the biomass it supports today, it must be properly managed to ensure that the resource will be renewed.

D. GEOTHERMAL ENERGY

The map presented for geothermal energy (Figure 4-5) differs from the previous three in that it does not attempt to quantify the size of the resource. It outlines

Figure 4-4: BIOMASS PRODUCTIVITY ZONES IN CANADA



Source: Love and Overend, 1978, p. 8.

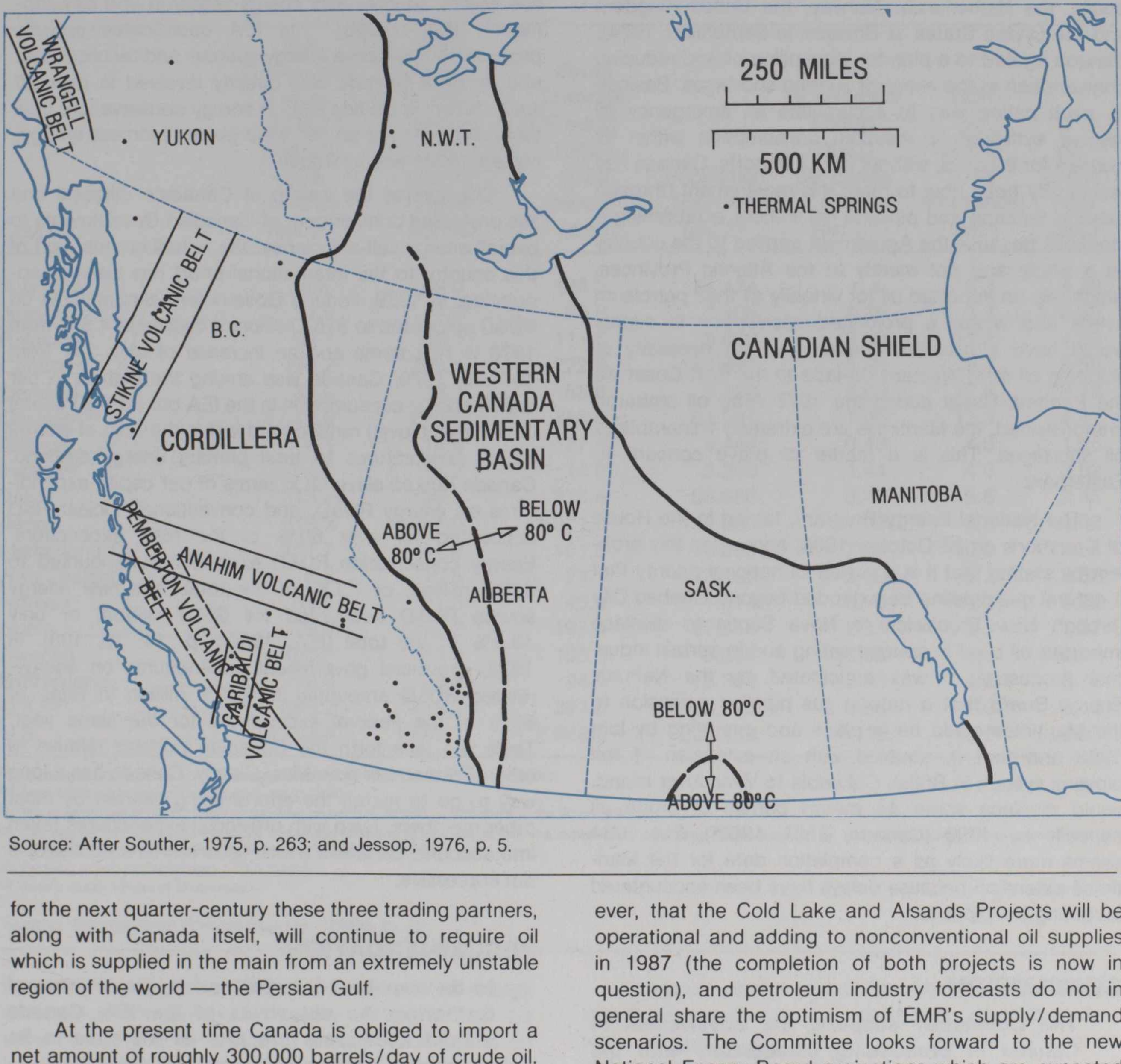
the areas of greatest potential for deriving geothermal energy instead. Since geothermal energy is defined simply as the natural heat of the Earth, a map such as this only indicates areas where the useful energy which can be recovered is thought to be great enough to offset the recovery effort. As outlined in the Geothermal Energy section, the two regions of greatest potential are the area of geologically recent volcanism in British Columbia and the Yukon, and the Western Canada Sedimentary Basin underlying the Prairie Provinces.

Whatever the local resources available, rising energy costs across Canada and incentives that encourage the development of new sources of energy will contribute to energy supply and demand developments. An unbiased approach will recognize regional differences and allow each area to use funding to develop what they perceive to be their best options. Incentives for alternative energy development should not, however, discriminate against the various options available on a national basis. Although general guidelines and financing must largely originate at the federal level, increased cooperation between all levels of government in energy-related matters is imperative. We must not allow domestic quarrelling to lead Canada into unnecessarily costly and Balkanized energy options.

6. STRATEGIC CONCERNS

Canada, whose people represent but one-half of 1% of all mankind, appears to the rest of the world as a thinly-populated nation which is affluent and largely self-sufficient in natural resources. This nation does not flourish in splendid isolation however. On the contrary, it is dependent for a large percentage of its GNP on foreign trade, trade which is mainly conducted with the United States, Western Europe and Japan. Canada's economic well-being is, therefore, tied to the prosperity and security of these three regions. The problem is that

Figure 4-5: GEOTHERMAL POTENTIAL IN WESTERN CANADA



Source: After Souther, 1975, p. 263; and Jessop, 1976, p. 5.

for the next quarter-century these three trading partners, along with Canada itself, will continue to require oil which is supplied in the main from an extremely unstable region of the world — the Persian Gulf.

At the present time Canada is obliged to import a net amount of roughly 300,000 barrels/day of crude oil. According to the supply and demand figures projected by the National Energy Board in its 1978 report, net crude imports would rise to about 760,000 b/d in 1985 and to 900,000 b/d by 1995, in its base case estimate. In a subsequent forecast and responding to world price increases to mid-year 1979, the Department of Energy, Mines and Resources projected that the crude shortfall under then-current policy would grow to 640,000 b/d in 1985 and thereafter decline to 335,000 b/d by 1995 (Canada, EMR, 1979b). The National Energy Program, which makes an unprecedented commitment to modifying demand, foresees net imports of 260,000 barrels/day in 1985 and oil self-sufficiency attained by 1990 (Canada, EMR, 1980e). This projection assumes, however, that the Cold Lake and Alsands Projects will be operational and adding to nonconventional oil supplies in 1987 (the completion of both projects is now in question), and petroleum industry forecasts do not in general share the optimism of EMR's supply/demand scenarios. The Committee looks forward to the new National Energy Board projections which are expected to become available soon after the tabling of this Report.

In 1980, almost 63% of Canada's imported crude oil was purchased from Saudi Arabia and 25% came from Venezuela. Iraq and Kuwait each supplied approximately 3.5% of our import needs and Mexico has begun to deliver small quantities of crude oil to Canada. Thus more than two-thirds of Canada's imports are shipped from the Persian Gulf via the Cape of Good Hope in vessels not of Canadian registry.

Defences against interruptions in this supply of crude oil are limited and weak. Under the International Energy Agreement (signed by Canada, Belgium, Denmark, West Germany, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, the United Kingdom and the United States at Brussels in September 1974), Canada agreed to a plan for stockpiling oil and reducing consumption in the event of sudden shortages. Basically, each nation was to accumulate an emergency oil reserve sufficient to maintain consumption within its borders for 90 days, without net oil imports. Canada has technically been able to meet this requirement (through existing tankage and pipeline fill) without establishing a stockpile because the Agreement applied to the country as a whole and not merely to the Atlantic Provinces, which rely on imported oil for virtually all their petroleum needs and where a prolonged interruption in supply would have a profound impact. As the necessity of shipping oil from Western Canada to the East Coast via the Panama Canal during the 1973 Arab oil embargo demonstrated, the Maritimes are extremely vulnerable to oil shortages. This is a matter of grave concern to Easterners.

The National Energy Program, tabled in the House of Commons on 28 October 1980, addressed this problem by stating that it is a matter of national priority that a natural gas pipeline be extended beyond Quebec City through New Brunswick to Nova Scotia to displace imported oil used in space heating and in certain industrial processes. It was anticipated by the National Energy Board that a natural gas pipeline extension to the Maritimes could be in place and operating by late 1983 and that it, coupled with an extension of the pipeline system in British Columbia to Vancouver Island, could displace some 44 million barrels of crude oil annually by 1990 (Canada, EMR, 1980f). But 1984 seems more likely as a completion date for the Maritimes extension because delays have been encountered in routing the pipeline.

CONCLUSION

The Committee supports the Government of Canada in proceeding immediately with the construction of a natural gas pipeline to the Maritimes. This should be an energy project of first priority in the effort to diversify our energy system and to reduce Eastern Quebec's and the Maritime Provinces' overwhelming dependence on foreign crude oil.

In the realm of alternative energy, Canada participates in RD&D through its membership in the International Energy Agency (IEA). The IEA has operated since 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) and has as one of its basic aims, "co-operation among IEA Participating Countries to reduce excessive dependence on oil through energy conservation, development of alternative energy sources and energy research and development" (IEA, 1980b). The IEA coordinates specific projects on alternative energy sources and technologies, and in 1979 Canada was directly involved in over 20 such studies, including R&D in energy conservation, coal technologies, solar power, wind power, biomass energy, nuclear fusion and hydrogen.

Considering the wealth at Canada's disposal and the professed commitment of Canadian Governments to overall energy self-sufficiency, the actual contribution of this country to the international effort has been disappointing. In 1979, Federal Government expenditures on RD&D amounted to $163 million, a decline of 4.5% from 1978 in real terms and an increase of only 3% from 1974. In 1979, Canada was among the highest in per capita energy consumption in the IEA but (at the Federal Government level) ranked third last in the ratio of energy RD&D expenditures to total primary energy demand. Canada ranked eleventh in terms of per capita expenditures on energy RD&D, and conventional nuclear R&D accounted for over 60% of the total expenditure. Energy conservation RD&D expenditures amounted to $12.5 million, or 7.7% of the total, and new energy source RD&D accounted for $21.7 million, or only 13.3% of the total (IEA, 1980b, p. 14, 19, 109). In 1978, provincial government expenditures on energy-related RD&D amounted to $99.9 million in total, or 63% of the Federal expenditure for the same year. Table 4-1 sets forth the Canadian position relative to other IEA member countries. Clearly, Canada has a long way to go to match the efforts being exerted by most other members. Even with provincial expenditures taken into account, Canada's effort, while more respectable, is not impressive.

RECOMMENDATION

In its own best interest and in the interest of furthering the objectives of the IEA, Canada should accelerate the rate of increase in its alternative energy RD&D expenditures.

7. SOCIAL CONCERNS

The lives and livelihoods of all people are unavoidably affected by energy concerns. Canadians in particular are especially affected because they use energy intensively for a number of reasons. The extremes of temperature experienced annually in this country are one factor and the broad geographical extent of our land and the fact that it is sparsely populated are others. Nevertheless, no matter where one lives, basic human requirements for food and shelter can only be met through the expenditure of energy. This is not to say,

Table 4-1: ENERGY-RELATED STATISTICS FOR IEA MEMBER COUNTRIES, 1979

Country	IEA Government Energy RD&D Budgets (US$ millions) (est.)[a]	Total Primary Energy Demand (TPE) (mtoe)[f] (1978 figures)	Gross Domestic Product (GDP) (US$ billions) (est.)	Population (millions) (est.)[b]	IEA Government Energy RD&D per capita (US$ (est.)[a]	GDP per Capita (US$ thousands) (est.)	TPE per capita (toe) (est.)
Australia	n.a.	69.0	120.5	14.434	n.a.	8.3	4.78
Austria	31.9	24.9	68.9	7.506	4.25	9.2	3.32
Belgium[c]	97.7	46.1	111.5	9.860	9.90	11.3	4.68
Canada[e]	139.2	203.4	222.8	23.691	5.88	9.4	8.58
Denmark[c]	31.0	19.3	65.6	5.120	6.05	12.8	3.76
Germany[c]	1 048.0	270.2	755.8	61.337	17.09	12.3	4.41
Greece	4.1	14.6	37.5	9.444	0.43	4.0	1.56
Ireland[c]	4.7	8.2	14.9	3.256	1.44	4.6	2.52
Italy[c]	213.2	139.5	318.6	56.888	3.75	5.6	2.45
Japan	919.3	357.0	1 021.6	115.880	7.93	8.8	3.08
Netherlands[c]	111.7	64.2	151.8	14.030	7.89	10.8	4.58
New Zealand	8.5	10.5	21.1	3.160	2.69	6.7	3.32
Norway	39.5	21.3	45.3	4.074	9.70	11.1	5.23
Spain	79.3	70.2	197.4	37.554	2.11	5.3	1.87
Sweden	108.5	51.0	103.3	8.296	13.08	12.5	6.14
Switzerland	52.6	23.8	94.1	6.318	8.33	14.9	3.77
U.K.[c,d]	389.2	212.2	391.2	55.783	6.98	7.0	3.80
U.S.	3 783.4	1 842.1	2 349.0	220.415	17.16	10.7	8.36

(a) Exchange rates used are annual averages from the *IMF International Financial Statistics*.
(b) From OECD Main Economic Indicators, March 1980.
(c) The expenditures of the EC Member countries do not include their contributions to the EC programme.
(d) With respect to nationalized industries, the United Kingdom figures include only the expenditures on energy RD&D financed by government funds. Other expenditures by nationalized industries on energy RD&D were £125.8 million in 1979.
(e) Excludes Provincial Government RD&D budgets.
(f) mtoe = million tonnes of oil equivalent.

Source: International Energy Agency, 1980b, p. 18.

however, that consumption of more and more energy automatically improves the quality of life. It must be remembered that in exploiting energy resources in an irrational fashion we can deleteriously affect other parameters, such as the environment, and actually worsen the quality of life. Thus governments, in formulating energy policy, must seriously consider the social effects energy policies will produce.

A good energy policy should strive to ensure that plentiful, affordable energy is available so that the necessities of life can be guaranteed for all. It should at least endeavour to ensure maintenance of present standards of living and it should offer the hope of an even more prosperous future. It must not create unemployment; on the contrary, it should generate jobs and bring people to a greater awareness of how energy affects and, in many ways, controls their lives.

In recent years a new concept has been introduced into the energy debate. This philosophy attempts to deal with energy by concentrating on demand and in so doing divides energy options into two basically different approaches, called "soft" and "hard" energy paths. Soft energy paths are seen as those which restrain demand and enable a society to be based totally or primarily on renewable forms of energy and decentralized sources of supply. A major commitment to conservation is thus an integral part of the soft energy option since demand must not rise beyond a level which renewable energy sources can handle. All other approaches to energy policy which deal primarily with energy supply, and which presuppose large centralized facilities, are called hard energy paths.

The Committee feels that such an arbitrary division of energy policy options is unnecessary. In fact, it can confuse the issue by making the general public feel that we are in an either/or situation — one must choose one route or the other in a mutually exclusive fashion. We believe that Canada is going to need a range of options extending from small, decentralized renewable energy sources to large, centralized sources of supply to meet demand. We further believe that conservation should be a cornerstone of any energy policy, regardless of whether that policy is described by some as soft or hard. No matter what our future sources of supply will be, in the short run conservation is the first priority in addressing the energy problems we face.

In terms of renewable energy sources, we do not yet know enough about each of them to be able to conclude definitively how much energy each will be able to supply. For example, it is difficult to assess what social ramifications a headlong plunge into large-scale use of biomass energy would have and therefore we cannot accurately assess how much energy this alternative source could realistically provide. Similarly, there are still a number of questions about what the effects of large-scale solar energy use would be — what are the material, energy and space requirements for a large number of solar installations — so we do not know how much energy solar will ultimately supply.

We believe that before any government can decide on the individual roles alternative energy sources and technologies can play, a great deal of research and development must still be done to answer questions such as those described above. This Committee believes that more RD&D in alternative energy sources and technologies should be proceeded with immediately — not because we advocate either a soft or a hard energy future, but rather because we see an urgent necessity for gaining greater insight into the options Canada should develop in the future.

Undoubtedly, one great step towards making this country more energy responsible will be to make everyone conscious of the amount of energy he or she consumes, how this energy was exploited and what the actual economic, social and environmental costs of its use are. And, since the Committee feels conservation is one of the most important aspects of an alternative energy policy, it is *essential* that the public become much more energy-aware. This can be done by increasing efforts to educate people about how and how not to use energy, and by giving people a "hands-on" feeling for energy — which can be illustrated by the following example. In apartment buildings which have a flat rate for tenants' electrical consumption there is no incentive to turn off lights and electrical appliances when they are not in use. However, when individual metering is installed in multi-unit buildings, overall electrical consumption drops because individuals can see the benefits of conservation reflected in lower electricity bills. Innovations which generate this kind of *feedback* about the consequences of our daily energy decisions are required to help us adjust to using energy more wisely.

Thus, implicit in the energy future envisioned by the Committee is the understanding that Canadians will find it necessary to modify their habits in ways which allow them to consume less energy. Fortunately this type of change already seems to be taking place to some extent. Thousands are switching to smaller cars, people are turning down thermostats, homes are being better built, and there is a return to living in the core of cities. This trend will undoubtedly continue and broaden in the future and, as present values change, smallness and energy efficiency will become the new status symbols.

This trend bodes well for the future because it means citizens are changing habits in a direction which is characterized by decreased energy consumption and heightened environmental awareness. Social developments of this kind are encouraging because they are amongst the prime goals the Committee wishes to foster. Conservation practices and the decentralized production of energy inherent in an expanded exploitation of renewables should allow Canadians to further develop a "hands-on" feeling for their energy consumption.

As the rate of growth in per capita energy consumption in this country declines and the use of alternative energy sources increases, the rate at which large power-generating establishments have to be constructed will diminish. Those large establishments which are required, however, will keep the generation of some energy localized and the benefits to be gained from such installations, particularly the ability to more easily control emissions from a centralized source, will help provide a cleaner environment. In other words, a mixture of what have been described as soft and hard energy options, coupled with accelerated programs of public information, should permit people to become more intimately involved with and aware of how they use energy. In our opinion, this should lead to a better quality of life.

We realize that the transition from a fossil fuel to a renewables-based economy will impose its hardships on energy consumers. Although most Canadians will benefit from increases in secure energy supplies, a greater diversity in energy supply sources, new growth in energy supply and related industries and improved economy-wide energy efficiency, some Canadians may find increases in energy prices difficult to contend with. Nevertheless, *it should be remembered that even today we all pay the cost of subsidizing energy use.* The indirect nature of these costs often deludes us into thinking that they do not exist and that they never will have to be paid, so no wonder the prospect of paying extra for each barrel of oil is distasteful. But the Committee recognizes that price increases will take place and that higher energy costs are inevitable.

In Canada today, oil prices are not based upon the cost of production alone but are regulated at a level below the international price. Energy consumers are thus protected both from high world prices and from sudden changes in those prices. Since the pricing of other energy commodities is linked, either directly or indirectly, to that of oil, Canada's energy system as a whole is governed by politically-determined oil pricing decisions. As the international price increases and as the domestic price rises towards it, as intended in present policy, the prices of other energy forms will also increase.

Along with the direct effect of higher energy prices on budgets, there will be inflationary impacts as these prices work themselves through the entire economy, raising the cost of living for all Canadians. Those Canadians who cannot adjust to the reduction in their disposable income that will come about because of higher energy costs will have to be protected. The shotgun approach to subsidizing lower-income Canadians through regulated oil prices is considered unwise by some, though, not only because this promotes the consumption of oil, which is perverse under present circumstances, but because it gives all oil consumers a subsidized ride. The point is made that higher energy prices are not the only cause of poverty and it is unreasonable to expect energy price regulation to improve or significantly worsen this perennial social problem. Other tools than price regulation exist for redistributing income.

In the transition to more expensive energy, those who are recognized as having difficulty coping with increased prices should be aided directly through the existing system of income supplements. This subsidization should receive a high priority. In addition, there are other benefits associated with providing income supplements for those hit hardest by higher costs — for one, by having more income to spend, those who are subsidized can invest in energy efficiency rather than in more energy consumption.

The promotion of some forms of alternative energy will have a pronounced and universal social effect if that policy brings about increases in food prices — the so-called "food versus fuel" controversy. Any future energy program which utilizes agricultural or food biomass for the production of alternative energy, if it is to replace a significant proportion of the petroleum currently being used, will necessarily require a large amount of land and other resources normally needed in agriculture and silviculture. This is a primary social concern in a world where food production is already insufficient, for a variety of reasons, to meet global demand.

This concern has both domestic and international implications:

- Further pressure on land prices, which have already undergone large increases in recent years (especially in the rural-urban interface), would be undesirable.
- Shifts in production between food crops and fuel crops in response to rapidly changing input costs, demand and profitability could destabilize agricultural prices and incomes. This would be undesirable from the point of view of producers and consumers who have been working toward greater stability in the food system.
- People who suggest that land should be reserved for agricultural purposes point out that there are already large segments of the human family which are under- or malnourished. They feel it is morally indefensible for man to utilize valuable agricultural land to grow crops to produce energy which will be consumed by a relatively small, and already well-fed, segment of the population. Despite the maturation of the "Green Revolution" in some parts of the developing world, foodstuffs produced in Canada provide an important source of supplementary food in certain world markets. Our food production relieves pressure on grain markets and contributes to a moderation in what otherwise might be prohibitively high prices in time of grain shortages. Cellulosic feedstocks such as hybrid poplar seem far more attractive than agricultural foodstuffs as energy crops because they can be grown on non-food-producing land and will thus not necessarily be in direct competition with food crops for prime soil. This would have to be carefully monitored though as energy crops that were profitable on rough or marginal land (Classes 4 to 7 of the Canada Land Inventory, Agricultural Land Classification System) could be even more profitable on higher quality land, which might be nearer energy markets and already served by transportation systems. Legislation might be required to prevent energy feedstock crops from displacing agricultural crops.
- The disparity between the "have" and "have-not" nations may be exacerbated if there is a global shift towards using biofuels. Underdeveloped countries may try to produce such fuels domestically, thus possibly taking food commodities out of production and hence out of international trade. Furthermore, if they try to cultivate energy crops for exportation in a desperate attempt to gain hard currency, this could lead to an increase in the already unacceptable rates of global deforestation and desertification (the spreading of deserts).

At the present time, there is much argument amongst scientists and energy analysts over whether there is a net energy gain in producing energy products such as ethanol from crops. In brief, approximately the same amount of energy is required to grow the crops and convert them to ethanol as is contained in the ethanol itself. But surely this is begging the question; if one has a great deal of difficulty in determining whether a process produces any net energy at all, it is obviously not an alternative which holds much promise for solving energy problems. There is, however, no question about the net energy balance involved in the "fuel" people use; food is essential for survival.

These arguments are countered by those who say the protein content of food crops is not consumed or damaged during fermentation and that developing new and marginal lands for energy crop production may actually increase the world's net amount of disposable protein. Furthermore, they state that this is more to the point since the world is starved of protein, not carbohydrate. The argument sounds convincing — at first — but further thought raises some serious doubts. This scenario would probably not, in fact, ever come about because the protein-containing dry distiller's grains produced during fermentation will almost certainly be used for animal feed in the developed countries producing ethanol. In fact, it is unlikely the protein would ever reach those peoples who desperately require it, at least not as long as the developed world continues to demand a large quantity of *animal* protein in its diet.

It appears that regardless of how attractive the biomass energy route appears to some, producing energy products from food crops on a broad scale will almost certainly lead to increased prices for agricultural products and to world shortages of food. It will probably never do a great deal to mitigate the oil crisis the world is caught up in now, and it will almost certainly exacerbate the food crisis the world is sure to experience in a not-too-distant tomorrow. Energy can be derived from a variety of sources and can be distributed and consumed in the form of a variety of energy currencies. The question thus arises: Why use the food resource, which is essential for one purpose — namely providing sustenance for the human race — for a purpose such as providing energy, when there are alternatives for the latter? One aim of proper resource management should always be to fit the resource to the end-use required. This basic principle may be violated in turning food crops into energy crops.

On the other hand, energy from *cellulosic* biomass, particularly wood, is an attractive alternative energy opportunity in Canada and seems well-suited to making a significant contribution to energy supplies. This is why in Alternative Energy Sources, Currencies and Technologies the Committee recommends that Canada develop methanol from cellulosic biomass rather than ethanol from food crops, for use as a fuel in the transportation sector. (The promise of producing ethanol from cellulose is also attractive but this process requires further R&D at the present time.)

Electricity and Hydrogen in Canada's Energy Future

There are two energy currencies which can be derived from all the alternative energy sources which we have considered. They are electricity and hydrogen. We see these two currencies dominating Canada's energy mix in the long term because they satisfy our criteria for determining the direction a new energy policy should take.

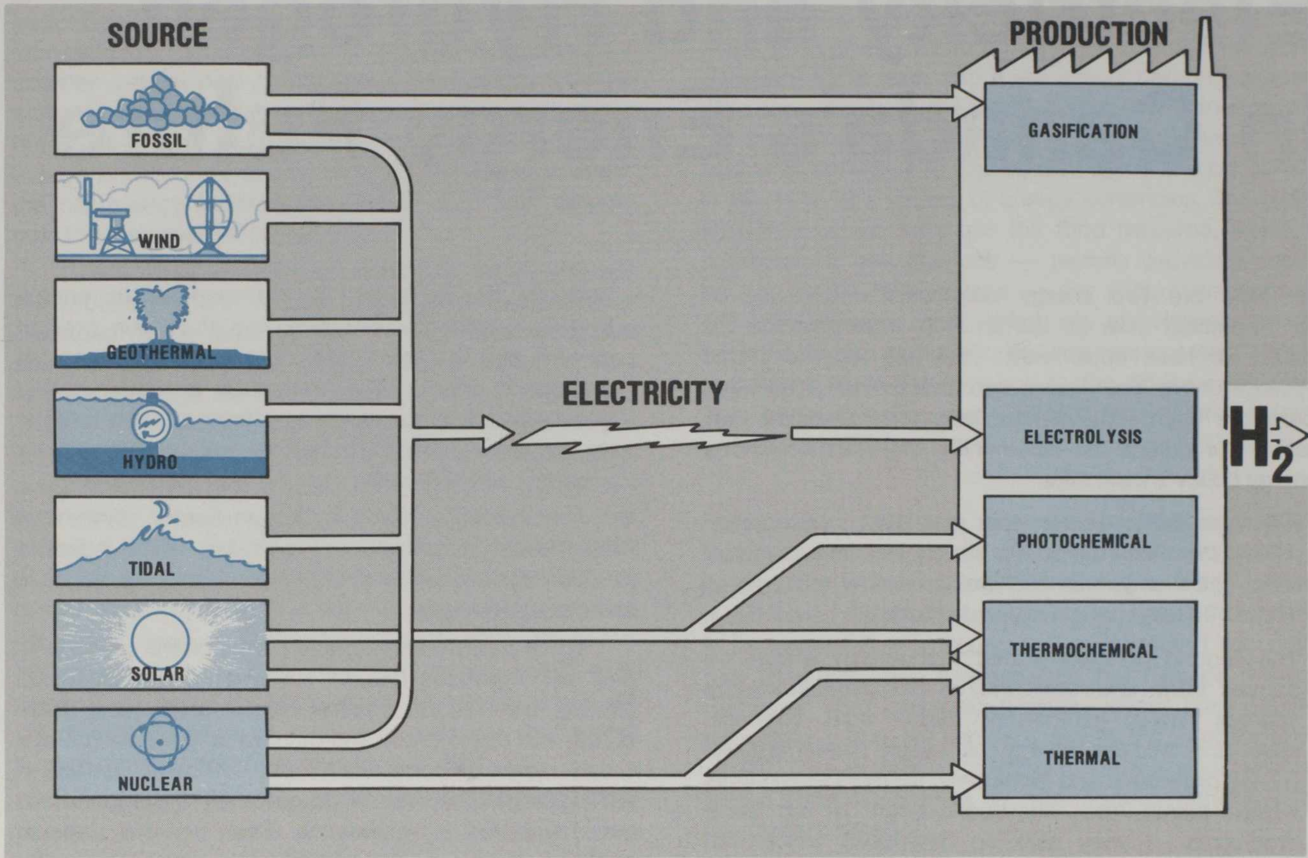
- Consideration number one was that *conservation* should be encouraged. This should be done no matter what the energy mix and simply means that energy should be used judiciously and efficiently.
- The second principle stated that energy should be derived from *renewable* and/or *inexhaustible energy sources*. Wind, geothermal, hydro, tidal, biomass, solar and nuclear energy all satisfy these criteria. (Living organisms and biomimetic systems — systems which mimic the chemical reactions of living organisms — may also be developed which can evolve hydrogen.)
- Third, all of the energy sources named (with the exception of nuclear, the environmental hazards of which have not yet been determined to our satisfaction) are relatively *environmentally benign,* as are the currencies produced (hydrogen and electricity) and as are the "combustion" products of these currencies (water and low-quality heat).
- Fourth, the variety of sources, diversity of production methods, options for storage and transportation, and spectrum of end uses possible for these energy currencies allow development of a system which will indeed be very *flexible.* (Another consideration worth noting in this connection is that electricity and hydrogen are *interconvertible* using electrolysis or fuel cells, further increasing the flexibility of this energy system.)
- Fifth, the resources required to produce hydrogen and electricity are plentiful in Canada, giving us the potential to become completely energy self-sufficient, thereby eliminating *strategic concerns.*
- Sixth, the flexibility of this system coupled with the wide variety of potential energy sources throughout the country ensure that Canada can achieve *regional diversity* in energy supply and demand management.
- Seventh, the facts that a hydrogen-electric energy system would be less polluting than our present system, that this mix would create employment across the whole country and that such a system would generate technological and economic spinoffs through the export of new Canadian technology abroad are excellent *social benefits.*

The flexibility of a hydrogen-electric system is indicated diagramatically in Figure 4-6, which indicates various possibilities for hydrogen production and use in an industrial society.

For a considerable time to come, oil will continue to play an important role in our energy mix since we already have the infrastructure for its production, distribution and use in place and because it is the source of a broad range of convenient fuels. Although Canada is lacking large reserves of light crude oil, our nation does have oil sands in abundance. Thus one way we will continue to meet our unavoidable requirements for petroleum products is through converting our heavy crudes into light oils by adding hydrogen. (The addition of hydrogen increases the hydrogen/carbon ratio of heavy oils, changing them into light oils.) Today the hydrogen required for this process is typically obtained by stripping it from the methane (CH_4) molecule, the main constituent of natural gas. But this practice is clearly wasteful of hydrocarbon resources and we believe that hydrogen produced by electrolysis (splitting of water into hydrogen and oxygen by means of an electrical current) should be used in the future to upgrade heavy oils. In this connection we have an abundance of sites for both small- and large-scale hydro-electric developments in Canada and even remote sites now considered uneconomic could be harnessed to generate electricity which could in turn be used to produce hydrogen.

We have observed the increasing requirement for energy in Canada's energy supply industries — our nation requires progressively more energy to extend conventional energy supplies. This suggests that Canada needs to be more innovative in approaching the supply problem. For example, Canadian utilities will build more thermal-electric generating stations and these stations, bound by the laws of thermodynamics,

Figure 4-6: HYDROGEN: AN ENERGY CURRENCY FOR THE FUTURE

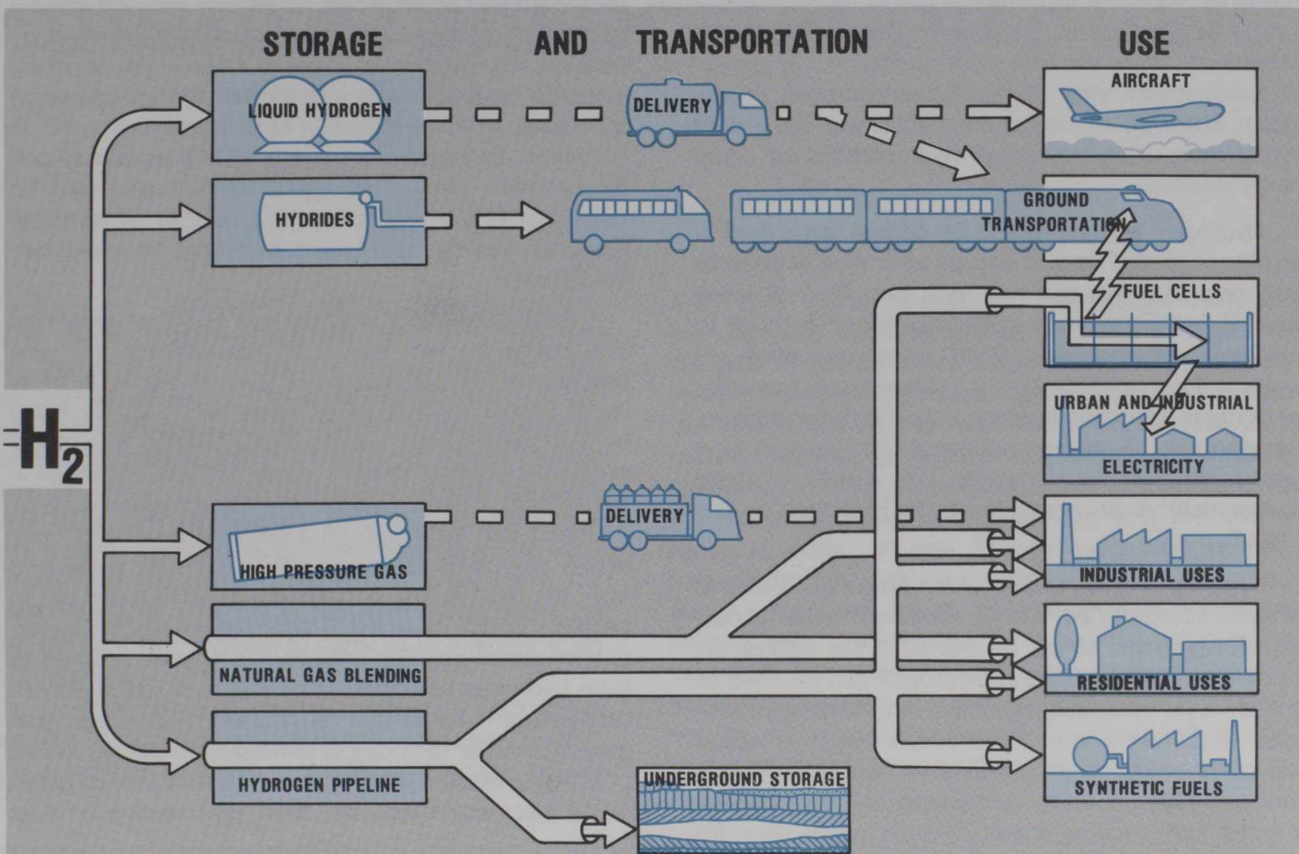


will produce little more than one unit of electricity for each three units of heat input. Locating one or more powerplants over oil sands deposits that can only be exploited with *in situ* recovery techniques would offer the following advantages: the rejected thermal energy from the powerplant could be utilized in heating the oil sand underground to allow heavy oil production, and the electric power could be employed to electrolyze water for hydrogenating the heavy oil produced. By connecting the powerplant/oil sands facility to the regional electric grid and to the gas distribution system, energy balances for the operation could be maintained with surplus electricity used elsewhere and surplus hydrogen blended with the regular gas supply.

Connecting the production of electrolytic hydrogen from remote hydro-electric sites or from on-site thermal-electric stations to Canada's fossil fuel resources accomplishes several goals: our supplies of oil are extended to allow time for the transition to newer energy sources to occur smoothly; in augmenting our domestic supply of light crude we improve our strategic position vis-à-vis oil imports; we conserve natural gas for direct use as an energy source; we acquire experience in generating, transporting and using hydrogen; and we develop a hydrogen infrastructure which will allow us to use this energy currency increasingly as we move off hydrocarbons. Nonetheless, the reader should bear in mind that this discussion does not address the liquid fuels problem of the 1980s; it is an approach for the medium term and longer. Elsewhere in the Report we examine Canada's difficulties in the coming decade.

Electrolytic hydrogen can also be coupled with the production of alcohol fuels from biomass as Canada shifts from an oil-based system — by "spiking" synthesis gas produced from biomass or peat with pure hydrogen it is possible to significantly increase the yield of methanol from a given amount of biomass (see the sections on Biomass and Hydrogen).

As shown in Figure 4-6, hydrogen produced from a number of non-fossil fuel sources can also be used to extend our reserves of natural gas. Up to 20% hydrogen can be added to natural gas without requiring any changes in pumping facilities and furnaces, boilers or appliances that now burn natural gas. The fact that the Federal Government intends to extend the natural gas distribution system through Quebec to the Maritime Provinces means that supplies of natural gas across the country could be augmented by hydrogen. Such a gas



blending scheme would also contribute towards building up our hydrogen-producing capability to parallel a decline in the use of hydrocarbons. Eventually the equipment now carrying and burning natural gas could be converted to utilize pure hydrogen. For environmental reasons, we recommend that the switch to hydrogen occur as quickly as feasible as use of this energy currency would help alleviate the buildup of CO_2 in the atmosphere and help reduce acid rain. Hydrocarbons will be used for decades to come but in diminishing amounts as fuels so that supplies should be sufficient to meet petrochemical and other non-energy demands for the indefinite future.

Canada's hydraulic resources and solar, wind, tidal, geothermal and nuclear energy all fit into a hydrogen/electricity-based energy system. They do not all fit in in the same fashion though. Solar and geothermal energy, which in this country hold their greatest promise for providing space and process heat, will conserve electricity for such applications as hydrogen production. Conservation and good energy management will accomplish the same end. Wind turbines provide high-quality energy but will be limited to regional use in Canada, as will any exploitation of tidal energy. At least in the Province of Ontario, where nuclear energy already provides one-third of the electricity, a hydrogen system will include a large nuclear input. Other parts of the nation may find the development of more remote hydraulic sites to be the best way to proceed. The great advantage offered by an electricity-hydrogen system is that it can accommodate a range of supply options and regional approaches without the need to change the distribution and end-use infrastructure.

So far the only method of hydrogen production which has been discussed is electrolysis. The Committee feels that given the fact that our present and future alternative energy supply options can all be used to produce electricity, and hence hydrogen, electrolysis should and will eventually be the production method of choice in this country. It is also possible to split water and produce hydrogen by the direct application of heat, but only when nuclear fusion reactors with their characteristic high temperatures become available will society be able to achieve this reaction — this option is a very long-term one. Nuclear fission reactors and concentrated solar energy may provide temperatures in the range required for thermochemical hydrogen production, and photochemical reactions (chemical reactions induced by sunlight) may also offer some potential for hydrogen production. One method which is used in Canada today to produce hydrogen is the steam reformation or partial oxidation of crude oil. The latter method is not part of this Committee's view of our future hydrogen energy system, however, as it is not compatible with the goal of moving away from the use of hydrocarbons as future energy sources.

Hydrogen can be stored in several ways and is versatile in its end uses. It can be kept as a super-cold liquid or under high pressure as a gas. Both of these forms of hydrogen can then be transported by truck to their point of end use. When larger quantities are involved, it can also be stored in underground cavities. For portable applications where weight is not a problem, hydrogen can be stored in chemical combination as a metal hydride or liquid hydride. The details of these storage methods are presented in the Hydrogen section of this Report.

If hydrogen is to replace oil it must be applicable to the same sectors of our energy economy. In this respect hydrogen appears to be an excellent fuel option. As depicted in Figure 4-6, liquid hydrogen can be used as an aircraft fuel. This application will require some modification to current aircraft but the high energy-to-weight ratio of liquid hydrogen makes it an attractive option. Work is already underway to demonstrate this technology and it may become one of the early applications for hydrogen, along with the fossil fuel resource extension already noted. Liquid hydrogen is also adaptable to ship propulsion and holds promise for use in ground transportation.

As a metal hydride, hydrogen can be stored for use in buses and probably in trains as well. In fact, a number of hydrogen-powered buses are already operating in the United States and West Germany. Hydrogen gas stored in high-pressure containers is already used in industrial applications, but the real changes in energy use connected with an evolving hydrogen energy system will be in the gradual replacement of natural gas and natural gas-hydrogen blends by pure hydrogen, delivered by pipeline. Hydrogen can replace natural gas in many industrial applications as a boiler fuel, for hydrogenation processes, for the production of fertilizers and so on. In the home, hydrogen can be used to fuel appliances and for providing heat. This useful element can also be employed in the production of a number of synthetic fuels, as already noted, and methanol from biomass feedstock.

Another attribute which makes hydrogen an attractive fuel is the fact that it is clean-burning. The only product of the combustion of pure hydrogen in air is water vapour. In large cities where air pollution caused by petroleum-fueled ground transportation is a major problem, hydrogen offers a handy solution. Hydrogen in the form of a metal hydride or a liquid hydride such as methanol can be stored on a bus or a commuter train. When propulsion is required the hydrogen is evolved from the hydride and combined with air in a fuel cell to produce electricity which in turn runs an electric motor. (Conventional gasoline engines can also be adapted to burn hydrogen.) In cities, large fuel cells which will run on hydrogen and air can be installed to allow electrical generation near the point of consumption without the air pollution problems usually attendant with utilities generating electricity from fossil fuels (see section on Fuel Cells).

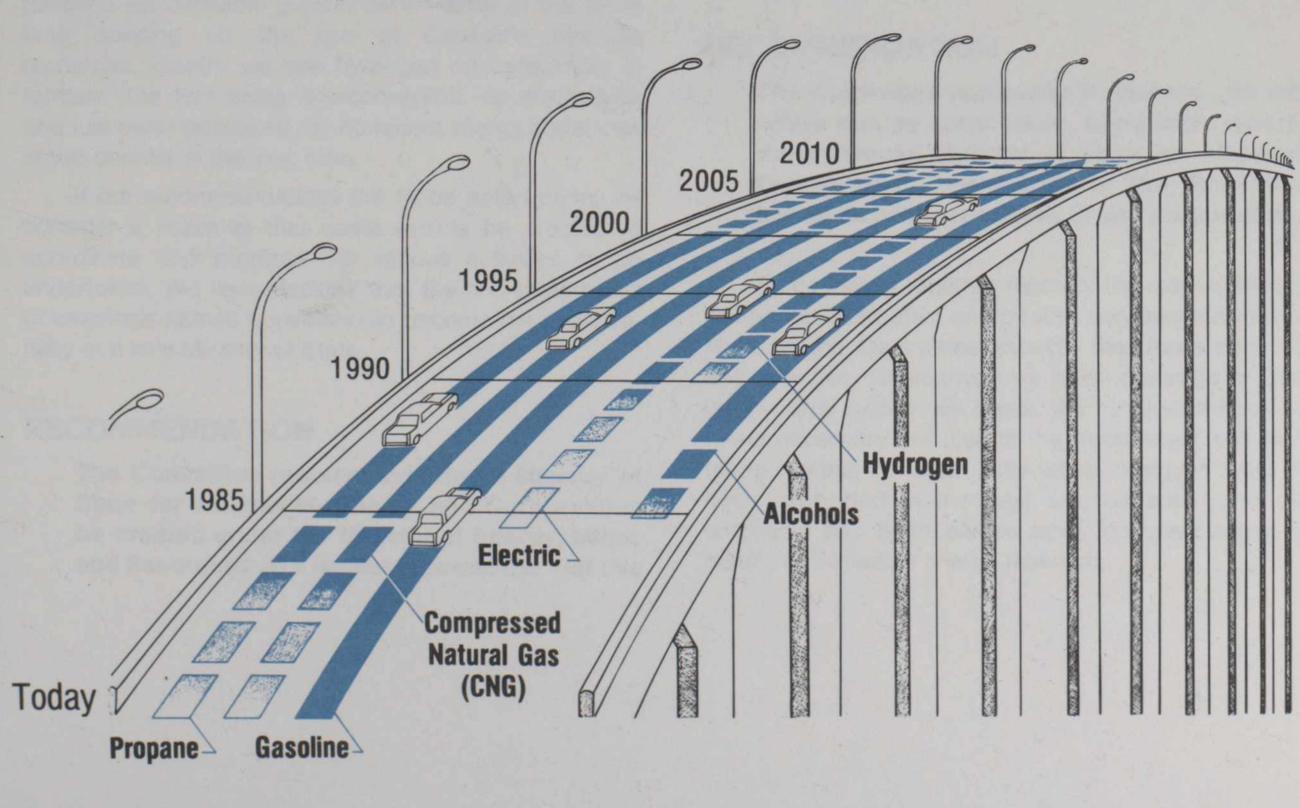
The speed with which an energy system based on hydrogen and electricity evolves will depend on a number of factors, not the least of which will be the political commitment to make it happen. Given the versatility of this energy source and the lack of environmental pollution engendered in its end use, the Committee strongly recommends that Canadian energy policy-makers adopt this energy system as their long-term objective and begin now to move Canada in that direction.

Future Transportation Fuels

We have considered what a hydrogen-electric energy system would look like in a very general way. But what about the specific case of the transportation sector? Transportation accounts for about 50 per cent of the petroleum we use and it has been stated on numerous occasions that the energy problem in Canada derives in large part from our need for portable transportation fuels. This question and specific options are dealt with in some detail in the Biomass, Hydrogen and Non-conventional Propulsion sections but, in summary, the Committee sees a variety of transport fuels coming on over the next two decades to carry us to the time when hydrogen and electricity will dominate.

Gasoline-powered internal combustion engines will continue to power a substantial but diminishing proportion of vehicles up to the year 2000 and beyond (Figure 4-7). They will be smaller and more fuel-efficient but their numbers will have to decline if we are to achieve the goal of getting off oil as an energy source. Some vehicles running on propane and compressed natural gas (CNG) are on the road today and we see their numbers increasing substantially. Most use of these alternative fuels will probably be made in fleets as there are problems in fuel distribution and with the driving range in such vehicles. Propane use may dwindle towards the year 2000 as supplies of this fuel are limited and we therefore see its application in a transitional strategy only. CNG vehicles could be used well past the year 2000 if the decision to do so is made by virtue of the fact Canada is rich in natural gas supplies. However, we do not advocate the very long-term use of this hydrocarbon in the transportation sector.

Figure 4-7: PROPELLING OURSELVES INTO THE FUTURE



Competitive electric cars may become available as early as 1985 but we do not see electric vehicles contributing significantly to Canadian transportation before 1990 to 1995. After this time electric vehicles should become increasingly common as we enter the electric-hydrogen age. We would also urge that careful consideration be given to electrifying elements of Canada's rail transport system.

Hydrogen-powered vehicles may take somewhat longer to come on-stream as a great deal of work must still be done to make hydrogen vehicles a competitive alternative. We do, however, see them having some slight impact as early as 1990 (perhaps in the form of modified internal combustion engines burning hydrogen) with broad penetration, possibly in the form of fuel-cell-powered cars, occurring only around the turn of the century.

Fuel alcohols (ethanol used primarily in gasoline blends and methanol primarily used straight) may have a significant impact on the transportation sector. Methanol cars and the fuel they require could be made available as early as 1985 and if a major commitment is made to go with methanol, this alcohol could become a very important player in the transition to the hydrogen and electric future we have described.

Since methanol can be derived from renewable energy sources such as biomass and since methanol is essentially a liquid hydride (hydrogen carrier), it could continue to play an important role in road transport for the indefinite future. (It is also interesting to note that methanol can be synthesized from CO_2 and hydrogen. Thus this currency fits in well to a hydrogen economy and provides a means of converting waste CO_2 into a utilizable energy commodity. This process would not, however, reduce the concentration of carbon dioxide in the atmosphere.)

Building a Hydrogen and Electric Economy

Taken together, the recommendations contained in this Report constitute a fundamental reshaping of Canada's energy system. Although our proposals span much of the field of alternative energy, there are four areas in which we believe primary emphasis should be laid.

First, an intensified effort in energy conservation is required without delay, especially as this is the fastest and least expensive approach to minimizing Canada's petroleum shortfall in the 1980s. Second, solar energy is a large and promising resource and we are recommending expanded activity in most aspects of solar research, development, demonstration and commercialization. In the next century, solar energy will be an important element in Canada's energy mix, particularly in the provision of lower-quality heat. Third, methanol should become a major player in Canada's energy future because of its attractiveness in the transportation sector. It can extend, and preferably substitute for, gasoline—a desirable goal in itself—while at the same time opening up the use of Canada's biomass resources. Fourth, we see hydrogen and electricity in tandem (the two being interconvertible via electrolysis and fuel cells) becoming the dominant energy currencies in this country in the long term.

If our recommendations are to be acted upon, we consider it essential that some vehicle be created to coordinate and promote the various activities to be undertaken. We have decided that the first three areas of emphasis named above should become the responsibility of a new Ministry of State.

RECOMMENDATION

The Committee recommends that a Ministry of State for Alternative Energy and Conservation be created under the Ministry of Energy, Mines and Resources. We further recommend that this new Ministry be divided into four sections responsible for Conservation, Solar Energy, Methanol, and Other Alternatives.

The fourth area of concentration, dealing with hydrogen, we believe should be coordinated by a new lead agency entitled Hydrogen Canada, as described in the Hydrogen section of the chapter on Alternative Energy Sources, Currencies and Technologies. This agency should have prime responsibility for fostering the development of a hydrogen-based energy system in this country and should report directly to the proposed Minister of State, as is recommended in the Hydrogen section of our Report.

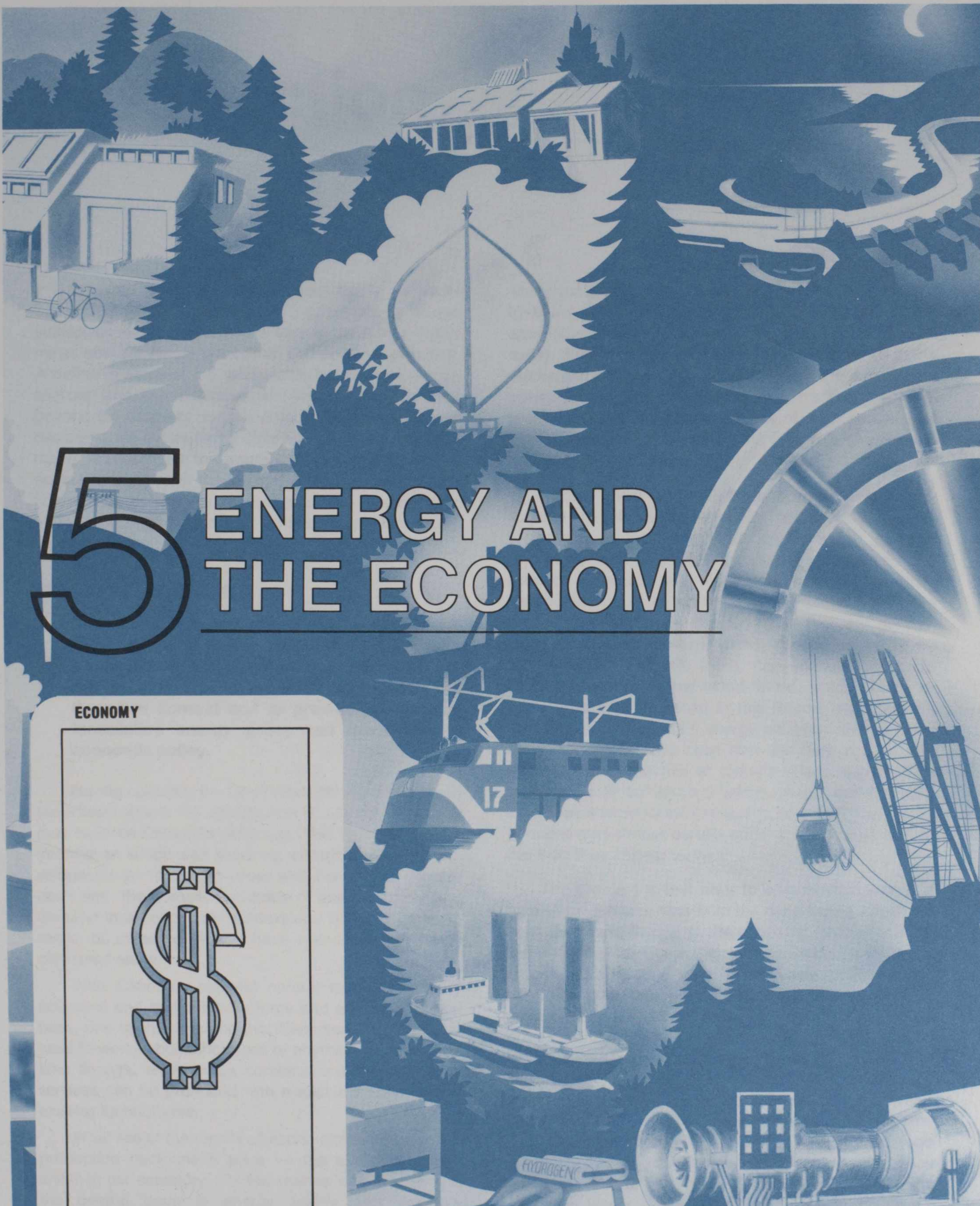
The Committee also believes that the proposed Ministry should oversee most aspects of renewable energy and conservation developments in Canada. This includes the efforts to commercialize new energy forms and technologies.

RECOMMENDATION

The Committee recommends that the new alternative energy corporation, Canertech, report to the proposed Minister of State for Alternative Energy and Conservation at the time that it becomes an independent Crown corporation.

By gathering together much of the responsibility for promoting alternative energy and conservation into one Ministry, the Committee expects that more consistent and effective development of these elements of Canada's energy system will result. We consider this restructuring necessary because of the inconsistent and inadequate manner in which alternative energy RD&D has been supported in the past and because insufficient emphasis has been placed upon commercializing the results of Canadian energy research.

5 ENERGY AND THE ECONOMY



Introduction

Economic considerations underlie nearly all major decisions made by governments and individuals — economics to a very large extent determines how we assess communal and personal priorities. A definitive study of the relationship between all energy sources and the economy requires an analysis well beyond the scope of our mandate, but we would like to declare at the outset that a clearer understanding of this matter is essential in this country. We found the state of economic analysis in the alternative energy field in particular to be lacking in many respects, with existing work often being inconclusive and contradictory. More study is clearly necessary.

RECOMMENDATION

The Committee recommends that the Department of Energy, Mines and Resources initiate a comprehensive study of energy and the economy to clarify this important relationship in the Canadian context and to provide guidance in formulating energy policy and more general economic policy.

Having said this, the Committee did receive input on the effects which the introduction of alternative energy may have on Canada's economy. This input, and other information which was available, contributed to the development of the ideas presented here. This chapter deals with the complicated issue of energy supply and demand in an economic context and brings together a range of ideas which we have not seen collectively discussed elsewhere.

With Canada's plentiful natural resources, highly educated and skilled labour force and extensive capital base, one might conclude that Canadians should never have to worry about shortages of anything. At any given time though, only certain combinations of goods and services can be produced with available resources and existing technologies.

What lies at the root of all economic purchasing and production decisions is price — the allocative mechanism in our economy. For this reason, energy pricing is the central issue in energy supply and demand. Although from the perspective of the economy as a whole the production and supply of alternatives to fossil fuels may make sense (that is, the *social* costs of the alternatives may be lower than the social costs of fossil fuels), these alternatives will only find acceptance in the marketplace if the price at which they are available is competitive with fossil fuel prices. This problem transcends the peculiar characteristics of each new energy form and emphasizes instead the total role of energy in the economy.

Today, most alternatives to conventional energy sources are still being developed. Their economic viability remains to be demonstrated: proponents produce favourable cost estimates for various alternatives and skeptics emphasize their inadequacies. Indeed, as alternatives have yet to carve a significant niche in the marketplace, one may conclude that they are demonstrably not competitive. But this conclusion would be too simplistic. For one thing, conventional energy in Canada is priced below world levels, making many of the alternatives discussed in this Report less competitive. However, Canada's energy situation is constantly changing: prices have risen over the past decade and what is noncompetitive at today's prices may well be competitive at tomorrow's prices. And, with the right incentives and successful research, technological breakthroughs may render certain options much more attractive than they appear today.

The problem is that prior to commercialization it is hard to tell the sure bets from the dead losses. Given the complexity and fluidity of the economy, feasibility studies will not always give the right answers. To illustrate, an analysis may conclude that producing methanol from hybrid poplar plantations on marginal farmland is economically feasible at today's prices. The activity of producing the feedstock may, however, force up the value of the land and consequently the cost of producing methanol. Furthermore, if the cash value of energy crops were perceived to be greater than that of conventional agricultural crops, farmers might convert prime land to energy production, leading to increased food prices and indirectly making methanol appear less attractive. Put another way, economic factors change and most would agree that hindsight leaves something to be desired as an approach to economic planning.

In order to appreciate the role that alternatives and conservation will play in Canada's energy future, it is important to understand the general function of energy in the economy. Therefore this chapter is devoted to a discussion of how energy fits into the economy and how it influences growth, the balance of international payments and employment. The last section provides the philosophical underpinnings for economically wise alternative energy incentives.

Energy Pricing

Although the price of energy is not the only factor affecting alternative energy supply and demand, pricing considerations are crucial to understanding the economic problems associated with introducing alternative energy forms and technologies. In this section we review the recent history of energy pricing in Canada and consider the implications of a range of future prices.

1. ENERGY PRICING IN THE PAST

In today's complicated world the price of energy is determined by factors which go far beyond simple considerations of supply and demand. In addition to the signals of the marketplace, policies and programs of foreign countries as well as those of the Canadian Federal and Provincial Governments determine the price of energy in this country. Since 1973, the overwhelming external factor has been the Organization of Petroleum Exporting Countries (OPEC) which, through supply restrictions and price setting, has increased the cost of oil twenty-fold on the world market within ten years.

In the 1940s, prior to the widespread development of petroleum resources in the Canadian West, the United States was this country's main supplier of oil. This oil was priced on a "Gulf Plus" basis — the price of oil at the Gulf of Mexico plus the cost of transportation to Canadian markets. During the 1950s, the price of oil in Canada was determined in the Chicago-Sarnia interface market, which meant that Western Canadian oil flowing to the Central Canadian market had to compete with the American supply on a Chicago price basis.

Restructuring of the Canadian petroleum market occurred in the early sixties. The Borden Commission on Energy (1958-59) recommended an east-west split in oil markets to foster development of Canada's petroleum industry. The National Oil Policy legislation of 1961 created the "Ottawa Valley Line" with markets west of the line supplied by domestic producers and east of the line supplied by imports. This meant that during the 1960s Eastern Canada was able to take advantage of low world prices ($US 1.80 f.o.b. per barrel for Saudi Arabian light crude throughout the decade) while the western market, including Ontario, paid a domestic price which was on average 25¢-50¢ per barrel higher.

By 1973, Canadian oil prices were again similar to U.S. prices and continued to rise in response to OPEC price adjustments until, on 4 September 1973, the National Energy Board recommended a freeze to protect Canadians from the inflationary impact of rising petroleum costs. In the fourth quarter of 1973 the world petroleum market began to change rapidly. OPEC price increases during, and in the aftermath of, the Arab-Israeli war of that October were such that by January of 1974 the world price of oil had climbed to $US 11.65.

To cushion Canada's economy from this shock, the Federal Government agreed to compensate oil importers for the difference between a pegged domestic price and the imported oil price, through an import compensation program. On 1 April 1974, a federal-provincial agreement established a single domestic price of $6.50 per barrel. A new Federal oil export charge, equal to the difference between the world and domestic prices, was imposed on Canada's oil exports. Periodic increases in wellhead price occurred after 1974 and, on 1 January 1978, the Canadian wellhead price stood at $11.75. A new arrangement was reached in February 1978 between the Alberta and Federal Governments which established increases of $2.00 per barrel each year. That agreement terminated in July of 1980 with the Federal Government allowing a further $2.00 per barrel increase on 1 August 1980. *The National Energy Program 1980* of 28 October 1980 provided for a 1 January 1981 wellhead price increase of $1.00 per barrel, bringing it to $17.75. A further $1.00 increase on 1 July will result in a 1981 average domestic price of $18.25 per barrel.

Canadian and world petroleum prices since 1970 are shown in *current* dollars in Figure 5-1. By the end of 1980, Canada was paying almost $Can 40 per barrel to import crude oil. In real or *constant* (1973) dollars, the world price of crude oil has increased five-fold since 1973 (Figure 5-2). In contrast, the Canadian wellhead price in real terms has not quite tripled over the same period. The increasing gap between the real import and domestic prices demonstrates that Canada has not kept pace with increases in world price over the 1973 to 1980 period. Thus the economic incentive (in the form of higher oil prices) to conserve energy and to introduce

Figure 5-1: IMPORTED AND DOMESTIC OIL PRICES SINCE 1970, IN CURRENT CANADIAN DOLLARS PER BARREL

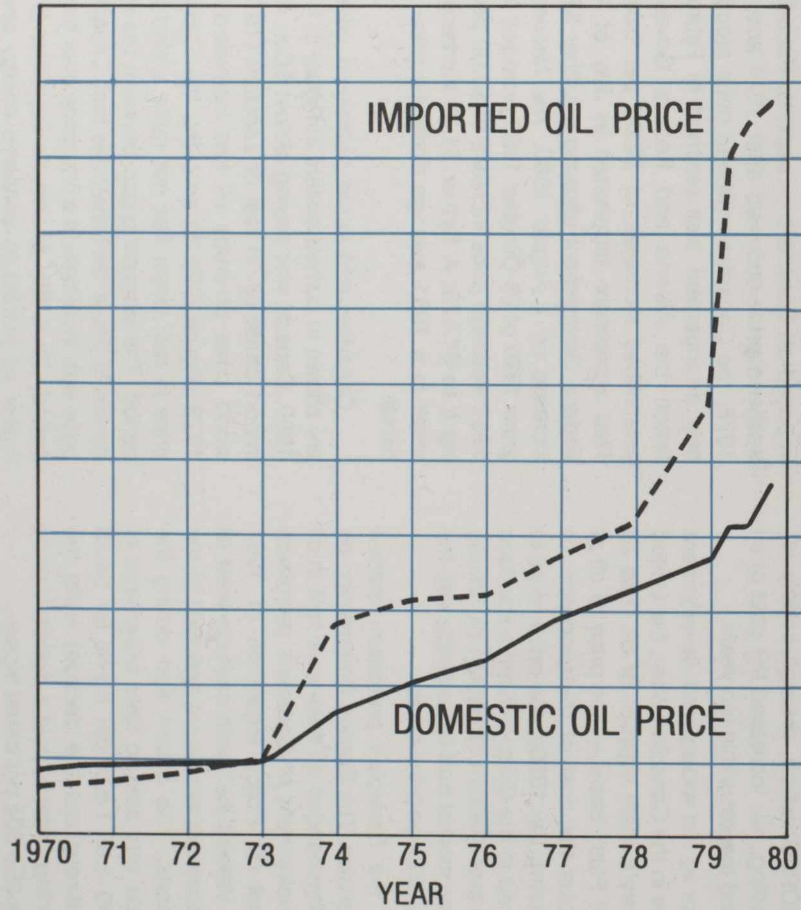
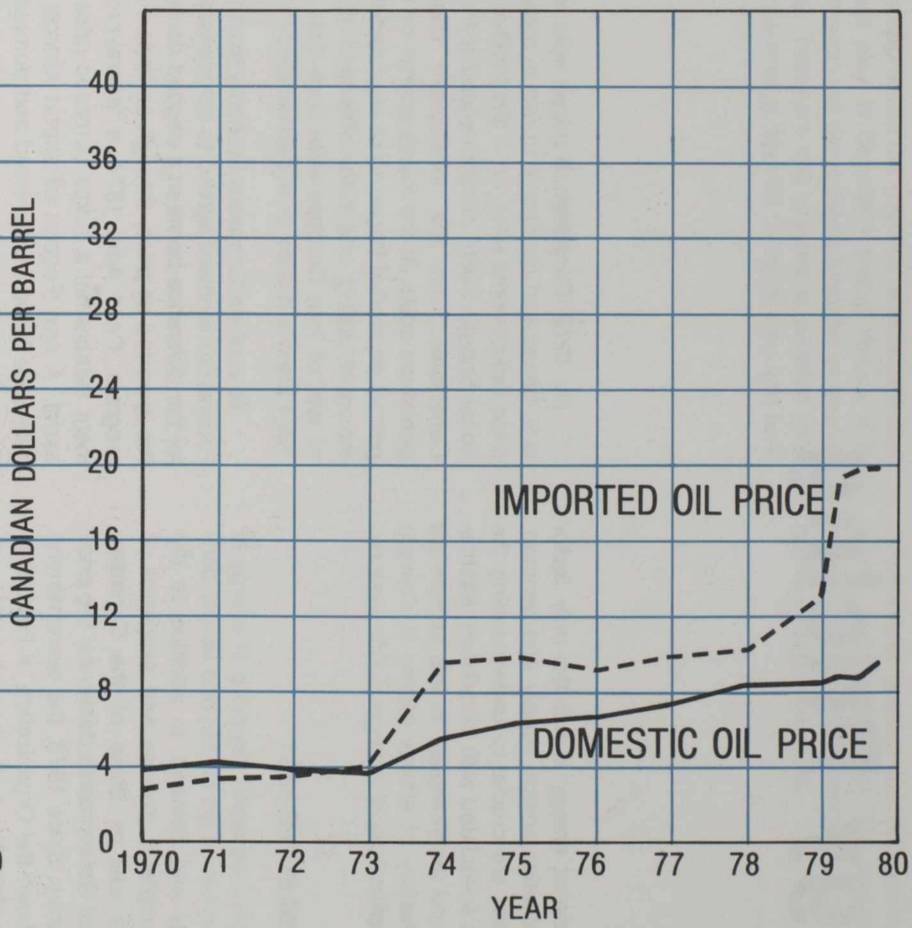


Figure 5-2: IMPORTED AND DOMESTIC OIL PRICES SINCE 1970, IN CONSTANT 1973 CANADIAN DOLLARS PER BARREL



Note: The imported price is the average annual (quarterly in 1980) cost of foreign crude oil landed at Montreal. The domestic price is the average annual (quarterly in 1980) cost of Alberta crude oil delivered to Toronto.

Source: After Canadian Enerdata, 1980.

energy alternatives is increasing more rapidly in other industrialized nations where price increases have been keeping up with those in the international market. If economic incentives continue to favour conventional fuels and energy services, this will work to slow down the introduction of energy alternatives in the Canadian energy system. The strategy laid out in *The National Energy Program 1980* indicates, however, that government policy is now somewhat less concerned with protecting oil consumers and more with establishing Canada's petroleum self-sufficiency.

The real price of gasoline (in constant 1971 dollars) — which is a composite of wellhead price, transportation charges, refining and marketing costs, and federal and provincial taxes — declined in the postwar period until 1973, then stayed relatively stable until the late 1970s, and is now increasing (Figure 5-3). We pay about the same price for gasoline today as in 1955, in constant dollar terms. Anyone now driving a more efficient car about the same number of miles as then may actually be spending a smaller share of his income on gasoline.

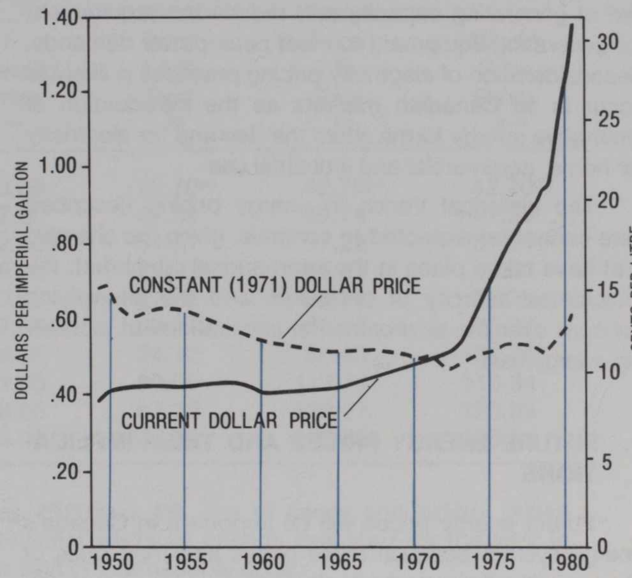
Despite the fact that Canada's reserves of natural gas increased in the 1970s, in contrast to oil, the price of gas has been increasing in step with that of oil. This has been the result of a policy decision in recent years to keep the price of natural gas at about 80% that of oil on an energy equivalent basis, as is indicated in Table 5-1.

The price of electricity in Canada has been rising in recent years as a result of higher rates of inflation and the dramatic rise in the cost of petroleum used for thermal-electric generation. The increased cost of borrowing funds for utility construction has also been of particular significance.

Prior to 1972, electricity prices were relatively stable in Canada (1.1¢ to 2.3¢ per kWh). Between 1973 and 1978, however, fuel costs per kilowatthour of electricity produced in fossil-fuel generation tripled. In the last several years, the overall rate of increase in electricity prices has been less than that of the cost of living in general and has been moderate compared to the Energy Price Index.

Electricity pricing has undergone extensive study in the past half decade. Electrical utilities generally have followed a practice of granting reduced rates to bulk power purchasers. Some have questioned this pricing arrangement, partly because it tends to discourage more efficient use of electricity. This and other aspects of electricity pricing were studied by the Ontario Energy Board between 1977 and 1979. The Board concluded that Ontario Hydro should continue to price electricity so as to cover accounting costs of operation. A pricing system has also been proposed whereby customers are charged less during those hours of the day in which

Figure 5-3: THE PRICE OF REGULAR LEADED MOTOR GASOLINE IN CANADA SINCE 1949



Source: Canada, Department of Energy, Mines and Resources, 1979b, p. 9; and personal communication, EMR, 1981.

Table 5-1: COMPARISON OF CRUDE OIL AND NATURAL GAS PRICES — ANNUAL AVERAGE

Date	Eastern Canada Gas Price ($/Mcf)	Gas Price as a Percentage of Oil[(a)] (%)
1970	0.43	75
1971	0.43	70
1972	0.48	77
1973	0.49	67
1974	0.59	52
1975	0.88	64
1976	1.33	83
1977	1.58	83
1978	1.90	83
1979	2.06	81
1980	2.42	80

(a) $1 per Mcf = $5.80 per barrel.

Source: Canada, Department of Energy, Mines and Resources, 1980e, p. 32.

demand is low and more at times when demand is high (such as late afternoon). Such a system (similar to Bell Canada's rate structure) would encourage a more even use of generating capacity and reduce the requirement for generating equipment to meet peak power demands. Reconsideration of electricity pricing practices is likely to occur in all Canadian markets as the introduction of alternative energy forms alters the demand for electricity for home, commercial and industrial use.

The historical trends in energy pricing described here cannot be expected to continue, given the changes that have taken place in the international oil market, the anticipated scarcity of petroleum and the intensifying concern over the environmental implications of increasing energy use.

2. FUTURE ENERGY PRICES AND THEIR IMPLICATIONS

Future energy prices will be important in Canada's energy system because these prices and their rates of change will influence which alternative energy forms can be commercialized and the timing of their introduction. Also, energy prices will directly influence the quantities of energy consumed and the proportion of incomes available for non-energy consumption and investment. There are limits to the size of the energy expenditure which we can afford and still maintain our standard of living, our commitment to social programs and our industrial momentum. Having some idea of future energy prices, and thus some notion of the proportion of personal and national income which will be devoted to energy in decades to come, is important if we are to plan for our economic future and make appropriate decisions today.

While this Report cannot give any precise timetable for the introduction of alternative energy forms, we can state that the rate of increase in energy prices — particularly oil prices — will influence the rate of development and commercialization of alternative energy. High rates of increase in real oil prices during the next decade will certainly accelerate the process of incorporating alternative energy sources and technologies into our energy system.

Ideally we would like to know in advance what future trends in energy prices will be in order to estimate their impact on the economy and to assess the urgency of developing alternatives. Furthermore, the way in which we go about encouraging conservation will depend on the extent to which higher prices help us reduce the growth in demand for energy. But one cannot know the future and therefore we must examine the various effects which a number of *possible* future energy price trends might have on the energy sector and on the whole economy. In order to project future energy prices, one must assess such pricing determinants as domestic energy policy, demand and supply trends, world economic conditions and political developments. While a broad margin of error may be attached to any forecast of world prices, it is necessary to make some estimation because of the impact that future prices will have on all Canadians.

In the course of its work, the Committee initiated economic analyses using three crude oil world price schedules. These analyses, performed by the Economic Council of Canada, covered the decade of the 1980s. The highest world price schedule considered was based on a 7% annual increase in real terms to 1990. The minimum price schedule thought likely to characterize the present decade was a 1 to 1.5% annual real increase. The third pricing scenario, simulating the type of international price shock which occurred in 1973-74 and again in 1979-80, incorporated a $15 per barrel real price increase in 1986 (superimposed on a 1 to 1.5% annual real increase during the 1980s). Pricing schedules similar to those used in the analyses are included in Table 5-2. The Committee believes that the upper and lower price scenarios represent an envelope likely to encompass future world oil prices.

On the other hand, the future *domestic* price of oil is known with more certainty because *The National Energy Program 1980* has set out a schedule of price increases to 1990. These prices are also included in Table 5-2. The wellhead price of a conventional Alberta crude (38° API gravity) will increase in current dollar terms by almost 300% from 1980 to 1990. This may seem like a large increase but, allowing for inflation, it is expected to roughly represent a 65% real increase in price over the decade. The reader should keep in mind too that these scheduled prices are not immutable; domestic or international circumstances change and the domestic pricing program may have to adapt to new conditions.

The National Energy Program 1980 establishes a pricing regime for natural gas which improves its competitive position relative to oil over the coming three years. This pricing policy will encourage a shift to gas from oil, both reducing Canada's requirement for foreign crude and addressing Western Canada's excess natural gas productive capacity. As part of this program, the Federal Government will set city-gate prices for natural gas at the same level in Toronto, Montreal, Quebec and Halifax to promote the extension of the gas distribution system into Eastern Quebec and the Maritimes. The future pricing of natural gas is summarized in Table 5-3.

Prices for electricity are expected to increase at a rate which will be about 1.2% more than the rate of increase in the Consumer Price Index (personal communication, Department of Energy, Mines and Resources, 1981).

Table 5-2: PROJECTED DOMESTIC AND INTERNATIONAL OIL PRICES, 1981-1990
Unit: Current Canadian dollars per barrel.

	Oil Sands Reference Price (a)	Tertiary Oil Price (a)	Conventional Wellhead Price (a)	Blended Price (b)	World Price 1.5% Real (c)	World Price 7% Real (c)	World Price Shock (c,d)
1981	38.00	30.00	18.25	23.30	42.70[e]	42.70[e]	42.70[e]
1982	41.85	33.05	20.25	27.80	47.39	49.74	47.39
1983	45.80	36.15	22.25	32.30	51.91	57.22	51.91
1984	49.85	39.35	26.13	36.18	56.91	65.87	56.91
1985	54.10	42.70	30.63	40.68	62.29	75.72	62.29
1986	58.55	46.20	37.00	47.05	68.04	86.88	93.04
1987	63.20	49.90	44.00	54.05	74.12	99.42	101.35
1988	68.30	53.90	51.00	61.05	80.69	113.71	110.34
1989	73.75	58.20	58.00	68.05	87.79	129.97	120.05
1990	79.65	62.85	65.00	75.05	95.52	148.55	130.61

(a) Canada, Department of Energy, Mines and Resources, 1980e, p. 26. The oil sands and tertiary prices become effective in January of each year; the conventional wellhead price is averaged for the year in question. The oil sands reference price is subject to the limit of international price.

(b) Canada, Department of Energy, Mines and Resources, 1980e, p. 30. The blended price is averaged over the year in question. The Petroleum Compensation Charge of $10.05 is assumed to continue after 1983. Imports are projected to fall to zero in 1990. The blended price will not be allowed to exceed 85% of the international price or the average price of crude oil in the United States, whichever is lower.

(c) Real price increases are in addition to the expected annual rate of increase in the U.S. Wholesale Price Index for 1981-1990, as estimated by the Wharton School in the United States. For example, if the U.S. Wholesale Price Index rises by 10%, the world price increases by 11.5% in the 1.5% real case, and by 17% in the 7% real case. This U.S. price indicator is used because the international price of oil is based on the American dollar.

(d) The world price is calculated to undergo a 1.5% annual real increase in 1982-1990, and a $15 (constant 1980 dollars) shock is added in 1986.

(e) $42.70 is the current, weighted average world price of crude oil delivered in Canada (personal communication, EMR, 1981).

Employing future energy pricing schedules similar to those presented here, the Economic Council estimated their effects on the Canadian economy for the Committee. As expected, it was found that the more self-sufficient Canada is in petroleum by 1990, the lower the rate of inflation; the smaller the Federal deficit; the smaller the current account deficit; the greater the value of the dollar; and the greater both employment and the growth in aggregate output. To the extent that Canada remains dependent upon foreign supplies of crude oil, we are prone to inflation arising from increases in the world oil price. By folding the total cost of imports into the blended price by 1983, the domestic price of oil will rise more than expected if Canada's imports remain large and if the international price undergoes major increases. Clearly, the health of the Canadian economy is improved by eliminating our reliance on oil imports.

The Economic Council's analysis was based upon the price and supply of conventional oil and gas, synthetic oil from the tar sands and possible frontier supplies. This is an appropriate approach since, in the short term, the domestic price of oil will continue to be the reference point for pricing energy in our economy. Energy alternatives will not make a significant change in this state of affairs in the 1980s.

Alternatives will enter the market and become competitive at prices which are about equal to those of conventional energy sources for the same energy services. Nevertheless, we may be willing to pay more for alternative energy because we believe there will be future economic gains and because of less tangible advantages such as security of supply. It is possible to roughly estimate when a given alternative may be competitive with conventional fuels and technologies, depending on the rate of change of conventional energy prices. Although such estimates are highly sensitive to the quality of data and the nature of underlying assump-

Table 5-3: COMPARISON OF FUTURE CRUDE OIL AND NATURAL GAS PRICES UNDER THE NATIONAL ENERGY PROGRAM

Date	Eastern Canada Gas Price ($/Mcf)	Gas Price as a Percentage of Oil[a] (%)
1980	2.42	80
Under the National Energy Program		
1981	2.98	71
1982	3.39	68
1983	3.84	67

[a] $1 per Mcf = $5.80 per barrel.

Source: Canada, Department of Energy, Mines and Resources, 1980e, p. 32.

tions about prices and costs, they can provide some insight into the timing of development in Canada's energy system.

Cost comparisons among conventional energy forms and alternative options, done by Middleton Associates for the Committee, used estimates of equipment efficiencies, system lifetimes, capital and operating costs, and similar parameters to arrive at such estimates. Three conventional energy price scenarios (similar to those used by the Economic Council in its work for the Committee), comprising elements of world and domestic price forecasts, were used in the analysis.

Middleton Associates found in the transportation sector, for example, that methanol could become competitive with gasoline by 1985 if higher rates of increase in domestic oil prices were allowed, but not until the early 1990s if oil price increases were small. Compressed natural gas and propane were found to be competitive as motor fuels today, regardless of gasoline price increases. The main barriers facing these two fuels are market readiness in the short term and supply limitations in the longer term.

As a substitute for oil in electrical generation, coal combustion using fluidized bed technology was considered to be economical with either high or low oil price increases. Wind turbines, on the other hand, may not be economical until 1990 if the rise in the domestic price of oil is small.

Among those energy sources analyzed for substitution in residential and industrial heating applications, solar water heating appears to be the most sensitive to conventional energy prices. At low rates of conventional energy price increase, solar heating of water may not be economic without incentives until after 1995. The same can be said for heat pumps competing in areas serviced by natural gas (although as a substitute for other fuels, heat pumps are economically preferable now or in the near future). Wood waste as a fuel is preferable, where applicable, through the present decade and beyond, regardless of conventional fuel prices.

Co-generating systems are largely competitive now, although higher rates of increase in oil prices could make oil-fired systems uneconomical towards the end of the decade.

It is accepted by most energy analysts that the real price of energy will continue to increase for a considerable time to come. As conventional energy costs escalate, the alternatives will become increasingly competitive and technological breakthroughs may be expected to lower the real cost of some of them. By reducing our energy requirements, we may also be able to moderate the rate of increase in the total cost of energy services even in the face of rising prices.

The Economics of Energy Supply, Demand and Conservation

We have already stressed that, notwithstanding Canada's present self-sufficiency in energy in an aggregate sense, this country faces a growing shortfall in the commodity that matters most — oil. Minimizing our petroleum imports in the 1980s would be reason enough to institute a vigorous program of energy conservation in view of the economic and strategic problems involved in such dependence. But conservation pays other dividends as well. We already know a considerable amount about energy-conserving technologies, which reduces the "trial and error" aspect of new initiatives. Restraining demand will in many situations be less costly than extending supply. Conservation technologies can often be more rapidly deployed than supply technologies. And energy conservation reduces some of the indirect costs of energy use such as environmental contamination.

Conserved energy represents a special class of alternative energy, not dependent on bringing forth new supplies. Conservation saves consumer dollars and capital, and contributes to an improved balance of payments through reduced expenditures on foreign oil. Conservation programs will likely create employment and income through expansion of that part of industry which supplies conservation goods and services. Other important and extensive benefits will derive from a conservation-oriented economy as well, not the least of which is the reward of long-term energy self-sufficiency.

The consequences of conservation decisions and policies are complex and numerous but a successful program of conservation would moderate the rate of growth in energy demand and lessen the pressure to find alternatives to present means of supplying energy. Conservation programs and energy supply programs require long-term planning, but through providing time, conservation increases the range of energy alternatives which may be evaluated and pursued. In other words, conservation can increase Canada's supply options if we seize the opportunity.

1. CONSERVATION DEFINED

Conservation has many connotations. To some it may imply a backwoods life style. To others the term may be associated with the imposition of strict controls on resource use, or even non-use. Certainly, the way in which Canadians view conservation will influence how Canada formulates a method for determining the best schedule of resource use in the future. Through a greater understanding of the market and institutional forces which influence conservation practice, we will be better able to assess the appropriateness of incentives and regulatory measures, "carrots and sticks", for encouraging enlightened energy use.

Conservation may be thought of as reducing the consumption of a resource in the near future so as to have more of it available in the more distant future. Conservation has also been defined as the

> ...careful use of renewable and non-renewable resources to ensure their greatest long-term benefit to society... (Crane, 1980, p. 67)

Conservation does not mean non-use, nor "wise" use, nor does it necessarily mean use at a constant rate. It is not synonymous with maximum sustained use nor maximum cumulative use. Conservation economics considers both demand and supply, and producers may (and frequently do) practice conservation as well as consumers. Deciding whether conservation or its opposite, depletion, is appropriate in a given situation is not always easy.

An Economist's Definition of Conservation and Depletion

Conservation is defined in a strictly economic sense as the redistribution of use rates of resources towards the future. Thus conservation always implies a comparison of two or more time distributions of use rates; that is, the supply and consumption of energy per unit of time over a number of units of time. The opposite of conservation is depletion — the redistribution of use rates toward the present.

2. WHAT FACTORS AFFECT CONSERVATION?

Many institutional and economic forces affect conservation. Among the most powerful influences are habits. Does one drive at moderate or at excessive speeds? Does one wear a sweater in a chilly room or turn up the thermostat instead? Altering, redirecting or replacing certain culturally-based practices and traditions will facilitate the adoption of conservation practices. While economic conditions may force us to conserve, changing our life-styles to cope with new economic realities will make the transition less painful. Higher gasoline prices may encourage many of us to buy smaller, lighter cars; however, if we learn to like small cars, we will not resent having had to make the change. We may even be happier for having contributed to the conservation effort.

There are numerous other economic forces which affect conservation, including interest rates, uncertainty, taxation, subsidies and prices.

Interest rates directly affect conservation decisions and are of particular practical significance in the analysis of resource use over time. Interest rates are employed in resource use planning for making net benefits (benefits minus costs) received in different time intervals comparable in the present. Those net benefits which accrue in the distant future are held to be less valuable than those which we enjoy today, therefore we tend to discount them the most. The factor by which we discount future benefits depends on the real interest rate (adjusted for inflation). A high rate of discount implies that current net benefits of resource extraction, for example, are far more valuable than future ones; therefore, depletion takes precedence over conservation and present use rates increase. Hence, when real interest rates increase, the present value of future net benefits decreases and depletion takes place. Conversely, a decrease in interest rates tends towards conservation by making benefits relatively more valuable in the future.

Interest Rates and Conservation

How might a change in interest rates effect oil conservation? The present value of a $100 annual saving resulting from an investment in energy-saving equipment (let's say from the installation of a new heating system), over ten years of operation of the equipment is $502 after being discounted at a 15% interest rate. At a 12% interest rate, however, the saving is discounted somewhat less such that the ten-year saving has a present worth of $566. Thus, at a 12% rate of interest, there is relatively more incentive to install energy-saving equipment. If the new heating system is more efficient and uses less fuel, then a decrease in interest rates acts to conserve energy.

The effects of uncertainty work similarly. People put greater emphasis on benefits they expect to receive in the near future because these benefits usually have the greatest certainty. When deciding which type of heating system to install, an individual will buy equipment with the greatest probability for generating savings in the first few years of operation. People are naturally reluctant to make such investments if they are uncertain about the savings they will bring. Reducing uncertainty therefore promotes better conservation decisions.

The imposition of taxes and subsidies will affect conservation decisions depending upon when they are introduced and how long they last. Taxation generally increases price and reduces profitability, thus resource consumers and producers shift use rates to those time intervals when the impact of a tax is smallest. Conversely, use rates are shifted to intervals in which subsidy benefits are greatest. In general, greater energy consumption will take place in periods with less uncertainty about profitability and supply, less taxation, greater subsidies and lower prices.

3. CONSERVATION OBJECTIVES, DECISIONS AND POLICIES

Toward what objectives are conservation efforts directed? On what basis can decisions be made regarding the appropriate level of conservation? How can conservation objectives be achieved?

When an individual makes a conservation decision, his objective is to maintain or increase his long-term standard of living. When a business makes a conservation decision, it is interested in reducing costs and/or increasing profits. Individuals and businesses are more likely to make good conservation decisions if they consider all of the costs and benefits arising from a proposed conservation measure. Once the relevant costs and benefits are estimated, it is a relatively simple matter to determine the *present value* of the proposed project by applying the market *discount* factor (that is, the discount factor relating to the rate of return which is likely to prevail over the life of the project).

Discounting and Present Value

Fifty-seven dollars placed in a savings deposit today with a 12% rate of interest will earn in five years approximately $43 (compounded annually), such that the savings deposit will be worth $100. Thus the *present value* of $100 five years hence, *discounted* at a 12% rate of interest, is about $57.

If the present value of future benefits exceeds the present value of future costs plus the initial investment, then the proposal is economically desirable. Such a cost-benefit analysis is as applicable to small projects (insulating a house) as it is to large projects (building a methanol plant).

Since individuals and firms do not need to consider external or social costs, their task when making such decisions is fairly straightforward. However, the desired state of conservation in the economy, while conceptually well-defined, is difficult, if not impossible, to determine in the real world — public conservation efforts involve costs and benefits which may not be readily assessed in dollar terms. For example, what is the ultimate value of a nation's energy self-sufficiency, or of the enjoyment received from an extra day's vacation bought with the money saved in driving a more efficient automobile?

Appropriate levels of public investment in conservation can in theory be determined by evaluating social net benefits but, in practice, this will be difficult. Although in principle the conservation objective is to increase total social net benefits, in practice we cannot know with certainty whether this is being achieved. There are nonetheless some practical guiding principles in formulating resource use policies. For renewable resources these include measures to prevent wastage, environmental damage and irreversible declines in resource flow rates. For nonrenewable resources, conservation objectives include rational rates of use and the discovery and development of efficient energy technologies and alternatives.

By influencing economic forces, governments may indirectly change the schedule of resource use rates over time to induce conservation. Direct intervention by the state may be necessary to achieve certain conservation goals. Direct tools include education in and regulation of use. Public education can be particularly effective in reforming habit patterns to make them conducive to energy conservation. Regulation of conventional energy use can also encourage conservation, minimum performance standards for automobiles being one example.

As individuals we will often make conservation decisions based on our incomes. One individual may choose to spend part of a week's wages on gasoline for a weekend jaunt while another person may receive more satisfaction from spending the money to improve the insulation in his home. As a society we will make conservation decisions based on the disposition of national income, relative to energy and all other goods and services.

Conservation decisions are predicated on our concern for the long-term viability of our economy and the welfare of future generations. Conservation of exhaustible energy resources will assure us of continuing supplies for years to come. Having conventional sources of energy in the year 2010 may be important if being without sufficient alternatives at that time would mean the deterioration of our economy and way of life. Conserving exhaustible sources of energy for the future is thus a form of insurance against unforeseen problems and events. It does not remove the need for effective, affordable alternatives.

4. PRICING CRITERIA FOR ALTERNATIVE ENERGY AND OIL SUBSTITUTES

The prices of the major conventional energy resources in Canada — oil, gas, coal and primary electricity — are regulated and therefore largely determined by government policy. We present the argument elsewhere in this Report that the true cost to Canadians of conventional energy is implicitly the world price and that we pay the difference in taxes, foregone oil revenue, and net income and production losses.

Determining the true cost of conventional energy in Canada is, as with all energy matters, complex. How can one then expect to determine the price of alternative energy, which for the most part will be supplied by technologies not yet in place and for which structured markets are only beginning to emerge? Fortunately, there are some methods by which the price of substitutes can be estimated. As a general rule, we may expect that energy alternatives will enter the system at prices which approximate those of conventional forms for given uses. The relevant value of each new unit of energy, however, is its replacement cost. What will the prices of alternative energy forms be in the long run? In a purely competitive market we would expect the price of a good to be based on its long-run cost of production. In practice, in real world energy markets beset by market imperfections, by economic power concentrations and by government intervention, energy prices will only crudely reflect changes in the long-run cost per unit.

Since time and future prices are factors in determining the role of alternative energy forms and the appropriate pricing of conventional forms, alternative energy sources cannot be properly assessed by considering only present circumstances. The pricing of energy over time should be related to the long-term value of the resource. Views of what the best pricing schedule is will vary considerably depending upon the perspective of the person or group making the decision.

Consider the Organization of Petroleum Exporting Countries, an influential body in oil supply and pricing on a world scale. It is advantageous for the OPEC nations to act in concert and price their oil in order to get the most return from their total resource. They manipulate supply in order to influence demand and price. By restricting supply the OPEC countries achieve two economic objectives (not to mention a few political ones):

they raise current prices, and they make more oil available in future years when the value of the oil may be higher still. Canada must balance the goal of pricing energy to get the most benefit from our natural energy assets with the goal of preserving the welfare of Canadians as a whole.

We have said that the pricing of conventional energy will influence the timing and the cost competitiveness of alternative energy sources. From the point of view of Canadians, the price of alternative energy sources should be such that the value of the benefits less costs derived from the use of these energy resources are as large as possible. Benefits will include employment and income gains, an improved trade balance and other less tangible benefits such as security of supply and environmental quality. Costs will include those incurred in shifting to alternative energy sources and technologies, especially if they are adopted before becoming economically competitive. It should be remembered nonetheless that society may choose to bear the cost of an early conversion to alternatives in order to benefit from security and diversity of energy supply.

5. DEMAND, CONSERVATION AND PRICES

The Committee recognizes that there is considerable debate over the effectiveness, fairness and wisdom of increasing the price of petroleum products as a means of promoting oil conservation and inducing greater use of alternatives. Some knowledge of the responsiveness of demand to price increases is essential, however, because such increases create hardships for many individuals in Canada, particularly those with low or fixed incomes. While it is evident that for most commodities increased prices result in diminished demand, with some goods this response is not pronounced and may be masked by income changes and other factors. With petroleum products, particularly gasoline, our perception of demand is complicated by changes in incomes, changes in consumer priorities in spending incomes, and by changes in technology. We have observed in Europe, where gasoline prices are three to four times those in Canada, that many people continue to drive, very often at high speeds. European drivers do, however, use substantially less fuel per passenger-kilometre travelled although it is unlikely that this would be the case if the real price of fuel in Europe were as low as in Canada.

Given sufficient time, the stock of automobiles (or heating systems or industrial equipment) will turn over to reflect the higher cost of energy. Time is needed for automobile manufacturers to redesign engines, remove excess weight and improve aerodynamics. Furthermore, consumers will not immediately trade a less efficient car for a more efficient one each time fuel prices increase, but they may well consider a smaller, more efficient vehicle when replacement does become necessary. As this also applies for other durable items which consume energy, several years may be required before we observe a change in demand determinants. Thus, in the long run, the demand (and supply) response to price changes will be greater as manufacturers are able to change designs and as consumers incorporate more efficient technologies into their lives.

Rates of price increase are an important factor. High and infrequent rates of increase have a shock effect but people can become accustomed to slow price increases and adjust to them. Even following a price shock, however, demand may be at least partially reestablished following an initial reduction in the rate of consumption.

Not all petroleum products are as price insensitive as gasoline. Consumption of industrial fuel oil and transportation diesel fuel has been estimated to decline by

The Relationship Between Demand and Price

Economists frequently measure the change in the quantity demanded of a good resulting from a change in the price of that good. This measure — the price-elasticity of demand — is usually expressed as the percentage change in the quantity demanded for a one per cent change in price, assuming no change in the tastes or incomes of the group of consumers whose demand characteristics are being studied. Such studies have determined that in recent years for each 1% increase in gasoline prices, consumption decreases by 0.18-0.45% (Friedenberg and Nixon, 1980, p. 32).

Put in more familiar terms, a demand price elasticity of -0.18 to -0.45 means that an increase in price from 25¢ to 30¢ per litre (a 20% increase) would cause an average Canadian driver, who normally consumed 500 litres of gasoline annually, to reduce consumption by 18 to 45 litres per annum. Of course this would apply only if he or she continued to drive a car with the same efficiency, maintained his or her driving habits, and drove the same mix of city and highway miles. Unfortunately this is difficult to observe in practice because drivers do buy more efficient cars and do change their driving habits. Furthermore, estimates of the responsiveness of demand to price increases apply only to a limited range of prices and quantities consumed over specific recent years, reflecting preferences and incomes prevailing at the time. With much higher prices, or with higher rates of increase of prices, the response may vary considerably.

about 1.3% for every 1% increase in price. Perhaps this is because industries and commercial transportation companies which are in pursuit of profits are quicker to adopt more efficient technologies or to change production or management practices. They may also have at their disposal a monitoring system allowing them to determine consumption and hence the conservation investment required to offset increased fuel prices.

Once again it must be emphasized that the estimates of the reaction of the commercial consumer to price are limited to a certain range of prices and quantities during the past decade. Furthermore, the sensitivity to price is likely to increase for some energy applications over the very long run. In the short run, price increases may have a small impact if individuals cannot substitute more efficient technologies.

6. DELAYS IN ADOPTING ALTERNATIVES

A number of energy alternatives and conservation measures appear to be economically viable today. It takes time, however, for a given technology to be put into place, for a new design to become widely accepted or for a practice to become widely adopted. There are basic economic reasons for this. Some are obvious; others are more difficult to explain.

Take the example of a house with an old oil furnace. More efficient heating systems are now on the market, including more efficient oil furnaces themselves. Why then do many homes continue to be heated with old furnaces in the face of higher heating costs? Such relatively expensive items tend to stay in service long after their replacement seems advisable. The reasons for this relate to the economics of fixed assets.

- Markets for such assets may be imperfect. Information may be inadequate and an individual may not know about cheaper alternatives.
- Decision-makers may not correctly assess the benefits of replacing an old inefficient system because the costs and benefits which accrue over time are ignored.
- The old system may continue to deliver service worth more than its salvage or trade-in value, while the normal requirements of the system do not warrant the capital outlay for a new system.

The first two points can be addressed by appropriate policies. The last point is an economic fact of life which is characteristic of all fixed assets, the effects of which can nevertheless be overcome by appropriate incentive programs. Conversion grants, for example, have the effect of decreasing the cost of the services offered by a new system. Two examples of such grants offered by the Federal Government are: (1) grants to assist homeowners and businesses for conversion from oil to gas, electricity, renewable and other energy sources, up to 50% of conversion costs to a maximum of $800; and (2) grants to commercial fleet owners of up to $400 per vehicle to convert to propane.

To further illustrate the impact of the above constraints, let us once again look at the example of replacing an outdated heating system. Canadians change residences frequently and many of us are tenants. We are therefore reluctant to make investments in insulation and more efficient heating systems because our costs may not be fully recovered. If the third constraint applies, then both owner and tenant are acting rationally. The owner may not, though, have full knowledge of heating system alternatives or may not be correctly assessing the benefits of a new system. In this regard, the dissemination of information about alternatives and about methods for correctly assessing costs and benefits over time through the application of "life cycle" costing analyses will be effective in overcoming delays in the adoption of alternative technologies.

Life Cycle Cost Analysis

Life cycle cost is the total of all relevant costs associated with an activity or project during the time it is analyzed, including all costs of ownership, operation and maintenance. The *life cycle* is the period of time between the starting point and cutoff date of analysis over which the costs and benefits of a certain alternative are incurred. If life cycle benefits exceed life cycle costs, then the project is economically desirable.

In any event, delays must be anticipated and taken into account when analyzing the probable impact of energy-related policies. Failure to do so may lead to frustration with the pace of adoption of new technologies and energy conservation measures, and hence unwarranted condemnation of good policies. Firm action and consistent policies will help assure rapid progress in the adoption of conservation practices and new energy-efficient technologies.

Energy and Growth

It is well accepted that the continued availability of energy is crucial for the improvement and even the maintenance of our standard of living. However, because it is also true that the amount of energy that we need to perform tasks is to some extent variable, both demand and supply considerations of all our energy resources deserve attention. The purpose of this section is to investigate the relationship between the production and consumption of energy and economic growth.

1. ENERGY CONSUMPTION AND THE GROSS DOMESTIC PRODUCT

Productivity has increased in Canada, generating more goods and improving services, because the use of capital has expanded as has the use of non-human energy sources. Economic growth has been possible because more plentiful and better resources of all kinds have been made available. With fixed resources and no technological change, there would have been little scope for increasing output. But more skilled labour, better organized production processes, cheap and plentiful energy, specialization of tasks and more efficient machinery all have contributed to growth. Textiles, for instance, no longer come from a labour-intensive cottage industry but instead are produced in automated textile factories which are capable of a much greater output for each worker employed.

As the industrial structure changed over time, the demand for energy grew. The limited energy services provided by wind, water, wood, animals and humans were no longer sufficient. The "new" energy sources answered changing demands for more reliable, plentiful and manageable sources of power and they, in turn, provided the ability to expand output. The process has been self-reinforcing, with output growth demanding energy and energy enabling growth.

Historically, economic growth has required more energy services from different types of sources. The response to changing demand has been an evolving pattern or mix of energy sources which in turn has been influenced by resource availability and by technological progress. These factors have affected the amount of energy used in production and the quantities and kinds of output generated. Consumption patterns for different fuels over time are shown for the United States in Figure 5-4. This illustration shows that the use of fuel wood in the nineteenth century was supplanted by the increased use of coal. Coal's contribution to satisfying U.S. energy needs peaked just after the turn of the century and its decline was offset in turn by the rising importance of crude oil and natural gas.

It is a simple matter to document the changing pattern of energy sources used and the increasing domestic output which has contributed to improved standards of living. However, the relationship between energy consumption and economic growth is not a simple one to uncover. From Table 5-4 it is clear that growth in output has occurred along with increased energy use. While few would say that this relationship is entirely fixed, many question whether growth can continue in an economy where a cheap and abundant source of energy is not available. We are thus approaching a turning point, similar to ones experienced in the past, when a transition will have to be made from one dominant fuel to another. The difficulty of this transition and the length of time it will take depend on many factors, some of which are outlined in this section.

Factors of Production

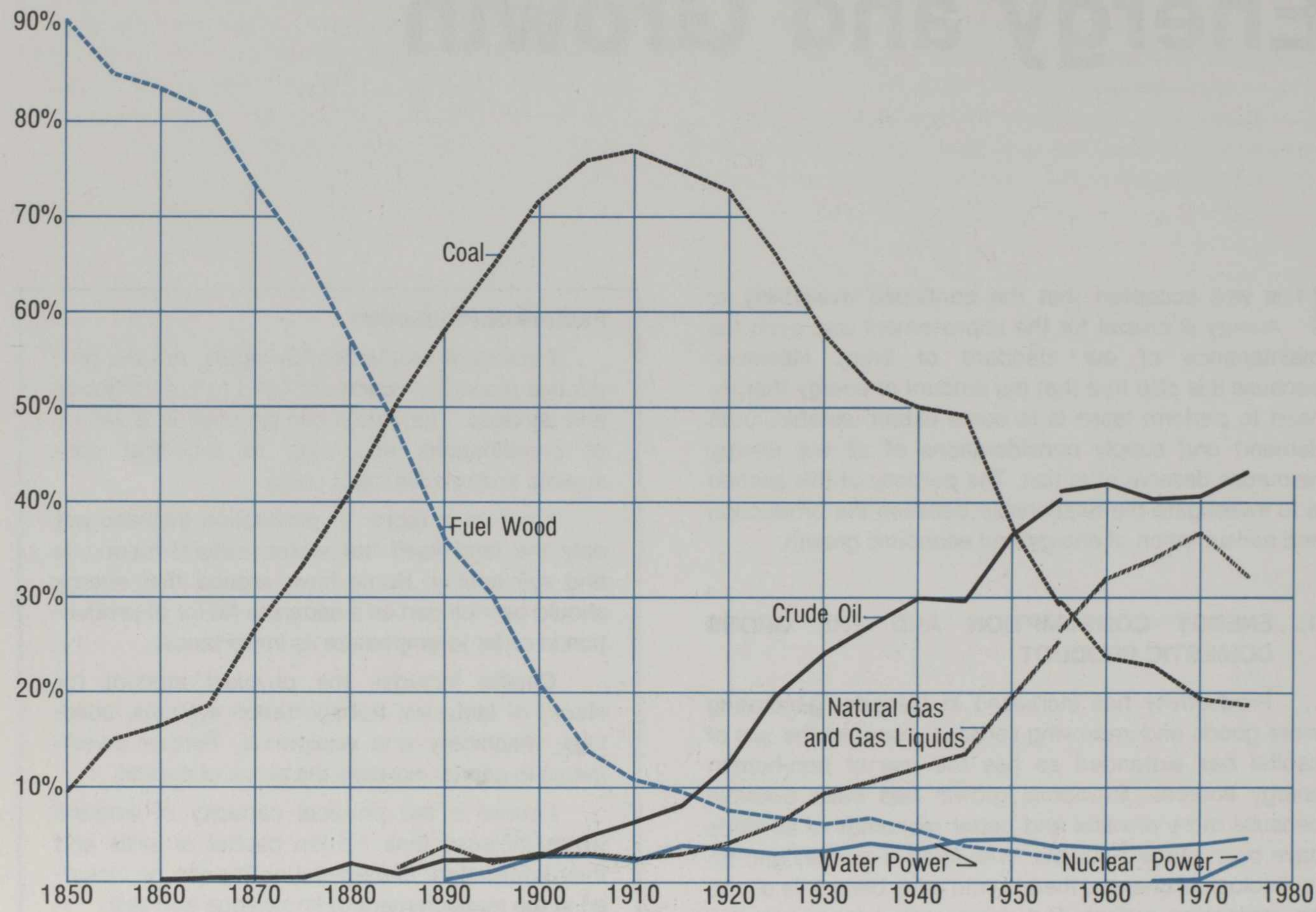
Factors of production, or inputs, are the productive resources which are used to create goods and services. The inputs can be used in a variety of combinations according to technical constraints and relative input costs.

Land as a factor of production includes not only the land itself but water, natural resources and soil quality. Some have argued that energy should be included as a separate factor of production in order to emphasize its importance.

Capital includes the physical amount (or stock) of factories, transportation systems, buildings, machinery and equipment. Further investments in capital increase the stock of capital.

Labour is the physical capacity of workers which includes their human capital or skills and their knowledge. Managerial ability can be included in the measurement of knowledge and skill.

Figure 5-4: ENERGY FORMS SATISFYING PRIMARY ENERGY DEMAND IN THE UNITED STATES SINCE 1850



Note: The break in the curves in 1955 reflects the slight discrepancies between the two sets of data used to prepare the illustration.
Source: After Rosenberg, 1980, p. 60; and DeGolyer and MacNaughton, 1980, p. 104.

Table 5-4: CANADIAN OIL CONSUMPTION AND REAL GNP, 1972-1979

Year	Domestic Consumption of Refined Petroleum Products (Thousand cubic metres/day)	Real Gross National Product (millions of 1971 dollars)
1972	253.1	100,248
1973	262.8	107,812
1974	269.8	111,678
1975	266.3	113,005
1976	272.5	119,116
1977	277.6	121,949
1978	284.5	126,127
1979	300.9	129,658
Average Annual Growth Rate	2.5%	3.7%

Source: Friedenberg and Nixon, 1980, p. 7.

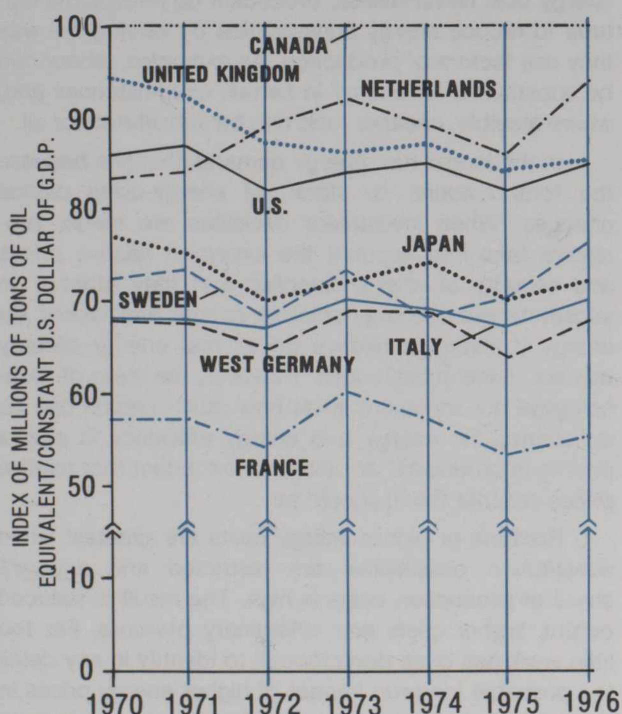
Gross Domestic and Gross National Product

Gross Domestic Product (GDP) is a measure of the value of production of goods and services in the economy. GDP includes all returns on investment within Canada's borders and therefore includes the returns on foreign investment here.

Gross National Product (GNP) is similar to GDP but it excludes the returns on investments in Canada which are received by foreigners and includes the value of goods and services produced by all Canadians whether resident or non-resident.

Other countries without indigenous oil resources faced the changing oil situation much earlier than Canada. Their major way of dealing with more expensive energy was to alter the way they used it. It would seem that they were able to adjust successfully because the amount of energy consumed in relation to the value of national output generated has been maintained (Figure 5-5), while the rate of economic growth was kept at a level at least as great as in Canada and in some cases much higher (Figure 5-6). In fact, in the 1977-1979 period, every other country surveyed in Figure 5-5 enjoyed improved economic growth while Canada, even with cheap oil, continued to suffer from a decline in the growth of real GDP. It appears, therefore, that since other economies can perform healthily on less energy, there must be opportunities in Canada for less energy-intensive methods of production.

Figure 5-5: INDEX OF ENERGY CONSUMPTION PER CONSTANT DOLLAR OF GROSS DOMESTIC PRODUCT IN SELECTED COUNTRIES, 1970-1976, NORMALIZED TO A VALUE OF 100 FOR CANADA



Source: After Slagorsky, 1979, p. 4.

The energy intensities of the economies of Figure 5-5 are reflected in the level of energy use per dollar of Gross Domestic Product while trends in the ratio reflect both a changing energy intensity and possible efficiency gains. Canada does use more energy per dollar of GDP than the other countries shown but it is not appropriate to draw too many conclusions from the comparisons of aggregate energy use among countries simply because this broad measure hides important differences. Energy intensity of the overall economy can be high in comparison with other economies even though energy efficiency may be high as well. This will be the case where there are many industries which require large amounts of energy to produce a given dollar value of output (aluminum smelting being an example). Energy-intensive industries may use technologies which are efficient in their use of energy but the process itself may simply require large amounts of energy. For instance, existing technologies dictate that some 35 megajoules of energy per kilogram of product must be used to produce fertilizer while 200 MJ/kg is necessary in the production of paint (Slesser, 1978).

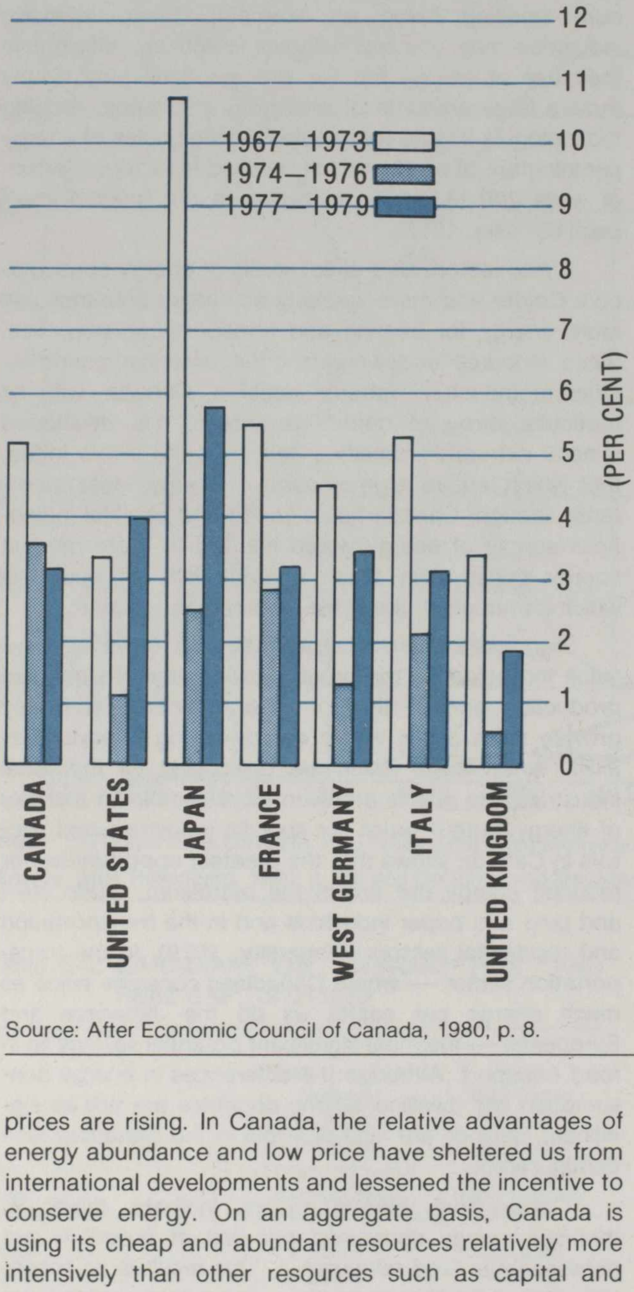
Other factors also affect levels of energy consumption. Colder and more sparsely populated countries use more energy for heating and transportation purposes. Since resource endowments differ amongst countries, different industrial patterns develop. Canada, with its particular array of natural resources, has developed mineral extraction, smelting and pulp and paper industries which require large amounts of energy. Most importantly though, Canada has a varied and plentiful indigenous supply of energy which has led to more modest energy prices than those characteristic of countries which do not enjoy the same resource abundance.

Aggregate energy/output ratios do, however, have value for indicating the broad performance of Canadian production against that of other countries and they provide clues about where energy-saving opportunities exist. When these ratios are calculated for individual industries, the results are even more useful. An analysis of energy/output ratios for specific industries and sectors in Canada shows that the greatest opportunities for reduced energy use are in the petroleum, crude steel and pulp and paper industries and in the transportation and residential sectors (Slagorsky, 1979). In the transportation sector — where Canadians consume twice as much energy per capita as do the Japanese and Europeans — the most significant potential savings lie in road transport. Although the differences in energy consumption per dwelling among countries are not as significant, savings are also possible in the Canadian residential sector.

Comparisons among nations indicate, therefore, that the energy consumed per unit of output is not necessarily a fixed relationship. This result is an extension of the idea that energy use and output growth have varied historically according to changes in the economic and physical environment. Energy use will evolve in Canada and experience in other industrialized countries is evidence that this change need not be economically destructive.

The primary incentive to lower the rate of growth in energy demand in many countries results from their lack of plentiful indigenous energy supplies at a time when oil

Figure 5-6: AVERAGE ANNUAL PERCENTAGE CHANGE IN REAL GROSS DOMESTIC PRODUCT, CANADA AND MAJOR OECD COUNTRIES, 1967-1979



Source: After Economic Council of Canada, 1980, p. 8.

prices are rising. In Canada, the relative advantages of energy abundance and low price have sheltered us from international developments and lessened the incentive to conserve energy. On an aggregate basis, Canada is using its cheap and abundant resources relatively more intensively than other resources such as capital and labour. Canadians can certainly use less energy in production in the short run but production costs will rise if more labour and capital must be employed instead.

The degree of total energy savings possible in this country is unclear. It seems that growth can occur with less energy usage — a truly desirable condition — but the relationship between growth and energy consumption has not been clearly uncovered. If, in fact, the long-term growth potential of the economy will be hampered by using less energy (particularly oil) today, then we should be aware of this since we will have to decide whether we were willing to accept smaller real incomes. If we are not willing to lower our income expectations, then investment in alternative sources of energy is urgently needed. Since the resolution of this uncertainty is imperative, *the relationship between energy consumption and economic growth in Canada should be thoroughly investigated.*

2. ENERGY CONSUMPTION BY PRODUCERS

The existing stock of capital in our economy is the result of investment decisions made in circumstances which were quite different from those prevailing today. In the past, as labour became a relatively more expensive input than energy, producers bought energy-intensive rather than labour-intensive machinery and equipment. Unfortunately, Canada is now locked, in the short term at least, into an economy which dictates a high rate of energy use. Nevertheless, producers do have some latitude to reduce energy consumption by varying the way they use factors of production. As examples, labour can be substituted for energy in certain circumstances and, where feasible, cheaper fuels can be substituted for oil.

In the longer run, energy demand changes because the total amount, or stock, of energy-using capital changes. When investment decisions are made, producers take into account the expected relative prices and security of energy supplies and they attempt to substitute more energy-efficient capital and labour for energy if changing relative prices and energy security warrant these substitutions. However, the state of technological advancement limits how much capital can be substituted for energy and energy efficiency is only a priority in producers' decisions to the extent that relative prices indicate that it should be.

Burdens of higher energy costs are greatest when substitution possibilities are restricted and energy's share of production costs is high. The result is reduced output, higher costs and inflationary pressure. Far too little work has been done though to identify in any detail the probable long-run impact of higher energy prices in Canada's industrial output. Studies should be done to first indicate how Canada's industrial mix will change as energy becomes increasingly expensive and, secondly, to offer ways of dealing with the change.

3. THE ROLE OF NEW ENERGY SOURCES AND TECHNOLOGICAL CHANGE

If future economic growth were to diminish to a condition of recession as a result of decreased energy use, then the energy strategy would be obvious — energy supply would have to be increased. Even with rigorous energy conservation, we can anticipate a time when energy demand management will no longer balance the supply-demand equation. Given the long-run physical limitations of conventional energy supply, the development of renewable energy sources is therefore essential and inevitable. Time is the variable.

Existing technology determines the manner in which production takes place. It also places limitations on the growth of the economy. As energy scarcity intensifies, changes in technology are unavoidable. The potential success of these changes and their contribution to overcoming an energy shortfall is unknown.

Canada's most pressing needs are for better information on feedbacks in the economy which involve energy; better market signals to reflect the changing costs of alternatives; and incentives which encourage technological change bearing on energy demand and supply. Easing the substitution of other inputs for energy and reducing the share of energy in total production costs are endeavours which could benefit significantly from new innovations.

Balance of Payments, Energy Trade And Investment

The Canadian economy is frequently under pressure due to the volume of our imports, and rising oil prices have meant even larger payments abroad. A major benefit of developing alternative energy forms in Canada should be a long-term amelioration in balance of payments problems.

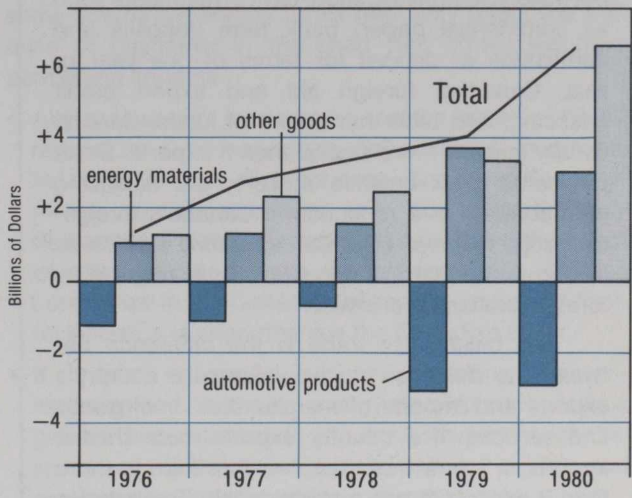
As a trading nation, Canada earns roughly 35% of its income from exporting goods and services. Canada has an energy-intensive economy and although we are a net exporter of energy overall (principally by virtue of natural gas sales in U.S. markets), we are a net importer of crude oil at a rate of about 300,000 barrels per day. The annual cost of these net imports now exceeds $4 billion, having approximately doubled in 1980 from the previous year. The rate at which oil is imported seems certain to increase at least through the mid-1980s.

Canadians purchase large quantities of foreign-made goods such as automobiles, electronic equipment, food, clothing and so on. We sell a combination of food, manufactured goods, semi-processed goods and raw materials. A substantial share of the export revenue needed to finance our imports throughout the 1970s has been provided by energy. Prospects appear good that exports of electricity will continue to grow and exports of natural gas, surplus to forecast domestic needs, will continue into the 1990s under existing contracts. Exports of alternative energy technologies offer yet another possibility for the future.

Balance of payments surpluses and deficits are more than obscure accounting entries. International transactions affect every aspect of our economy and the lives of all Canadians. Properly managed, our trade and foreign investment capital inflows can be advantageous in terms of increasing incomes and maintaining employment. Energy development is a critical part of the balance of payments equation because it is capital intensive in nature and because, traditionally, it has required large amounts of foreign investment.

Canada's current account deficit, as a proportion of GNP, was amongst the highest in the Western World in the late 1970s — despite the fact that our merchandise trade balance was positive and rising during that decade (Figures 5-7 and 5-8). The sale of energy has therefore made an important contribution in offsetting deficits in other goods and services (the deficit in "invisible exports" such as foreign travel is notable). More recently, the decline in the value of the Canadian dollar has helped make Canadian goods more competitive on world markets, and this coupled with a moderation in the growth of imports, generated an impressive merchandise trade surplus in 1980.

Figure 5-7: CANADA'S MERCHANDISE TRADE BALANCE



Source: Bank of Nova Scotia, 1980, p. 2.

Canada has been one of the largest borrowers on international money markets. Our debt service payments to foreigners have more than doubled since the 1950s. Large borrowings in foreign capital markets by provincial crown corporations for investment purposes in the 1970s contributed to a significant increase in debt service payment outflows (which come under the current account).

The deficit on interest and dividend payments to foreigners has continued to grow (Figure 5-8). Thus the strengthening in Canada's trade balance is not necessarily indicative of a medium-term trend towards overall surpluses, especially in light of our medium-term energy needs and the rising cost of foreign petroleum. Foreign capital inflows to finance the development of energy supplies in the 80s and 90s will be advantageous in terms of the overall balance of payments.

What Is Meant by the Terms Balance of Payments and Balance of Trade?

The balance of payments is a summary of all the transactions between Canadians and residents of the rest of the world over a given period of time. The balance of payments is divided into two accounts. The *current account* records the flow of goods and services between Canada and the rest of the world: merchandise imports and exports and non-merchandise transactions such as travel and tourist spending, payments and receipts for business services, interest and dividend payments, and research and development.

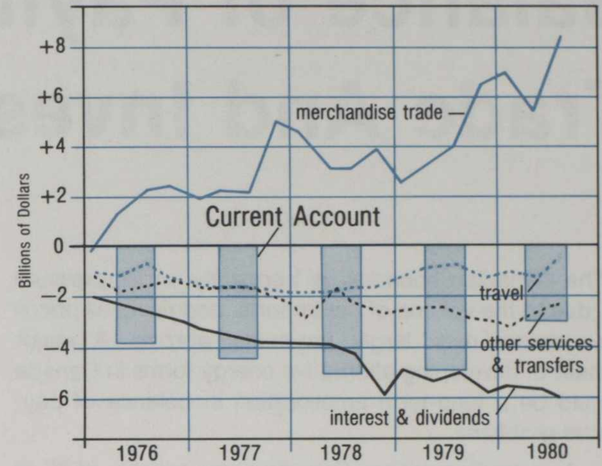
The *capital account* consists of long- and short-term capital flows between Canada and other countries. These flows include direct and portfolio investments, short-term investments such as commercial paper, bank term deposits and certificates of deposit for terms of one year or less, Canadian foreign aid and export credit financing, and other movement of funds. Canada usually imports more capital than it exports. Since payments must balance at zero, the balancing item consists of a reduction in Canada's foreign-exchange reserves or, if Canada has a surplus on its current and capital accounts, an increase in its foreign-exchange reserves.

The balance of trade is the difference between the dollar or money value of a country's exports and imports of merchandise or of goods and services. If a country exports more than it imports, it has a trade surplus; if it imports more than it exports, it has a trade deficit. The balance of trade plays an important role in determining a country's overall balance of payments.
(Source: After Crane, 1980, p. 17)

Recent balance of payments studies which have concentrated on direct conventional energy investment foresee enormous capital requirements for energy development in the short and medium term. Indeed, whether or not alternative energy developments supplant certain conventional energy projects, future capital requirements will be massive. Energy investment may very well be the dominant component of fixed capital investment over the next several decades.

Capital spending in the energy sector in 1979 was 4.5% of Gross National Expenditure (numerically equal

Figure 5-8: CANADA'S EXTERNAL ACCOUNT BALANCES



Source: Bank of Nova Scotia, 1980, p. 2.

to Gross National Product) or 22% of gross capital formation. This is high relative to the resource boom of the 1950s, but capital spending in this sector has not taxed the economy or financial markets since gross capital formation in the economy other than for energy has been weak in the late 1970s.

An energy investment boom may change the picture markedly. Energy investment in the 1990s could reach 9% of GNP and current dollar energy spending in 1990-2000 may increase by more than 40 times over the 1970 level. Historical and projected energy sector spending levels in current dollars are listed as follows (Waddington, 1979):

	Billion Dollars/Year
1970	3.0
1979	11.7
	Annual Average
1980-85	21.7
1986-90	46.5
1991-95	76.7
1995-2000	131.0

Total cumulative capital requirements for energy investment for the period 1979-2000 are forecast at $1.4 trillion. Such seemingly awesome capital requirements, if realized, will certainly place burdens on domestic capital markets, and will necessitate vast foreign capital inflows if the historical percentage of foreign capital investment is maintained.

One forecast suggests that capital markets will provide about 54% ($750 billion) of required energy investment dollars and the remainder will be raised internally, from operating profits. A significant proportion of this capital will come from foreign sources and thus will flow through Canada's foreign exchange markets and affect our balance of payments. Assuming the historical proportion of domestic to foreign capital, estimates indicate that domestic capital markets will be asked to provide about $400 billion and foreign sources $350 billion. Capital inflows to finance investment from foreign sources may account for nearly 79% of the projected current account deficit in 1979-1990; however, the forecast current account deterioration in the 1990-2000 period may be such that inflows will cover only 67% of the deficit. Thus, a problem may arise in the latter period — keeping interest rates moderate while at the same time encouraging an adequate level of capital inflow.

Capital Markets and Capital Investment

The capital market refers to the various markets in which governments and corporations raise long-term capital. The sources of such capital include pension plans, insurance companies, trust companies and individual investors. The agents through which these savers act include investment dealers, stockbrokers, bond traders, underwriters, trust companies and banks, while the principal institutions include the bond market and various stock exchanges.

Capital investment is the amount of spending in the economy each year to replace worn-out and obsolete production facilities and to increase the productive capacity of the economy. Public capital investment consists of spending on new government buildings, highways, schools, hospitals, and the like. Private capital investment consists of spending by private and crown corporations on new factories, mines, machines and equipment, housing, offices, hotels, refineries, power plants, railways, and so forth.
(Source: After Crane, 1980, p. 46)

In the absence of effective conservation and practical alternative energy forms, Canada could very well be placed in the position of being forced to sell a portion of conventional energy supplies to pay for the development of our oil and gas resources. Some level of export, particularly of gas, is likely to be both necessary and economically wise; however greater benefits may be realized from the sale of alternative energy technologies than from a higher rate of depletion of our conventional energy reserves.

Canada will not be alone in tapping the world's savings for energy development. Demand for capital throughout the world, in what may turn out to be two decades of unprecedented energy development, will contribute to the cost of money (debt servicing). Fortunately for Canadians, capital seeks out safe investments. A well-planned program of energy resource and technological development together with a broad program of conservation is likely to create an investment climate in Canada which will be attractive to both domestic and foreign capital markets. Policies to reverse recent postponements in energy projects such as Esso Cold Lake will thus become increasingly necessary if an adequate conventional/alternative energy system is to be developed.

What benefits might one anticipate in Canada's balance of payments as a result of alternative energy development? Beyond their direct impact on the balance of trade, energy imports and exports have indirect effects on international payments through their influence on employment, investment, the exchange rate and the money supply. Export revenues or import savings from some alternative energy forms may only affect the balance of payments in the short run; others will have permanent impacts.

- Alternate energy forms which replace imported oil will reduce by a corresponding dollar amount payments made to foreign oil producers. Compensation payments to oil importers will be proportionately decreased. Taken in isolation this will have the effect of relieving pressure on the national debt, building confidence in the Canadian economy, improving capital inflows and strengthening the Canadian dollar.
- If complete energy self-sufficiency resulting from conservation and alternative energy development allows a general improvement in the economy, more capital resources will be available for investment in large and small energy projects and for other purposes.
- Development of alternative energy technologies can generate export goods and services, and result in increased exports and investment capital inflows. The Third World may be a particularly important market for Canadian energy technologies suited to decentralized energy systems.
- Development of alternative energy technologies at home will reduce the need to import them. Failure to move ahead aggressively in developing alternative energy technologies will result in falling behind the rest of the industrialized world in the energy technology market.
- A strong Canadian economy which is energy self-sufficient may allow more economic independence and enable this country to pursue policies to reduce its dependence on foreign capital.

- Alternative energy technologies may not have the political or strategic problems associated with the export of nuclear technology.

Canada has the potential to achieve energy self-sufficiency almost across the board in the next decade. This could occur through rapid development of frontier oil resources, the tar sands, alternative energy forms and by aggressively pursuing conservation. Studies undertaken by the Committee indicate that a range of benefits will be derived from achieving petroleum self-sufficiency in particular. They may, however, require ten or more years to become fully realized in the economy.

In assessing the balance of payments effects of a policy of energy self-sufficiency, it is important to distinguish between long-run and short-run consequences. The more self-sufficient in energy Canada is, the more likely it is that the current account balance will be stronger towards the end of the decade although during the interim period, spending on foreign goods out of income derived from energy investment could weaken the current account balance. (Income from direct and indirect employment associated with developing conventional and alternate energy resources will be spent by workers on imported as well as domestic goods and services.) Furthermore, the achievement of self-sufficiency in all energy forms will help insulate the Canadian trade balance from the effects of high world oil prices. In the absence of the development of major conventional and alternative energy projects, our trade balance could be much less favourable and much more volatile.

Estimates indicate that complete energy self-sufficiency would strengthen the Canadian dollar in the long run. Nevertheless, as with the trade account balance, the economic activity which would be associated with a drive toward self-sufficiency in the early part of the decade could weaken the dollar. Unfortunately, this may be part of the cost of achieving self-sufficiency in energy. This might not be the case, however, if Canada received large capital inflows to support energy development. Self-sufficiency would also protect this country from world oil price shocks. A strengthened dollar would mean reduced import costs towards the end of the decade, although too strong a dollar would dampen export sales.

The overall implication of energy self-sufficiency is difficult to discern with clarity. At the very least, however, this brief discussion has demonstrated the complexity of the international sector of our economy with respect to energy. Failure to curb our costly petroleum imports will certainly result in highly undesirable energy trade and current account deficits in the near future.

Energy And Employment

Changes in the intensity of commercial and industrial energy use together with shifts in energy consumption patterns have implications for employment in Canada. While some have advocated the development of alternative energy sources and the promotion of conservation for the express purpose of creating employment, others regard the employment effects of energy policy as secondary. The Committee believes that a more thorough understanding of the relationship between energy and employment is essential and this section discusses some of the issues involved.

Full employment is an important target in developed economies. Conflicts arise, however, because full employment is only one of many societal goals: controlling inflation, promoting industrial development and equitable distribution of income among people and regions, and achieving energy self-sufficiency are examples of others. Unfortunately, the simultaneous attainment of these objectives continues to elude both governments and the natural workings of the economy.

Our economy depends upon plentiful energy. With energy being a vital input to production, changes in its use, supply, price and type influence market reactions and, therefore, the employment of labour. Beyond this, government policy and altered consumer tastes concerning energy use can also affect employment. These interactions are discussed here.

Increased economic activity generally has the effect of increasing the demand for labour. Increasing energy prices tend, however, to have a depressing effect on labour activity because as the costs of production rise, output cutbacks generally follow. Nevertheless, even in the short run, labour is often substituted for energy when the price of the latter rises. This may well result in a net positive effect on overall employment even if output levels fall. In the longer run, if industries can substitute other inputs for more expensive energy, output levels, and consequently employment, may not necessarily fall. If, on the other hand, the longer-run effect of higher energy prices is reduced economic growth, then employment may decline simply because aggregate productive capacity is reduced.

At the level of the consumer, other goods will be substituted for energy as its cost increases. For instance, people will insulate homes if this is cheaper over time than spending more on space heating. Substituting insulation for energy stimulates the insulation industry and bolsters its associated employment. There is evidence to support the view that the positive effects of energy-saving options on labour more than offset labour losses in the replaced energy supply industries. This is not to say though that disruptions within the total labour market will not occur.

In the auto industry we are witnessing sales reductions, production cut-backs and employee lay-offs occurring at least partially in response to changes in the demand for energy. The main cause of the demand change in Canada though is probably attributable to rising costs for automobiles themselves and to changes in consumer tastes, because the real price of domestic gasoline has remained relatively stable over the last decade. Regardless of whether the reduction in demand for the typical, large North American automobile is in response to the rising cost of fuel, to the cost of the car itself or to preference changes, adjustment is hindered by the inflexibility of the automobile production process. Such rigidities lead inevitably to employment losses.

It is possible to substitute labour for energy in transportation by walking and bicycling, or it is possible to produce vehicles very labour-intensively (as is done in Rolls Royce production), but these solutions are costly in time, convenience and dollars.

On the other hand, if energy prices continue increasing, the energy supply industries will be stimulated and employment in that sector will expand. More oil and gas wells will be drilled, additional tar sands plants will be considered and the development of alternatives to conventional oil will be encouraged.

Decentralized energy options lead to regionally dispersed benefits in employment. For some areas the net employment benefits are clearly positive because an industry develops where no activity existed before. This improves local economic conditions and stimulates local growth. The overall effect, when total Canadian employment effects are weighed, is not so clear however. Regional employment gains must be measured against real income losses if the decentralized industry provides energy which costs more than energy obtained from a centralized source. Employment gains in one region, or in one market sector, will be matched to some extent by losses elsewhere.

The encouragement of the conventional energy sector also has a local employment impact when a large project is undertaken in an area which does not already have the population or the infrastructure to support development. While it is true that the local economy temporarily benefits from the growth and income generation resulting from the project, severe and costly disruptions can also occur. The costs of sudden and specific labour force demands can spread across the country as the need for those workers skilled in particular trades rises and wages are pushed up — demands in one area affect the labour force balance and employment costs in other regions. There are also labour skill implications because the demand may exceed the supply of specific kinds of labour.

Labour is not perfectly mobile across Canada and not all workers have the skills which are in demand. These two problems contribute to the disruptions and costs associated with large, centralized energy projects. After the "boom" in local growth associated with the construction period, there is the danger of a "bust" when the specialized workforce moves on. The demand strains associated with the bunching of large projects can also exacerbate inflation.

The appeal of decentralized energy supply is obvious — the labour market costs associated with large projects disappear. The benefits of the economies of scale which accrue to large projects are lost with decentralized development, however.

Well-planned, large projects can be economically stimulating during recessions. The tar sands plants planned for the late 1980s can be expected to counteract any recessionary tendencies existing then, and the benefits of improved economic activity will undoubtedly spill over to the labour market.

Energy policy affects employment by changing the pattern of market activities. If nonconventional energy supply is encouraged, employment gains are promoted in these new industries but moderated in conventional energy supply industries. The net employment effect of such a policy is consequently unclear. The effects of energy conservation policies are similarly complex. Research done on the employment effects of conservation policies indicates that initially there are greater employment gains in conservation industries than there are employment losses in energy supply industries. The net gain, however, may be in lower-wage jobs. There is some doubt that long-run growth can continue with a strict energy conservation policy.

Tax incentives which promote activity in the petroleum industry are really an indirect subsidy which enhances employment. Similarly, incentives for the development of alternative energy sources and technologies can stimulate employment. Price setting can have the same effect — regulations which maintain high energy prices (such as those put into effect in the 1960s for the Western Canadian oil industry) encouraged growth and stimulated employment. On the other hand, enforcing low energy prices can depress activity and therefore employment in the energy sector.

Government employment policy has a role to play in improving labour market flexibility. The better-prepared the labour force is to respond to higher energy prices, increased alternative energy supplies and energy-efficient technologies, the better-off all Canadians will be. It is thus incumbent on government and industry to identify future skill requirements, to encourage and undertake necessary training procedures, to aid in making labour more mobile and to attempt to reduce occupational barriers. This applies to the conventional energy sector, the evolving alternative energy supply industries, the industrial sector which will be providing more energy-saving technologies and, indeed, all industry. In any event, *coping with employment effects, not aiming at creating jobs, should be the major employment concern in formulating energy strategy*.

As the attitudes and goals of society change, consumers will alter the types of services they demand. With energy efficiency and energy self-sufficiency gaining prominence at a time in Canada's economic development when concern about quality of life is becoming more and more important, the kinds of goods and services which are demanded will change to reflect these goals. These changes will be followed by the alterations in production made to meet consumer desires. As this latter development progresses, employment patterns will also be affected. Industries likely to expand will be those whose products complement altering tastes.

Canada's economic structure is undergoing modification which extends well beyond the energy sector. Employment patterns, labour participation rates and the whole industrial structure are changing as the economy and society in general evolve. The high-technology revolution, for instance, is likely to make our industrial sector less energy intensive than it is now. The growing emphasis on the service sector will also reduce energy intensity without a reduction in labour intensity. Job sharing, the substitution of communication for transportation, and similar innovations will lead to energy/output relations which are based on very different circumstances than those prevailing today.

Incentives

Economic conditions in a market economy may not be conducive to an adequate or timely development of alternative energy forms and systems. The role of government in creating appropriate incentives for alternative energy research, development and commercialization is discussed in the following pages. The problems with and the effectiveness of subsidies aimed at producers and consumers of energy and at potential consumers of conservation technology are dealt with in the context of market and implicit (social) energy prices.

The recommendations in this Report are based on the realization that while the present energy situation is undergoing change it is not in a state of crisis. It is certainly not imperative to map out our future under "war-time" conditions. Canada does have diverse energy options and although we must take action now, we do have the opportunity to consider the cost implications of our choices. Since incentives cost money, we must take the time to consider the cost implications of our best options. There are unique circumstances where specific government involvement is appropriate and in this section we set out some of these special features and indicate the kind of government response that we think they require.

In mixed economies the public sector plays the role of influencing market decisions for the promotion of social well-being. The maze of taxes and subsidies which influences energy consumption and production decisions in Canada today is clear enough indication that government intervention is not only complex but extensive as well. Since the market mechanisms in our economy still produce less than perfect results in many cases, one could advocate stepped-up intervention in just about every market. Nonetheless, there are those who also argue convincingly that the government should leave the market to itself because they have complete faith in the "competence of markets and the incompetence of administrators." Unfortunately, extreme attitudes of this sort are rarely helpful in the resolution of problems. Striking a balance between these two views is probably the best approach in the formulation of an alternative energy policy.

If the economy functioned perfectly in the use of all resources (natural resources, capital and labour), then there would be little need for government incentives to promote energy efficiency or the commercialization of alternative energy sources and technologies — correct market signals would lead to resource allocations which maximize society's well-being. This would be true because producers and consumers would make decisions which take into account the total social implications of their actions. For example, car drivers would perhaps make different decisions about the amount of driving they do if they were to bear the cost of the environmental pollution they cause by driving their cars, the ultimate cost of recycling their cars, and if they had to account for the increase in market power that OPEC gains to raise future prices when more and more imported oil is demanded today. Individuals do not consider all of these costs simply because everybody in society shares them; those who impose the burdens do not pay the full cost personally. If we could add up all these costs we would arrive at the price for energy which accounts for all the costs to society of oil production and consumption (the socially optimal energy price).

The energy market does not account for all costs and this inadequacy has not been overlooked by the public sector. In fact, there is a complex and detailed incentive and regulatory framework already set up in the energy market. The list of available government tools which can, and do, influence energy production and consumption decisions is a long one. It includes grants; subsidies; income tax credits; income tax deductions; low-cost loans; guaranteed loans; taxes on fuel; price ceilings; price deregulation; and protective tariffs, to name only a few. Programs and incentives already over-

The Canadian Economic System

A mixed economy is an economic system like Canada's where both the government and the private sector have important roles to play. Both private and public corporations exist and the government intervenes through the use of laws, regulations and other methods which modify the workings of the market in favour of protecting the public interest.

lap, real costs are often hidden and the effectiveness of all the measures is unclear. To further complicate the picture, a new consumer incentive program for switching off oil has recently been announced. The fact that this program is only partially described adds to the confusion.

The Socially Optimal Energy Price

Canadian consumers do not pay the *true cost* (the total cost) of oil. The true cost is higher than the *price* in Canada for a variety of reasons. (1) The relatively low price of oil discourages production and encourages consumption. Ideally, therefore, if it is best from a *social* perspective to discourage consumption and encourage production, then a higher oil price would be "better" than a lower price. We recognize, of course, that political and institutional realities also introduce important limiting factors into oil pricing arrangements. (2) By increasing our oil dependency *today,* and therefore our imports, we give OPEC more power in the *future* to raise the world price of oil that we will eventually have to pay. This is one part of the real cost of consuming more today. (3) Acid rain, the production of carbon dioxide and the numerous emissions which result from burning fossil fuels impose environmental costs.

Theoretically, by adding up all of these various factors, what is called a *socially optimal energy price* can be determined. The accounting task itself is in reality impossible to perform. It is clear though that if oil is substituted for by alternatives that do not embody the real costs associated with oil consumption, then the value of the substitution is at least equal to *the cost which is avoided.* For the United States, the Department of Energy has estimated that the socially optimal price for oil in the U.S., when only some cost factors are accounted for, is about $3 per barrel above the world price; while in *Energy Future* it is estimated that the socially optimal price was between $35 and $85 in 1979 even when some social and political costs were excluded (Stobaugh and Yergin, 1979).

The task of finding the appropriate mix of incentives and regulations is indeed a difficult one. Even more elusive is the philosophy concerning whether the market should be interfered with and why. This philosophy must be clear, so that the purpose of programs is consistent and clear.

Barriers to alternative energy commercialization obviously exist. Most agree, however, that when an

Subsidies

Subsidies are indirect or direct payments usually made by governments to reduce the cost of purchases to consumers or the cost of production to producers. Consumers receive an indirect subsidy on oil consumption when they pay less than the import cost of oil. The *direct* subsidy on oil imports is financed by all Canadians through general tax revenues, by oil producers through the oil export tax and by oil consumers through the Petroleum Compensation Charge. Oil producers also finance (through foregone earnings) an *indirect* subsidy on domestic oil consumed in Canada because they receive less for their oil than they could receive on the world market. The indirect subsidy facing consumers is therefore also an indirect tax (negative subsidy) on oil production because revenue is indirectly transferred from producers to consumers. Alternative energy production is inhibited because consumption of its output is not subsidized to the same extent.

alternative is competitive with the socially optimal energy price (or the international price) it should be commercialized. But what is the incentive to innovate or commercialize in Canada when energy services can be conveniently derived from oil at a subsidized price of about $20 per barrel? Although the current commitment is to higher domestic prices, if we want more alternatives to come on-stream quickly, it is evident that government incentives will be necessary.

In a country where the domestic price of oil is still subsidized, the best incentive government can provide to alternative energy sources is one which subsidizes each new unit of alternative energy which replaces oil. The subsidy should, ideally, be equal to the difference between the regulated oil price and the socially optimal oil price. This constitutes an output subsidy.

When the use of alternatives is foregone, imports are consumed instead, markets remain undeveloped, gains in achieving domestic security of energy supply are foregone, and continuing pollution from oil consumption results. In the case of conservation there is good argument for rewarding the saving of a barrel of oil because that barrel need not be imported at the world price and national security potentially threatened.

With an output subsidy, new, more expensive energy sources would likely be developed because producers would effectively receive a price competitive with that of oil, and as domestic oil prices increased the output subsidy could decrease. Consumers would not need to receive energy incentives directly but simply could make their decisions based on market prices. Unlike tax credits, loan guarantees and loans at the government's borrowing rate, *direct* output subsidies are much more visible. Such incentives, therefore, are more desirable because they do not mask the real cost of incentives to society.

Output Subsidy — A Technical Definition

A per unit subsidy on alternative energy output which is equal to the difference between the domestic price of oil (P^d), and the import cost (P^*) (or, ideally, the socially optimal price), less any oil input subsidy (S^i), theoretically will induce the same amount of alternative energy supply as would occur without the oil consumption subsidy. When the cost of production is subsidized, the price of the alternatives could be set competitively with that of oil.

Output subsidy/unit = $P^* - P^d - S^i$.

The output subsidy must be based on a replacement value for oil in actual usage. The subsidy must further be net of any subsidies already received.

Ideally, the best incentives would not discriminate amongst energy supply technologies and hence the investor would be afforded the opportunity of choosing the most promising alternative. It is best to treat all sources equally because restricting the range of options prejudices the market and excludes innovation. Forcing a narrow view of opportunities would not be in our best long-term interests. Rather than *managing* commercialization of new technologies, the provision of output subsidies promotes commercialization directly. The Committee, however, has identified some options which are better than others in terms of attaining long-run energy goals. For this reason, and because funds are inevitably limited, the choice of those options which should qualify for output incentives should be managed to a certain degree.

In the event that output subsidies are provided and the private sector is still not willing to invest in certain options, then a very strong argument must be made before tax dollars are invested. Private investors will commit their funds only when they believe they will yield a positive return. The rule for public investments should be no different, although "returns" in the public sector do not have to be measured in commercial terms alone. Those options which are clearly good from a social perspective but which are not favourable ones from the point of view of the private sector would require further incentives.

Government-supported demonstration projects are a good choice when the project necessary to identify technical and cost aspects must be of commercial scale and when no private firm is willing to undertake it alone because the information gained will be free to others. It is important that the relevant technology be well in hand before government becomes involved since a failure will provide a major disincentive to further market developments. In cases where the private sector is involved in joint demonstration projects, competitive bidding for project involvement would encourage efficiency through minimized costs. The commercialization process would be facilitated and bottlenecks in implementation would be minimized with private sector involvement and therefore it should be encouraged.

Governments should not, however, get involved in development which would have taken place without it as this would constitute a waste of government funds. If the barriers to development are related to legislative or institutional problems (such as lack of "rights to light" or inadequate building codes), then the solutions involve removal of these barriers, not subsidization of the production or consumption of the alternative technology. In the same way, if lack of information or market ignorance is the commercialization barrier, subsidization is inefficient but education and instruction programs are appropriate.

Efforts should be made to reduce the amount of uncertainty regarding future government policy because the more uncertain future events are made, the more risky are investments. Policies regarding market intervention and energy prices must be as clear as possible if appropriate responses are expected of investors who depend on their impression of the probabilities of future events when making investment decisions today.

Commercialization incentives, regulations and institutions should be sensitive to changing circumstances and be altered accordingly. A variety of factors contribute to the changing appropriateness of the energy mix. As energy prices change, the economic viability of alternatives also changes. As technological change takes place the economics again improve.

It is necessary to improve the consistency of the calculations of the oil-saving value of conservation and energy efficiency gains if subsidies are to be applied in the most efficient way. This is where government RD & D has a definite role to play. Energy audit requirements and standards will also be necessary if the energy saving opportunities of retrofit and efficiency measures are to be accurately quantified.

Input subsidies are those which cover the cost of installing *particular* technologies of *specific* dimensions. They therefore dictate the design and operating choices available to energy producers and consumers and exclude choices which may be better. In an evolving market, too much uncertainty exists to enable any one policy to determine the best opportunities at all times. If the government adopts only input subsidies we run the risk of locking ourselves into overly costly alternatives. Subsidies which are related only to cost tend to encourage preliminary funding requests which underestimate eventual needs. Also, when specific emphasis is on a limited set of options, attention is detracted from other technologies and sources. Innovators in the excluded technologies are implicitly punished for their foresight in the same way that newly instituted incentives tend to reward only the laggards who wait for public funding.

There is a valuable role to be played by government lead agencies which bridge the transition from R & D through demonstration to commercialization. Such bodies would have the mandate of identifying private sector applications and providing information. They could also ensure that R & D does not take place in a vacuum away from the economy. This role could potentially spill over to involving the private sector more actively in R & D activities. Although it is appropriate to invest in as many options as possible at the R & D level in order to provide a "safety net", it would be the job of the lead agencies to identify the smaller set of options which are most promising to render them ready for commercialization.

The lead agencies would ideally work on a regional basis so that developments could be matched to regional needs and opportunities. But there is a need to avoid replication of the work being done by various departments of the Federal Government, other levels of government and the private sector. It is not always necessary to create a new agency but it is necessary to identify the coordinating role of one group so that it has a well-defined responsibility to ensure that efforts and money are not wasted.

To act as a lead agency for the alternatives will be up to the newly-formed government agency Canertech. In its role as an entrepreneurial organization, Canertech will bridge the gap between RD & D and established industry. It intends to take an equity position in the companies assisted to generate a cash flow and to become self-sustaining.

Canada should continue to develop its alternative energy supply policy in view of changes in the rest of the world. Changing energy supply patterns are global events which contribute to changing future needs and dependencies everywhere. Since domestic industry depends on external markets, there should be domestic development which answers the need for providing export opportunities in the future. Canadian technology and energy supplies will be important earners of foreign exchange if they are sold in other countries. Incentives to promote alternatives which may not necessarily be broadly applicable in Canada, such as wind technology, may be beneficial if they make important contributions to energy supply elsewhere. Intercountry cooperation in ongoing energy projects in fusion and coal technologies, for instance, may also be of eventual importance for Canada's balance of payments and should therefore be encouraged.

Since the energy policies of other countries can influence Canadian circumstances, there will be certain situations in which the protection of Canadian industries is appropriate. The incentives available to the American solar industry, for example, have led to that industry having an advantage over its Canadian counterpart. For this reason, protective trade barriers to the importation of American solar equipment were instituted to protect the young Canadian solar industry. Tariffs and other trade barriers do not go to the root of the competition problem: they force Canadian consumers to pay more for Canadian equipment; they delay oil substitution; and they cause Canadian solar equipment to remain non-competitive internationally. Output subsidization, on the other hand, is efficient because it encourages the same production as would be the case without a regulated domestic price. It is a temporary subsidy which is intended to diminish as domestic oil prices climb to higher levels. With such a program trade protection is less necessary; consumers are given more choice; producers are forced to compete, thus encouraging innovation and a more viable industry; the danger of tariff retaliation is reduced; and oil import substitution is accelerated.

Pressure on government to encourage alternative energy supply is growing but the efforts usually required to prove government is actually acting for society's welfare involve higher government expenditures and specific new programs. If subsidization of alternative energy and technology is inevitable then we must try to get as much as possible for the money spent. It is Canadians who must pay taxes to pay the bills and it is the government's responsibility therefore to spend the money wisely. Taxpayers are obliged to support whatever the government decides to subsidize. Unlike energy consumers who can avoid higher costs by restricting their consumption, taxpayers have no choice. If resources are wasted all Canadians lose.

6 ALTERNATIVE ENERGY SOURCES, CURRENCIES AND TECHNOLOGIES

Introduction

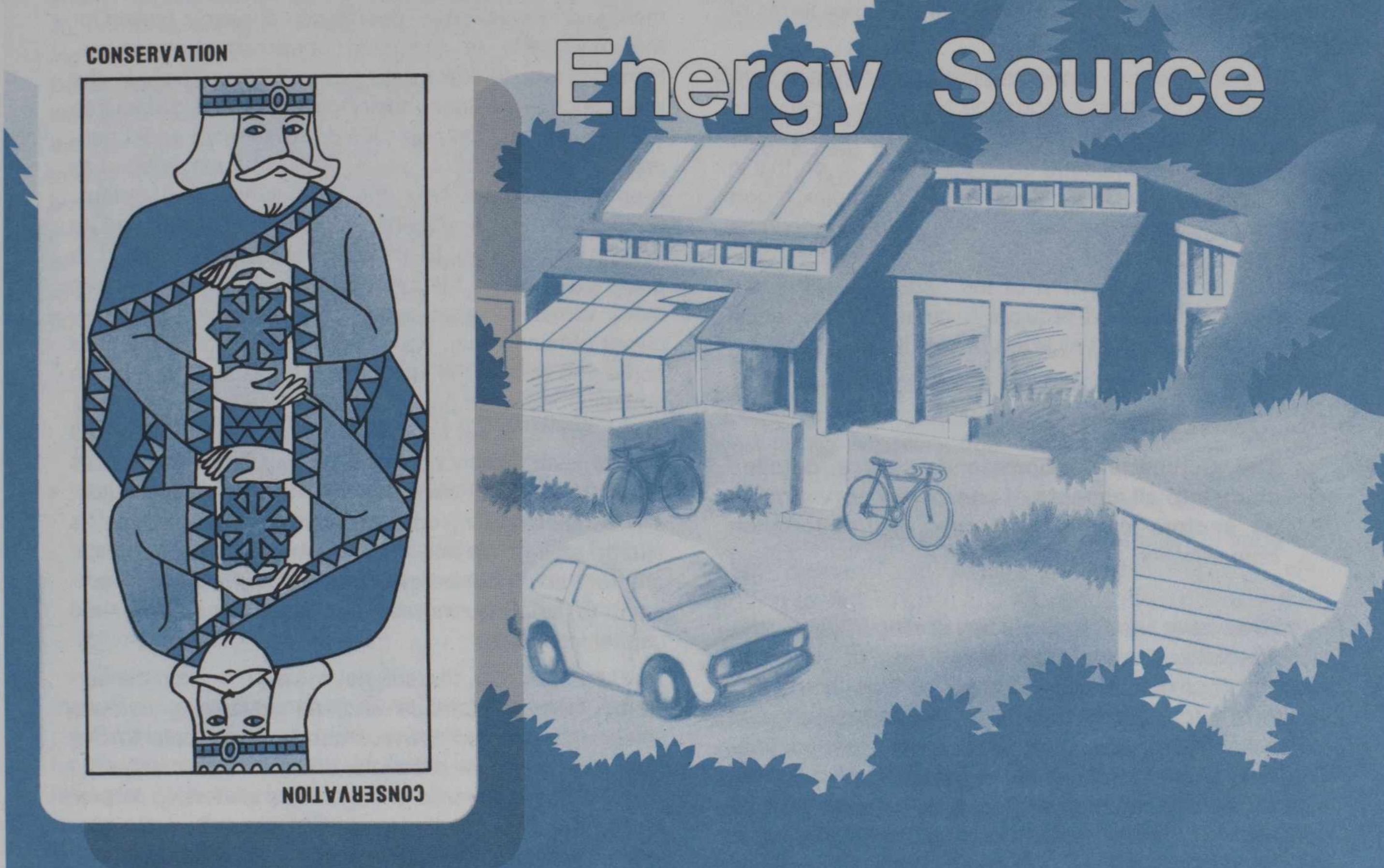
The Committee realized early in its study that the complex subject of energy would have to be broken down to make it manageable. For instance, the sun is clearly a *source* of energy but is coal liquefaction? No, the latter is a *technology* which transforms a conventional energy source, coal, into a commodity such as methanol which has the potential to play an important role in a new Canadian energy mix. This technology can be further qualified as *alternative* because it has not previously been exploited commercially in this country. It is not a new technology since coal liquefaction facilities have existed since before the Second World War. It does, however, represent a new and alternative option for Canada.

Other subjects for discussion could not be termed either alternative sources or alternative technologies, hydrogen and electricity being examples. We have not viewed hydrogen as a source of energy since energy must be used to produce it and to concentrate it. Hydrogen does, however, store energy and can be exploited as a fuel to perform useful work. If, for example, energy were produced in a tidal installation and not immediately consumed, it could be stored in the form of hydrogen (through electrolysis which uses electricity to break water molecules into hydrogen and oxygen). The hydrogen could then be transported in liquefied or compressed form or moved by pipeline. Thus one can think of hydrogen as an energy *currency* which can be "spent" at any time to provide useful work. Electricity also acts as a medium of energy exchange or an energy currency, in that it can be generated in one location and perform useful work elsewhere.

For the purposes of this Report, the word currency has been adopted to characterize those commodities which are neither energy sources nor energy technologies. They are intermediaries between the source from which energy is derived and the point where energy is consumed. Energy currencies are often known as fuels, but the term fuel normally refers to combustible materials and therefore does not aptly describe electricity. An energy currency is thus a medium of energy exchange which can be spent in return for work. We see a variety of alternative energy sources, currencies and technologies being exploited in concert to produce a technically, economically, environmentally and socially acceptable energy mix for Canada in the future. These alternatives are briefly described in succeeding parts of this section in order to acquaint the reader with the range of possibilities considered by the Committee and to provide basic information about some energy possibilities which may not be familiar. Each subsection describes the nature of the source, currency or technology, lists some of the advantages or difficulties which may accompany its exploitation, discusses development activities on the national and international scene, and suggests where Canada should go from here concerning each option.

We do not claim to have exhausted all the possibilities for study. Indeed, such a task would be unending because technology is continually evolving and it is difficult to predict where research will lead. We therefore view the Committee's work as one step in a continuing process of evaluating Canada's energy opportunities.

Conservation as an Energy Source



It may seem unusual at first glance to include conservation in a section entitled Alternative Energy Sources, Currencies and Technologies, but the Committee has come to view conservation as an energy source. We feel that the conservation resource is large in Canada, principally because energy efficiency was not a prime consideration in the past. Energy has traditionally been inexpensive and for this reason our economy has evolved in a way which results in Canada spending more energy per dollar of gross domestic product generated than other countries. Paradoxically, this means that although our former wasteful practices may be regrettable, they do provide a substantial conservation energy resource which can generally be exploited more easily and more economically than any other energy source today. By reducing demand, the value of existing energy supplies is increased in relative terms.

Many witnesses told the Committee that conservation must be the cornerstone of any alternative energy

Conservation and the Energy Supply Gap

Suppose a country can only supply 60% of its energy needs; that is, the ratio of supply to demand is 60/100. If that country reduced its demand to 80% of its former level, then the supply-to-demand ratio would become 60/80 or 75%. In other words, by tapping the conservation energy resource, this country could improve its supply-to-demand ratio from 60% to 75%, an improvement of $\frac{75 - 60}{60} \times 100$ or 25%, without investing in the supply of one additional unit of energy.

strategy and we agree wholeheartedly with this conclusion. It is, in fact, this conviction which has led us to give conservation a prominent position in our Report, even though it was not specifically mentioned in our terms of reference.

It is one thing to recognize and accept that conservation is of uppermost importance but it is quite another to suggest what specific steps should be taken to ensure that we exploit this resource. To undertake to do this in the context of this Committee's already complex report on alternative energy would, we feel, greatly understate the importance which this subject carries. Because conservation is not a concern of the Federal Government alone, it deserves and requires a detailed study which looks at this subject at all levels of jurisdiction.

RECOMMENDATION

The Committee recommends that a detailed study into all aspects of energy conservation, in all sectors of the economy, be undertaken immediately.

There have been many studies dealing with individual conservation technologies and studies of industrial, residential or commercial energy conservation. This wealth of information needs to be pulled together and the study we propose could well carry out this function. The study should be aimed at the needs of policymakers and should offer recommendations on specific policies and standards which could be implemented. Regional variations in the supply and demand for energy must also be accounted for as no single policy will be suitable for all regions of the country nor for all sectors of the economy. The study should also differentiate in some detail between capital and operational costs so that a clear picture of the payback from conservation initiatives is obtained.

While we have not undertaken a detailed examination of conservation, we have been exposed to a wide variety of concepts, proposals and opinions on this subject. We therefore present the following observations and comments as examples of the information we have received and the opinions we have formed, knowing full well that we have only touched briefly upon the subject.

To take complete advantage of the conservation resource, two approaches must be taken: wastefulness must be discouraged and the efficiency of all our energy-consuming activities must be improved. The first approach needs no explanation; the second requires us to begin thinking of our daily activities in terms of the amount of energy they consume. In short, we must build energy efficiency into products, processes and lifestyles. We have to develop a sense of energy responsibility.

Initially, progress in conservation may be slow because the market for energy and energy technologies is ineffective at signalling appropriate levels of investment in conservation — people do not have a feeling for the real costs of foregoing conservation measures. Homeowners, for example, may react negatively to the initial price of insulating their homes and fail to take into account the real savings such an investment could generate over a period of years. Programs are needed to prompt people to make the correct energy decisions. For instance, Hydro-Québec has recently introduced an innovative program to promote home insulation. It is designed to make the initial capital cost — a barrier in many cases — disappear. Under its terms, a homeowner obtains a loan from Hydro-Québec to insulate his home and repays the loan over five years by paying the difference between pre- and post-insulation heating bills. The customer is not faced with a large capital outlay and for five years simply continues to pay his heating bill as he would have otherwise without the added insulation. Thereafter, his billing drops to the new level reflecting his energy saving. We see no evident reason why a similar program could not be extended by the Federal Government to small businesses and industries with limited capital resources.

Unfortunately, there is not a well-organized conservation lobby in Canada and, as advertising is overwhelmingly directed towards convincing people to buy and consume most products, this message is reflected in our attitude towards energy. Thus leadership in promoting the conservation ethic must come from Governments, which have only recently begun funding and encouraging energy conservation efforts. The Federal initiative has begun well and the Committee recognizes that Canada's public education program in energy conservation has been widely applauded. Despite this, there remains room for improvement and greater public and governmental commitment to conservation is imperative. With these concepts in mind we now consider some of the conservation suggestions which the Committee received from various sources.

Electricity will contribute a larger share of end-use energy in Canada in the future, and this energy currency should be wisely managed and spent. Two measures which would help ensure that this is accomplished are listed here.

- The current practice of charging less for higher levels of electrical use should be discontinued.
- Utilities should consider rate structures which encourage the use of off-peak electricity.

The transportation sector is one of the largest consumers of energy in our economy and Canadian drivers seem as reluctant as ever to abandon the convenience of private automobiles. This is not surprising as our cities, towns and villages are built around personal transportation. A large potential exists, however, for energy economizing in moving goods and people. Automobiles are becoming lighter, engines are becoming more efficient in their use of fuel, auto bodies are being made with improved aerodynamic efficiency, tires with less rolling resistance are being developed — these are some of the design approaches already generating energy savings and much more can be accomplished along these lines. More innovative changes, such as incorporating flywheels into vehicles, may produce similar benefits in the future. Energy savings can also be realized through improved management of vehicular flows, as the following examples suggest.

- Although existing speed limits are acceptable and practical for this country, they must be *enforced* so that vehicles are driven at speeds which make efficient use of fuels.
- Stop signs should be replaced by yield signs wherever safety permits to reduce energy-wasting stops and starts. Similarly, whenever possible, traffic lights should switch to flashing amber, instead of continuing through a full amber, red, green cycle when traffic volume does not warrant it.

There are significant savings to be realized by manufacturing industries as well. This sector was built predominantly in an era of low-priced energy and, as a result, it was often inefficient in its use of energy. In response to a call by the Federal Government in 1974 for an aggressive and voluntary program to cut energy demand, the industrial sector established 15 conservation task forces. Each task force represented one segment of the industrial sector (pulp and paper, chemicals, food and beverage, industrial minerals and so on) and each set its own goals. Industries responded very favourably since conservation quickly paid off for them and results have been encouraging. Some sectors met their 1980 targets ahead of schedule and are formulating new goals for even greater savings. Although this is only a start and a sustained effort will be necessary, the Committee is encouraged by the early success of these voluntary activities. We would like to see this initiative continue to ensure that:

- Industrial processes are redesigned, changed or retrofitted when and wherever feasible to reduce the amount of energy they consume.
- Industries place added emphasis on maintaining machinery at levels of maximum energy efficiency and replace "extravagant" energy users with new and energy-efficient equipment.
- Every effort is made to utilize what is now considered waste heat generated in industrial processes.

Since a large amount of Canada's energy is used in heating and lighting buildings, there is significant potential for energy savings here as well. In this sector, however, the message of conservation should be accompanied by information concerning the concept of passive solar design.

RECOMMENDATION

All levels of government should cooperate in ensuring that architects, builders and contractors learn and practice energy-efficient design and construction. In particular, these people should be made aware of the energy-saving benefits which result from the passive use of solar energy.

Passive solar design incorporates a number of energy-saving features such as insulated night shutters, double or triple glazing, removal of most north- and west-facing windows, the use of windbreaks and/or earth berms (embankments) to the north and west of buildings, or building into the south face of a hill.

Other measures to reduce heat loss, which apply to both ordinary and passive solar buildings, include adding extra insulation and improving airtightness. It has been demonstrated in Canada that these two measures, plus using a larger area than usual of south-facing windows, make it possible to construct houses in which energy consumption is reduced by 80 to 90% compared with similar houses built to existing standards. The Committee had the opportunity to visit the most well-known of these energy-efficient homes, Saskatchewan Conservation House, during the course of its cross-country hearings.

Demonstrating that these levels of energy saving are possible was an important first step, but what people really want to know is, "Can it be done cost-effectively?" Unfortunately there is not yet a great deal of data on the costs and benefits of energy-efficient passive solar design due to the limited number of passive solar homes and the minimal amount of monitoring which has been done on those which are in place. Nonetheless, there seems to be sufficient information available to make at least preliminary estimates.

A recent study done for the Department of Energy, Mines and Resources (Gough, 1980) performed such an analysis. It concluded that in new construction the most cost-effective strategies, in order of priority, were to (1) relocate as much as possible the normal window area of a house on the south wall; (2) increase the insulation in buildings by about 50% beyond the 1978 NRC standards; and (3) either further increase thermal specifications or further increase the south-wall window area beyond redistribution.

The conclusions of this study agree with testimony heard by the Committee. Energy-efficient housing can use standard building materials and techniques, so the technology is available now. Furthermore, it appears that substantial energy savings can be achieved within a reasonable payback period for the added investment. If all of these conclusions are correct — and we have no reason to believe that they are not — then why is such housing not being constructed on a much broader scale in Canada today? Several Committee witnesses described barriers to the construction of energy-efficient housing and certain factors were identified time and time again. The proposed energy conservation study will perhaps identify other obstacles which are not now apparent.

Economics play a very large role in determining the adoption of energy-conserving construction practices and the inclusion of passive solar features. The initial capital investment can be justified by savings in energy costs over time; however, the consumer faces the problem that the return on his investment may not be realized for as much as 10 or 15 years. Certainly the current high rates of interest for loans and mortgages deter many would-be "conservers" from making such an investment. Moreover, the uncertainty of future energy prices clouds the issue of the length of the payback period.

A person's eligibility for a mortgage is based on a calculation of the proportion of his or her monthly salary available to make payments. With an energy-efficient house and the resultant lower energy costs, a person would have more money available each month — perhaps enough to cover the increased mortgage charges occasioned by adding the cost of the conservation measures to the mortgage. This suggests that the method of calculating mortgage limits should be changed to take energy saving into account. This would seem to be a particularly appropriate measure for the Canada Mortgage and Housing Corporation (CMHC) to consider when funding non-profit housing.

CONCLUSION

Federally-financed housing provides an excellent opportunity for the Government to demonstrate the benefits of conservation and passive solar design.

RECOMMENDATION

The Committee urges that Federally-financed housing incorporate energy-conserving and passive solar design in order to demonstrate its benefits.

In this regard, the Committee welcomes the announcement in the 1980 National Energy Program of a $6 million measure to promote energy-efficient housing through workshops, training programs, and the design and construction of 1,000 energy-conserving homes across Canada. If this program were extended to social housing, it would provide the added benefit of shielding those in need of such homes from increasing energy costs.

The NEP initiative provides a chance to gain much-needed practical experience in the operation of passive solar heating systems. Such systems are by no means simple and there is a complex relationship between energy collection, storage and conservation in these buildings. Unless these elements are properly balanced, a passive solar house can be a very uncomfortable place to live in.

Another barrier to the widespread use of energy conservation measures and passive solar systems is the lack of suitable building standards. In October 1980 the ten provincial Energy Ministers called on the Federal Government for improvements in the National Building Code (NBC) to ensure that energy conservation features were included. This call for action followed the publication of a set of building standards known as *Measures for Energy Conservation in New Buildings* (1978). As with the NBC however, adoption of these measures by the provinces is voluntary and, as of the end of 1980, not one province had adopted the new standards. The Division of Building Research at the National Research Council carried out a study to determine why none of the measures has been adopted and the major reason was found to be the lack of inspectors qualified to oversee the new measures. The cost involved in retraining building inspectors would have to be borne by the provinces and this illustrates the type of jurisdictional problem facing the Federal Government in its attempts to promote energy conservation through the building code.

Several witnesses suggested to the Committee that the Federal Government ought to develop a new building code based on energy performance standards. They believe that such standards are an important signal to the construction industry and to consumers that conservation is an important priority with the Government. The Division of Building Research (DBR) is in fact developing guidelines for energy budgets in four types of buildings: office buildings, shopping centres and retail stores, apartment buildings, and schools. DBR hopes to publish these guidelines in 1983 as a first step towards a comprehensive set of building energy performance standards. As the standards develop, DBR is also assessing how compliance with the guidelines can be assured as this is seen as one of the main problem areas. All levels of government will have to work together if progress is to be made.

RECOMMENDATION

Energy performance standards for buildings should be incorporated in the National Building Code so that conservation and innovative design and construction are promoted.

RECOMMENDATION

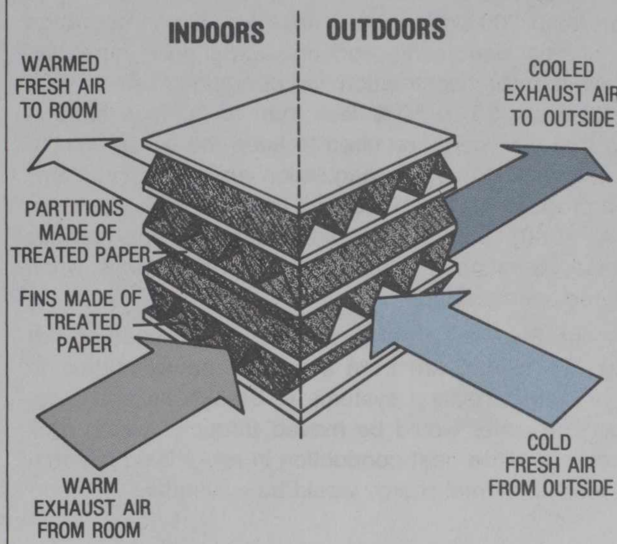
Standard tests for the energy performance of buildings should be established by the Federal Government so that energy-efficiency ratings can be assigned.

The Committee has concluded that performance standards are preferable to prescriptive standards since they do not stifle innovation and thus allow architects and builders freedom of choice in developing energy-efficient housing. Nonetheless, prescriptive examples must still be provided to assist the building trades in adapting to the new standards. The Committee recognizes that building performance is more difficult to assess, but feels that the extra effort is worthwhile. We also recognize that in developing a performance code, regional standards will be required to take account of climatic variations across Canada. The proposed development of such standards for the Canadian Arctic (Canada, EMR, 1980e) is an appropriate beginning to this process.

Another interesting suggestion put before the Committee recommended conducting a voluntary performance test on new housing. A 24-hour airtightness test, similar to a mandatory test done on all new homes in Sweden, would provide a fuel economy rating which consumers could use as a basis for comparing homes. That is to say, like the miles per gallon ratings on cars, such a system would not provide a guaranteed fuel consumption figure but rather a means of comparison. Once homebuyers are made aware of the potential energy savings which can be realized in energy-efficient housing, it is felt that they will begin to demand this sort of home in the marketplace. As a first step, the Federal Government should subject its own buildings and those which it helps finance to such tests. Private contractors should then be encouraged to assign an energy performance rating to their buildings as well.

Airtightness does conserve energy but it may also lead to the accumulation of unacceptable levels of indoor pollutants and to excess humidity if proper precautions are not taken. This problem can be overcome by providing adequate and controlled ventilation in the otherwise airtight building. By passing incoming cold air and outgoing warm air through an air-to-air heat exchanger (Figure 6-1), proper ventilation can be achieved without losing excessive amounts of heat to the outdoors. A number of air-to-air heat exchangers are on the market at prices ranging from $100 to $500, and plans are also available for inexpensive do-it-yourself units.

Figure 6-1: A SIMPLE AIR-TO-AIR HEAT EXCHANGER



As warm and cold air pass each other in separate and alternating layers of the heat exchanger, heat is transferred from the outgoing stale air to the incoming fresh air. This ensures air exchange but recovers most of the heat which would normally escape with the vented air.

Source: After Hand, 1980, p.77.

RECOMMENDATION

The Committee recommends that the Federal Government establish a standard procedure for testing the airtightness of buildings. The Committee further recommends that, once established, the test be applied to Federal buildings and to all new homes financed through the Canada Mortgage and Housing Corporation.

Further energy savings in buildings can be achieved by reducing lighting levels (provided that the lighting is not already serving to handle part of the heating requirement of the structure).

RECOMMENDATION

Lighting regimes in business and homes should be designed to ensure that electric energy is not wasted.

In a greater departure from typical building design, one witness advocated underground construction as a means of lowering the energy requirement for space heating and cooling. This saving can be realized because temperature fluctuations within the soil or bedrock are much smaller than in the air. For example, an estimated 10% of all cold storage in the United States is underground in Kansas City. In Scandinavia more than 200 underground units are now in operation for storing petroleum products. Experience here has shown that the construction and operating costs of such facilities are 30 to 50% less than for surface storage and that the energy required to keep the oil warmed to 50 to 70°C (to avoid coagulation and other problems with product quality) is reduced by 60 to 80% (Jansson *et al*, 1980). Cold storage and frozen storage facilities similarly demonstrate impressive energy savings when located underground.

The Swedes are also considering transporting hot water up to 120 km from a nuclear power station to serve district heating systems in Stockholm and Uppsala. The water would be moved through unlined rock tunnels because heat conduction in rocks is so low that the loss of thermal energy would be minimal.

While the groundwater regime and other subsurface conditions will prevent underground construction from being practiced in some locales, this approach should be receiving more serious consideration in Canada.

RECOMMENDATION

Underground construction should be encouraged in appropriate circumstances as an energy-conserving building technology.

As we noted at the beginning of this section, we have done little more than give examples of some energy-conserving suggestions made to the Committee. Nevertheless, the breadth of these suggestions has reinforced our conclusion that the conservation resource is rich indeed and worthy of much more attention than it has thus far received.

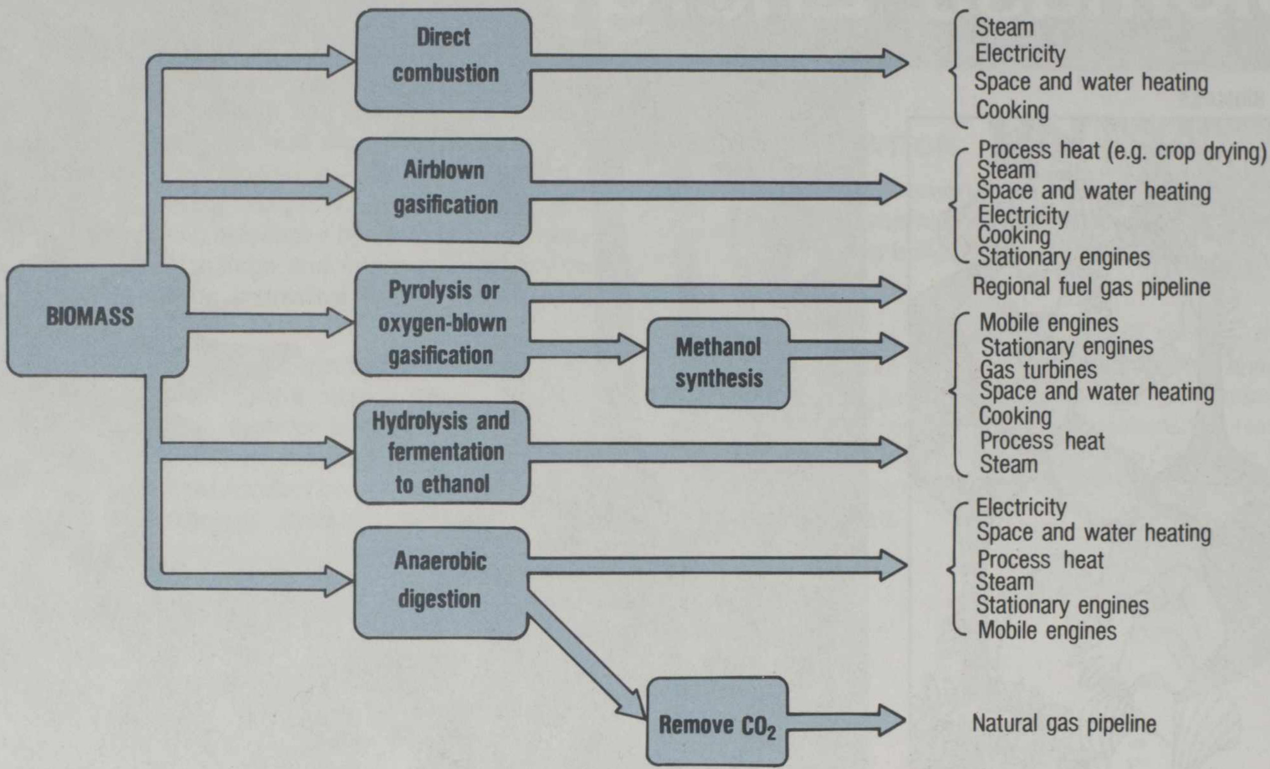
Biomass Energy

The term biomass refers to all matter of plant and animal origin excluding fossil fuels. This organic material is an exploitable energy resource because the carbon contained in the large molecules of biological organisms can be made to undergo a variety of chemical reactions which either release energy directly, or convert the original substance into new forms which can be reacted later to release energy.

The abundance and variety of organic matter which makes up the biosphere contains a large amount of energy. With petroleum destined to lose its preeminent position in our energy affairs, biomass has become more attractive as an alternative source. Originally biomass supplied most of this country's energy needs but when inexpensive fossil fuels became available to consumers, first coal then petroleum supplanted biomass as Canada's most important energy source. Today biomass meets only 3 to 4% of Canada's primary energy requirements.

Strictly speaking, biomass energy can be classified as a form of solar energy because plants are really organic solar receptors which intercept, transform and store the energy of the sun's radiation in the chemical bonds of large, complex, organic molecules. The chemical energy contained in such macromolecules can be released in a variety of ways (Figure 6-2): it can be burned directly; it can be gasified under anaerobic, aerobic or oxygenated conditions to produce synthesis gas; it can be hydrolyzed and fermented to alcohols; or, it can be anaerobically digested to produce biogas (methane). Thus biomass is a flexible energy source which can produce a variety of products, all of which are eventually combined with oxygen to release energy and do useful work.

Figure 6-2: FUEL USES FOR BIOMASS



Source: United States, Office of Technology Assessment, 1980a, p. 24.

There are a number of advantages which accrue from exploiting biomass as a source of energy.

- It is an abundant resource.
- It is available in many different forms and can be adapted to a variety of uses.
- Biomass is continuously renewable provided adequate resource management practices are carried out.
- Its combustion can not only provide energy but it can also help reduce the waste disposal and/or pollution problems associated with the forest, pulp and paper, and food processing industries, and with the municipal and agricultural sectors.
- The combustion of recently living organic matter does not significantly alter the concentration of carbon dioxide in the atmosphere as does the combustion of fossil fuels. (This presumes proper management of the biomass resource.)
- Biomass is a widely dispersed resource which can often be well matched to regional requirements and small decentralized sites for energy production.
- Biomass can replace high-sulphur-content fossil fuels and, in so doing, can reduce sulphur dioxide emissions, one of the prime causes of acid rain.

There are, however, a number of difficulties associated with using biomass for energy production on a large scale.

- The harvesting of vast amounts of biomass could radically modify natural ecosystems and irreversibly damage them or, even worse, completely displace them. (This impact could be reduced with proper resource management; however, if very large amounts of energy were to be derived from biomass, the amount of growing space required would be correspondingly extensive.)
- There is a great deal of controversy over whether large tracts of land should be used for food or energy production.
- The resource is often remote in location.
- It typically has a low energy density (contains a low amount of energy per unit weight).
- It is often difficult to ship and store because of its wide variety of forms, which means that much of this resource is not economically exploitable with prevailing energy costs.
- Biomass usually has a high moisture content, meaning it must be dried before burning because energy con-

tent is inversely proportional to water content and combustion efficiency increases with fuel dryness.

- If biomass is burned in numerous, small, widely-dispersed combustion units, it is difficult to control or contain emissions.
- Biomass has a relatively high ash content.
- The incomplete combustion of biomass, such as occurs in most wood stoves and fireplaces, releases polycyclic organic matter (including benzo [a] pyrene and several other known or suspected cancer-producing agents) to the atmosphere.

1. ALCOHOL FUELS

There are two types of alcohol which have recently received attention as possible transportation fuels. These alcohols are methanol, characterized by the chemical formula CH_3OH, and ethanol, C_2H_5OH. Although the former is usually associated with the feedstock wood (methanol has long been referred to as wood alcohol), it can also be synthesized from other biomass feedstocks, as well as from natural gas and coal. Ethanol can similarly be derived from wood but the process has not yet reached the commercial stage and nearly all ethanol is produced from the fermentation of sugar- or starch-containing biomass.

Alcohols have long been considered attractive as liquid fuels. Henry Ford originally designed the Model T to run on alcohol and later modified the design to accommodate alcohol, gasohol or gasoline when petroleum-derived fuels became cheap and plentiful. Alcohols are well suited for use as fuels because they are completely biodegradable, are easily portable, have a relatively high Btu content per unit weight (Table 6-1), burn cleaner than petroleum-derived fuels, and have a higher octane rating than pure gasoline with no additives (octane number is a measure of a fuel's resistance to self-ignition). The combustion products of ethanol are discussed in the section on Nonconventional Propulsion.

Table 6-1: ENERGY CONTENT OF METHANOL, ETHANOL AND GASOLINE

	Btu/lb	MJ/kg
Methanol	8,570	20
Ethanol	11,500	27
Gasoline	18,900	44

Source: After Mathers, 1980, p. XXII-11.

A. ETHANOL

Ethanol (C_2H_5OH) is produced almost exclusively by fermentation and all such processes consist of four basic steps: (1) the feedstock is processed and/or treated to produce a sugar solution; (2) yeasts or bacteria convert the sugar to ethanol and carbon dioxide; (3) distillation is used to remove the ethanol from the fermentation solution, yielding an ethanol/water solution which is at best 95.6% ethanol at normal pressures; and (4) any remaining water is removed to produce "dry" or anhydrous ethanol. This latter step is usually accomplished by a second distillation in the presence of another chemical.

Distillation

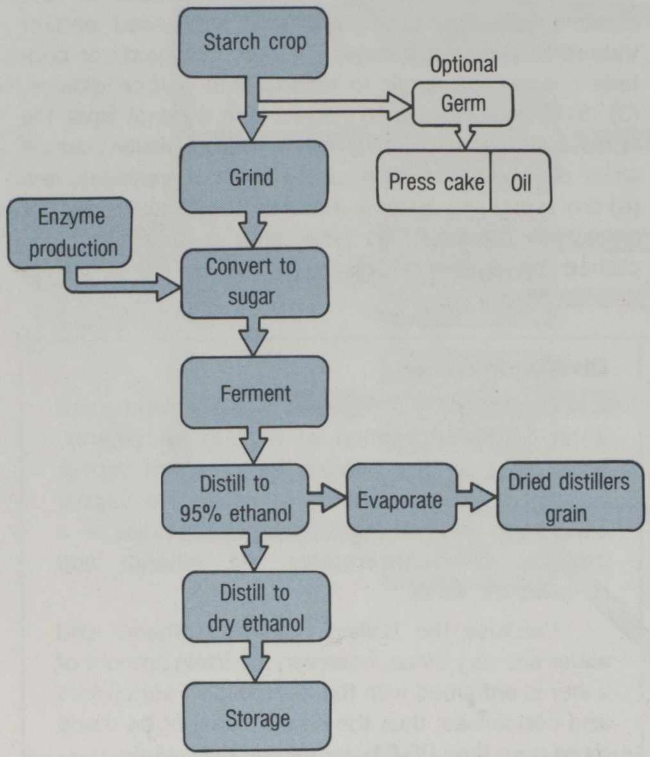
Distillation is a physical process which consists in this application of heating an ethanol-water solution and passing the resultant vapour through a cooling column in which the vapour condenses and revapourizes numerous times — a process that concentrates the ethanol and removes the water.

Because the boiling points of ethanol and water are very close, however, a certain amount of water is entrained with the ethanol as it vapourizes and condenses; thus the ethanol cannot be made more pure than 95.6% by this process alone.

The main distinctions among fermentation processes utilizing different feedstocks arise primarily out of differences in the *pretreatment* steps to which the feedstock is subjected. Sugar-containing crops such as sugarcane, sweet sorghum, sugar beets and sugar mangels yield sugar directly upon processing, but the sugar must be concentrated or treated in some other fashion for storage to prevent it from being broken down by bacteria. Starch-containing feedstocks such as corn and other grains need to be broken down (hydrolyzed) with enzymes (biological catalysts) or acids to reduce or convert the starch to sugar. Similarly, cellulosic (woody or cellulose-containing) feedstocks such as crop residues, grasses, wood and municipal wastepaper require extensive hydrolysis (either acidic or enzymatic) to reduce their more inert, long-chain, cellulose molecules to sugar subunits. No commercial cellulose-to-ethanol installations exist at the present time but pilot plants have been established in Brazil using eucalyptus wood. Small-scale experiments are being carried out in Canada as well.

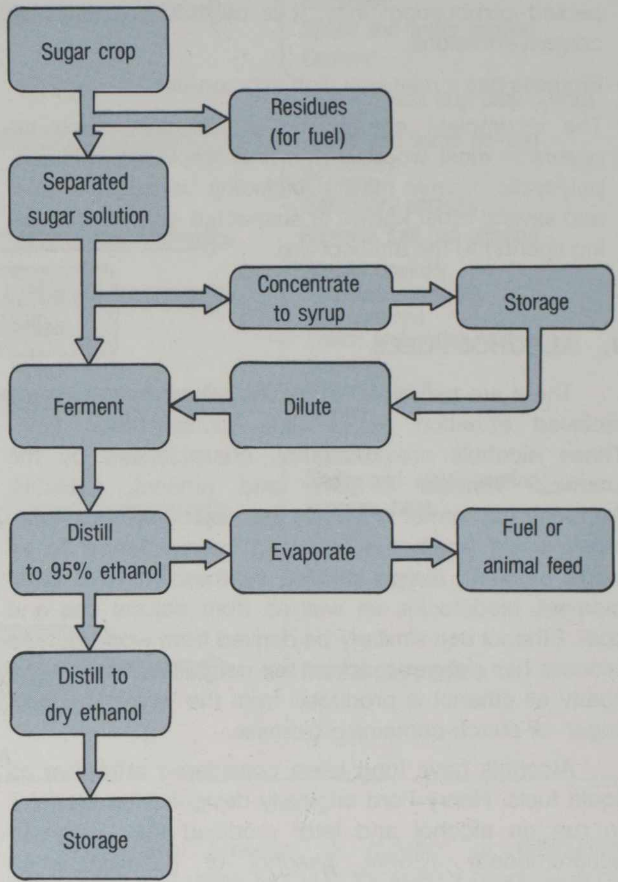
Ethanol can of course be produced from starch and sugar feedstocks with commercially available technology. Starch feedstocks are primarily grain crops such as corn, wheat and oats, but also include various root plants such as potatoes. The sugar feedstocks are

Figure 6-3: PROCESS DIAGRAM FOR THE PRODUCTION OF FUEL ETHANOL FROM STARCH-CONTAINING CROPS



Source: United States, Office of Technology Assessment, 1980b, p. 160.

Figure 6-4: PROCESS DIAGRAM FOR THE PRODUCTION OF FUEL ETHANOL FROM SUGAR-CONTAINING CROPS



Source: United States, Office of Technology Assessment, 1980b, p. 160.

plants such as sugarcane, sweet sorghum, sugar beets, mangels and Jerusalem artichokes. The two processes for producing ethanol from starch and sugar feedstocks are shown schematically in Figures 6-3 and 6-4.

The attractiveness of ethanol derives from the fact that it can be used directly as a portable liquid transportation fuel or it can be mixed with gasoline to produce gasohol. In either case, it reduces demand for gasoline.

Mohawk Oil is the first company in Canada to produce gasoline-ethanol fuels. This company will be using ethanol, manufactured from damaged or surplus agricultural crops at the rate of approximately two million gallons per year (roughly 155 barrels per day) in a revamped distillery, to produce gasohol for sale in retail outlets in Manitoba.

The proposal to make ethanol from *cellulose* is very appealing as it would allow exploitation of Canada's substantial cellulosic biomass resource, including wood wastes, spruce-budworm and fire-damaged wood, for feedstock. This resource is much larger than that represented by our starch and sugar crops and our food processing wastes combined, and its exploitation would avoid using food crops for energy production. Unfortunately, there are problems in breaking down cellulose to sugars which can be fermented to ethanol.

Wood

Wood is composed primarily of cellulose, hemicellulose and lignin. Cellulose can be broken down to sugar and then fermented to alcohol. Hemicellulose, on the other hand, is composed of 5-carbon sugar (pentose) subunits and is more difficult to convert to ethanol. Researchers at the NRC have, however, made good progress in developing organisms capable of pentose fermentation. Lignin binds the woody material together, makes the cellulose difficult to hydrolyze and is itself not fermentable to alcohol.

A new process has been developed in Canada whereby cellulosic material is steam exploded to open the wood structure and make the cellulose accessible for hydrolysis. This technique, together with the development of new hydrolytic enzymes, new genetically-engineered fermenting organisms and new ways of separating and utilizing the lignin by-product of the process, promises to make the production of ethanol from cellulosic feedstocks much more attractive in the future. If biotechnological research produces new organisms which can improve the efficiency of the overall process, ethanol from biomass may become a much more attractive alternative energy option in the future.

CONCLUSION

Canada could become a world leader in cellulose-to-ethanol technology by encouraging the research, development and demonstration of novel processes already being developed in this country.

RECOMMENDATION

The Committee recommends that the Federal Government, through Canertech, encourage the research, development and commercialization of cellulose-to-ethanol technology.

The controversy over whether or not ethanol production from agricultural crops results in a net energy gain remains to be resolved. If there is a net energy gain, it is certainly small. Similarly, the controversy over whether agricultural crops should be used for food or for fuel rages on. Many observers now agree, however, that two competing end uses for the same product will inevitably lead to increased food prices and perhaps, in some instances, to food shortages in the future.

CONCLUSION

The Committee believes that fuel ethanol should be produced from spoiled and/or surplus crops and from crops grown on marginal land. Only in special circumstances should prime agricultural land or crops be exploited.

CONCLUSION

The Committee believes that exploitable ethanol feedstock resources (not counting cellulose) cannot provide enough ethanol to power the whole transportation sector.

RECOMMENDATION

Ethanol should be used as a gasoline extender only and not as a substitute transportation fuel in pure form, except perhaps on farms.

Individuals and members of farm co-operatives may wish to proceed with alcohol production using surplus or damaged crops or biomass grown on marginal land. To date, experience with the on-farm production of alcohol in the United States has shown that this can be an expensive and frustrating venture. Nevertheless, some farmers feel such production could be profitable and provide a measure of energy self-sufficiency on the farm. There is no single recommended method for ethanol distillation and each operation must consider the availability of conventional fuels for the distillation process as well as the kind of ethanol feedstock available. For example, the amount of ethanol which can be derived from different crops varies widely (Table 6-2). Furthermore, farmers must take into account the capital investment required for stills and the use to which the alcohol and by-products of distillation will be put.

Table 6-2: POTENTIAL ALCOHOL YIELD FROM SELECTED STARCH- AND SUGAR-CONTAINING CROPS

Crop	Yield[a] (litres/tonne)
Corn	430
Winter wheat	410
Barley	390
Rye	390
Spring wheat	380
Mixed grains (West)	350
Buckwheat	350
Peas, beans	350
Mixed grains (East)	330
Oats	270
Potatoes	110
Jerusalem artichokes	87-100[b]
Fodder beets	70-77[b]
Sugar beets	70
Field roots	30

[a] Yield assumes a maximum theoretical conversion to alcohol of 95%. The efficiency on farms would more likely be 50 to 85%.
[b] Preliminary values.

Source: Canada, Department of Agriculture, 1980, p. 4; and personal communication, Department of Agriculture, 1981.

The on-farm distillation of ethanol can give a measure of independence from conventional fuels because gasoline engines can burn gasohol containing between 10 and 20% ethanol without modification and apparently without causing damage. Kits are being developed to allow gasoline and diesel engines to burn mixtures of gasoline (or diesel), alcohol and water, and engines which run on pure alcohol have been developed although they are not commercially available in Canada.

The economic risk of farm-scale alcohol production is not well defined. Farmers may find this activity worthwhile if they are good handymen and can build a still rather than buy a commercial set-up. They may also not count their own labour in overall costs. In any event there will be some capital outlay and interest to be paid on the capital. In addition, the farmer must consider the loss in revenue from not selling that portion of a crop which is used as ethanol feedstock, plus the costs of depreciation, operation, energy inputs, chemicals, enzymes, insurance, licensing and bonding. (Feeding the mash or residue from ethanol production to livestock could help offset some of these expenses.)

CONCLUSION

Evidence suggests that on-farm alcohol production can be a risky business. Some knowledge of chemistry, engineering, microbiology and plumbing is required and careful economic planning must be carried out before any such operation is attempted.

One way in which Canada is attempting to make it easier for interested and enterprising individuals or groups to begin alcohol fuel production is to ease regulations set out in the Excise Act. Under existing legislation, alcohol must be collected in a "locked receiver" which can only be opened by a customs and excise inspector. The alcohol must also be rendered undrinkable (denatured) by adding a prescribed chemical if the alcohol produced is to be free of excise duty. Furthermore, a distiller's license ($250 per year) is required as well as a surety bond of $200,000 which costs $500 per year. These restrictions inhibit would-be distillers from making alcohol fuel.

CONCLUSION

The Committee welcomes the Government action to amend the Excise Act, making it easier for interested people to begin distilling alcohol fuel.

RECOMMENDATION

The Committee recommends that the Government ensure, in its amendments to the Excise Act, that production of ethanol in excess of individual requirements may be sold to retail suppliers of alcohol fuel or gasohol.

RECOMMENDATION

The Committee does not endorse pure ethanol from starch or sugar feedstocks as a major alternative liquid transportation fuel for Canada. It does, however, recommend that fuel ethanol be permitted for personal use or for the production of gasohol.

B. METHANOL

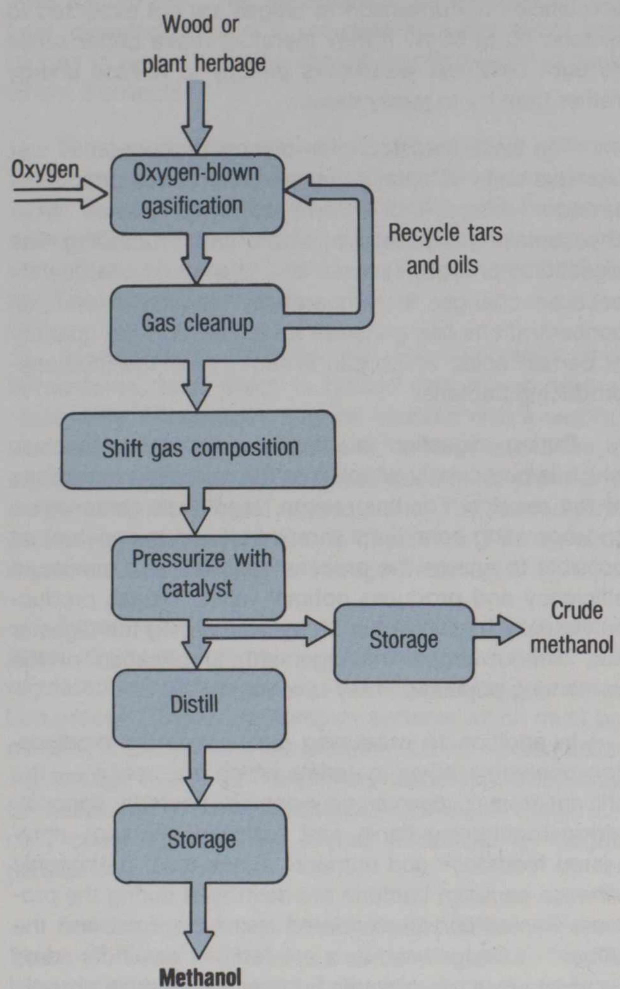
Methanol (CH_3OH) can be synthesized from a variety of sources including biomass, natural gas and coal. In the cases of biomass and coal, the raw feedstock must first be gasified before synthesis.

In the production of methanol from wood biomass, three basic steps are involved: gasification of the wood, cleanup and modification of the gas produced, and liquefaction of the gas. Generally, gasification occurs when the wood is heated in an atmosphere deficient in oxygen. This prevents complete combustion of the wood and produces a gas containing principally hydrogen, carbon monoxide, carbon dioxide and hydrocarbons. These gaseous compounds are not produced in concentrations ideal for the synthesis of methanol; therefore, their relative proportions are altered to obtain a hydrogen to carbon ratio which will provide good yields of methanol. In the final step, methanol is produced by subjecting the modified synthesis gas to from 50 to 150 atmospheres of pressure at 230 to 270°C in the presence of a catalyst. A flow diagram for methanol synthesis is given in Figure 6-5.

Initially, a methanol industry could be fueled by unusued mill wastes, forest residues, and other recoverable biomass not currently utilized. In the long-term, however, significant potential exists for tree farming (energy plantations) to provide the cellulose required to feed methanol plants. These plantations would allow abandoned farms and marginal lands to provide high yields of forest biomass with rotation times of from two to five years.

Since the quantities of cellulosic feedstocks are so much greater than those of sugar or starch crops, it would seem there is greater potential for alcohol production via the methanol route than via the ethanol route (although production of both alcohols can be encouraged). The provision of cellulosic feedstocks for methanol production requires less energy than does raising agricultural starch or sugar crops. In other words, the chances of achieving net energy gains from methanol may be greater than from ethanol. Fewer land-use arguments should arise in producing feedstock for a methanol industry than for an ethanol industry as trees can be grown on land which ranges widely in quality and topography. Indeed, there is unlikely to be

Figure 6-5: PROCESS DIAGRAM FOR METHANOL SYNTHESIS



Source: United States, Office of Technology Assessment, 1980a, p. 95.

severe competition between crops for energy and crops for food if methanol is produced, thus resolving the "food versus fuel" controversy to some extent.

Witnesses before the Committee described a unique Canadian opportunity for development of a methanol industry, incorporating a combined natural gas/biomass primary feedstock. Since the carbon/hydrogen ratio in biomass is higher than ideal for methanol synthesis, significant gains in yield can be made by spiking the synthesis gas with hydrogen. Canada has abundant supplies of natural gas which is a hydrogen carrier, as CH_4 has a high hydrogen to carbon ratio. Therefore combining natural gas with the biomass synthesis gas is essentially spiking it with hydrogen and high yields of methanol can thereby be achieved. High yields translate into reduced production costs and mean that the methanol industry can produce methanol at costs competitive with gasoline at present world prices for oil.

This technology would allow Canada to use natural gas in the short term to produce some liquid transportation fuel. It would also allow us to exploit biomass for methanol production faster and on a larger scale than by any other route. Methanol could be produced via this hybrid technology within two years, whereas developing a pure biomass-to-methanol technology would require an estimated seven years before commercial production could begin. Not only would yields be high using this hybrid approach, but experimentation with biomass gasification (the last untried step in methanol-from-biomass technology) would allow Canada to develop an expertise which could later be applied in methanol plants based completely on biomass as a carbon source and using pure hydrogen to spike the synthesis gas. This would give Canada a lead in the research, development and commercialization of methanol production from biomass and, when perfected, the expertise and technology could be profitably exported.

CONCLUSION

The Committee concludes there is a great potential for developing a methanol-from-biomass industry in Canada and that this country could become a world leader in methanol technology.

RECOMMENDATION

The Committee recommends that the construction of a hybrid natural gas/biomass methanol plant be encouraged to demonstrate this technology of methanol production as soon as possible.

RECOMMENDATION

Since hybrid natural gas/biomass methanol plants are a transitional step in establishing a fuel methanol industry, the Committee further recommends that such plants be converted when feasible to operation using biomass alone or biomass spiked with electrolytic hydrogen.

It has been suggested to the Committee that one of the major stumbling blocks to the introduction of methanol as an alternative fuel is the fact that Canadian consumers presently have to pay world-level prices for this commodity as a petrochemical feedstock.

RECOMMENDATION

In the short term, Canada should allow fuel methanol to be sold at prices lower than gasoline in order to make it attractive as an alternative transportation fuel.

2. BIOGAS

Biogas is produced by the anaerobic digestion of biomass. In this process various types of bacteria degrade organic material in the absence of air to produce a gaseous mixture composed predominantly of methane (CH_4 or natural gas) and carbon dioxide in varying proportions. The organisms which cause the breakdown may already be present in the feedstock or may be added to it as an inoculum (a small volume of a bacterial culture).

The energy value of biogas derives almost completely from its methane content which may range from 50 to 70% of the evolved gas. The carbon dioxide can be removed if the biogas is to be mixed with natural gas in pipelines but this involves treating the gas with a complex and expensive technology. Other gases such as ammonia may also be produced in varying proportions during the digestion process, but the main contaminant is usually hydrogen sulphide (H_2S). This compound can cause corrosion in engines using biogas fuel and it may cause irritation and nausea in people exposed to it. H_2S can be removed with simple, inexpensive technology.

Digestion usually takes place at temperatures ranging from 35 to 65°C, depending upon the feedstock used and upon which kinds of bacteria one wishes to favour for growth. The digestion process is well suited for treating wastes which are found in, or can be converted to, a wet slurry. Thus, in addition to producing a valuable energy commodity, anaerobic digestion can reduce the toxicity of waste materials, and hence their pollution hazards, and can reduce the odour problems usually associated with animal wastes.

Digestion is carried out by a mixed assortment of bacteria not all of which have been identified. The breakdown processes are complicated and the biochemistry of degradation is not completely understood; however, degradation generally takes place in three steps. First, decomposition of large organic molecules yields smaller molecules such as sugars and amino acids. Second, these smaller compounds are converted to organic acids, and third, the organic acids are transformed into the gas methane.

Cellulosic materials digest slowly, particularly those with a high lignin (complex cementing substance found in wood) content because this material makes the cellulose less susceptible to attack. Treatments such as hydrolysis can improve the susceptibility to attack but efficiencies of conversion to biogas are not expected to exceed 40 to 50%. It may therefore make better sense to burn cellulosic feedstocks directly to release energy rather than try to gasify them.

The best feedstock for biogas production is wet biomass such as animal manures, some aquatic plants, sewage sludges, or food-processing wastes from cheesemaking or potato, tomato or fruit processing. The digestion process must be monitored frequently because changes in temperature, feedstocks or toxin concentrations can generate an increase in the quantity of certain acids which can in turn inhibit the methane-producing bacteria.

During digestion a bacterial population evolves which is particularly adapted to the operating conditions of the reactor. For this reason, feedstock composition and operating conditions should be kept as constant as possible to ensure the process operates with maximum efficiency and produces optimal yields. Biogas production usually begins within a day of charging the digester but, without proper management, stabilization of the fermenting population may take months.

In addition to producing gas, anaerobic biodigestion generates other materials which are useful — the effluent from a digester may contain bacteria, lignocellulosic (containing lignin and cellulose) material, undigested feedstock and nutrients. Since most pathogenic (disease-causing) bacteria are destroyed during the process, wastes can be rendered less hazardous and the effluent or sludge used as a soil fertilizer or, under some circumstances, as a water fertilizer to enhance aquatic plant growth. Dewatered digester wastes also hold the promise of providing animal feed, a possibility under active investigation. Certainly, the economics of biogas production from animal manure and other feedstocks would be improved if digester wastes could be used for feed.

Despite the reduction in pathogenicity, the major potential problem associated with biogas production concerns treatment of waste waters which may contain heavy metals, pesticides and high levels of nutrients. This, however, is only a design and operational problem as the technology exists for treating such waters to render them environmentally harmless.

There are many designs for anaerobic digesters and these reactors are found in many forms and sizes around the world. They range from primitive structures to technologically-advanced units and R&D in this technology is advancing so rapidly that any list of digesters quickly becomes outdated. However several basic reactor types are described in the following paragraphs.

The single-tank plug flow system is a simple adaptation of the digester type which has long been used in Asia (Figure 6-6). The feedstock is loaded through the inlet, digested material is removed from the outlet and biogas is taken from the top of the fermentation tank where it collects.

Multitank batch systems consist of a series of tanks which are sealed after being charged with feedstock. When the digestion process is complete the biogas is drawn off and the effluent is emptied. Such systems are well adapted to operations which produce feedstock in batches rather than steadily.

A single-tank complete mix system consists of a fermentation tank which is heated and mixed several times daily. This system may be coupled with a second unmixed, unheated storage tank to form a two-stage digester in which additional degradation takes place and solid wastes are allowed to precipitate. The second tank allows yields of biogas to be improved. This type of reactor is used primarily for sewage treatment.

Experiments are now being carried out with multiphase digester systems in which successive tanks are regulated to optimize the various steps in the fermentation process. These are complex systems which must be carefully managed and are presently being studied utilizing sewage sludge as the primary feedstock. They may be adaptable to other feedstocks as well and theoretically could achieve high overall efficiencies in biogas generation.

Another variation in reactor design utilizes different types of "beds" to act as a material support for the bacterial populations which bring about the digestion of the raw organic matter. In this design the feedstock slurry is fed upwards through a vertical column packed with small stones, plastic balls, ceramic chips or other inert materials. The bacteria attach to this column material and degrade the organic matter as it flows past them. The design allows large quantities of slurry to pass through the digester while maintaining a high concentration of bacteria on the support material. This system is best suited to dilute municipal sewage as thicker feedstocks rapidly clog the column.

CONCLUSION

A wide variety of digesters has been described in the literature and a number are available from manufacturers. This type of system can help farmers attain energy self-sufficiency on their farms, and for operators of large feedlots and stockyards it offers the added bonus of reducing pollution problems by treating hazardous wastes. There are other advantages to be gained from anaerobic digestion, including the production of fertilizer and, possibly, animal feed.

RECOMMENDATION

The Committee recommends that the technology of anaerobic digestion should be actively pursued in Canada and that additional biogas reactors should be installed to demonstrate their effectiveness in the Canadian environment.

Figure 6-6: CHINESE DESIGN OF A BIOGAS DIGESTER

Source: United States, Office of Technology Assessment, 1980b, p. 185.

3. WOOD

Wood has been used as a fuel in this country since it was first inhabited. In fact, the burning of fuel wood is probably as old as civilization and continues to a greater or lesser extent throughout the world today. Wood is certainly Canada's most abundant biomass resource. It is available in most parts of the country either as waste material produced by the forest products industry or as standing, living biomass. In the future, with proper management of Canada's existing forests (which has not traditionally been the case) and with the development of energy plantations on marginal or abandoned farmland, this country's biomass resource could significantly increase in size.

At the present time biomass supplies about 3.5% of Canada's energy requirements (somewhat more than that contributed by nuclear fission), most of which is derived from our forests. Its main use is for the production of process heat and steam and, to a lesser extent, electricity. Virtually all of it is utilized by the forest industries.

The $104 million Forest Industry Renewable Energy (FIRE) program was designed to replace fossil fuels used in the forest industry by unutilized combustible biomass residues. Its goal is to save the equivalent of 23 million barrels of oil per year by 1985. FIRE provides financial incentives to the forest industry for the installation of proven biomass energy equipment and the companies involved receive progress payments of up to 20% of the eligible costs of approved projects. The program was initiated in 1978 and to date some 45 applications for assistance have been approved at a total commitment of $21 million. The type and distribution of fuels replaced through the FIRE program are shown in Table 6-3.

Table 6-3: CONVENTIONAL FUELS REPLACED PER ANNUM BY "FIRE" PROJECTS APPROVED TO 22 JUNE 1980

Type of Fuel Replaced	Per Cent of Total
Oil	70.0
Natural Gas	23.4
Coal	3.8
Electricity	2.7
Propane and Butane	0.1
	100.0[a]

[a] So far the equivalent of 2.5 million barrels of oil per annum has been replaced.

Source: Canada, Department of Energy, Mines and Resources, 1980f, p. 12.

Most FIRE funds have gone to pulp and paper mills rather than to the wood industry as the former generally have a higher energy consumption per unit of product output than the latter. Energy consumption for pulp and paper manufacture amounts to about 20% of the value added compared to less than 5% for wood products. Pulp mills require larger, more expensive and more complex energy systems, and it is easier to promote the program among 150 pulp mills than among the approximately 8,000 wood operations.

The Federal Government has also provided $30 million for the period 1978 to 1984 through the Energy from the Forest (ENFOR) program to help fund research projects and demonstrations of innovative techniques in biomass resource production and conversion. ENFOR is administered by the Canadian Forest Service of Environment Canada and evaluates proposals for biomass plantations, wood combustion and gasification, and liquid fuels production from biomass, to name some of the most important. As of early 1980, the Government had funded some 46 projects worth around $3.7 million.

CONCLUSION

The Committee concludes that the ENFOR and FIRE programs have been largely successful and applauds the recent announcement in the National Energy Program of a near tripling of the budget for FIRE.

Some say the amount of energy derived from biomass (primarily wood) could be trebled by the year 2000, an optimistic view which is shared by the Committee. The main problems to be overcome are those inherent in the resource itself: the size of the capital investment required to allow exploitation of the resource, and the lack of a well-developed commercial and industrial infrastructure geared to the harvesting, distribution and utilization of biomass in its many forms.

Many of the disadvantages involved in exploiting all forms of biomass, such as its low energy density, its variety in form and the attendant difficulties in its transportation, can be mitigated to a large extent by upgrading. This can be achieved by such means as pulverization, drying and densification, or chemical conversion. In fact, a variety and combination of steps can transform the organic matter of biomass into standard commodity fuels which are both convenient and economic to ship, store and burn.

There are many ways wood can be used to provide energy (Figure 6-7). It can be burned directly to provide heat, process steam and, via co-generation, electricity as well. It can be gasified to provide a fuel gas to replace oil and natural gas. It can be converted to methanol via synthesis after gasification, or to ethanol via fermentation. Finally, by means of slow heating under pressure, it can be converted to oil.

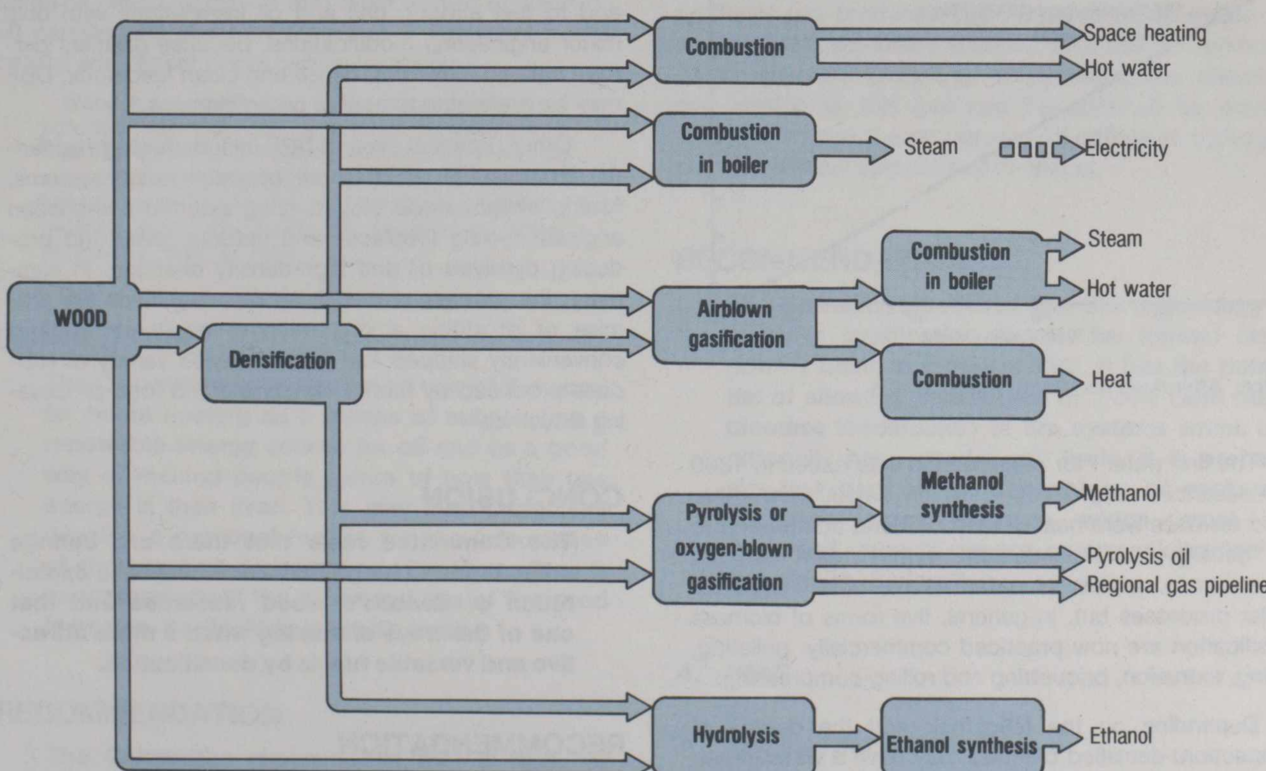
A. DIRECT COMBUSTION OF WOOD AND DENSIFIED BIOMASS FUEL (DBF)

Wood can be burned directly for residential use or for industrial purposes but certain conditions have to be met to maintain a positive net energy balance in exploiting this resource. The energy contained in wood justifies its cutting, handling and transportation for up to 40 to 60 miles depending on the region; however, further processing or transportation means that more energy may be spent in delivering the fuel to the user than is provided during combustion. It does not make good *energy* sense to spend more energy in providing a fuel than is contained in the fuel itself (although such use may be justified in the short term if the wood substitutes for oil). The use of unprocessed wood should remain local then and, fortunately, the wide dispersion of the wood resource very often allows this condition to be met.

Wood tissue is comprised primarily of cellulose, hemicellulose, lignin and water in varying concentrations. Biomass typically has a low *mass* energy density (MED) or low amount of energy which can be delivered per unit of mass. Similarly, biomass has a low *volume* energy density (VED). This is unfortunate as fuels with a high MED (or VED) are preferable to those with a low MED (or VED) because the former type is more efficient to store, ship and burn. Thus the large resources of wood in areas far from population centres or resource utilization locations are not economically exploitable unless they are upgraded or converted to fuels which have a high MED (or VED) before shipping. The prime energy commodities which can be derived from wood and wood waste are densified wood and, as described elsewhere, the alcohols methanol and ethanol. An increase in MED and VED is most desirable because combustion efficiency increases with increasing energy density and low moisture content; the efficiency of boiler heat exchange is a function of the quantity of gas produced from a given volume or mass of wood and the water content of the fuel.

Mass energy density and volume energy density values for raw wood and densified wood are shown in

Figure 6-7: CONVERSION PROCESSES FOR WOOD



Source: United States, Office of Technology Assessment, 1980a, p. 64.

Table 6-4. These data show that the densification of wood converts this resource into a substance which is superior to the raw feedstock in terms of fuel value per unit of volume. Figure 6-8 shows the typical energy content of biomass versus moisture content.

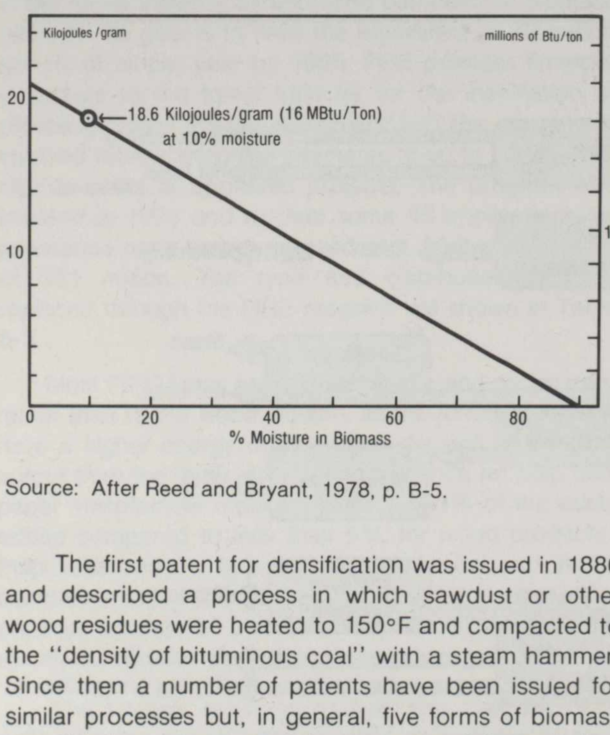
Table 6-4: ENERGY DENSITIES OF WOOD BY MASS AND VOLUME

Fuel	Water Content (%)	Density (gams/ cm³)	Heat of Combustion[a] Mass (MED) (kilojoules/gram)	Volume (VED) (kilojoules/ cm³)
Wood	10	0.6	18.6	11.2
Densified Wood	10	1.0	18.6	18.6

[a] Values shown are representative of a range for each fuel.

Source: After Reed and Bryant, 1978, p. B-2.

Figure 6-8: SENSITIVITY OF ENERGY CONTENT TO MOISTURE CONTENT IN WOOD



Source: After Reed and Bryant, 1978, p. B-5.

The first patent for densification was issued in 1880 and described a process in which sawdust or other wood residues were heated to 150°F and compacted to the "density of bituminous coal" with a steam hammer. Since then a number of patents have been issued for similar processes but, in general, five forms of biomass densification are now practiced commercially: pelleting, cubing, extrusion, briquetting and rolling-compressing.

Depending on the feedstock and the degree of compaction, densified biomass may have a water-repellent skin. However, exposure to water should be avoided during storage, particularly if the DBF has a high paper content. Because compacted fuels have a low moisture content, they biodegrade slowly and can be stored for long periods but only if kept dry. Biomass pellets make a satisfactory fuel for fixed-grate boilers, either supplementing or replacing coal.

While DBF does not share two advantages of coal — concentrated sources of supply and an established industrial infrastructure — neither does it share many of its liabilities, such as sulphur emissions, environmental disruption by strip-mining and black lung disease in coal workers. Although any economic analysis of DBF versus coal is highly site- and time-sensitive, it appears that DBF may have an economic advantage in regions with abundant biomass but no coal. DBF may also be preferable to coal for industrial or utility processes where sulphur abatement is required.

The technology for burning DBF in supplement to or in replacement of coal is well developed. Suspension and spreader stoker coal-firing systems can burn DBF with little or no modification. Boilers specifically designed to burn wood — fluidized bed combustors, small firetube boilers, bark burning boilers, and vortex combustors — will also burn DBF and are commercially available today in a wide range of capacities.

It is neither practical nor economical to substitute DBF in existing gas and oil boilers. DBF is, however, an attractive feedstock for low- to medium-Btu gasification. The product gas can be used to produce process heat and to fuel existing gas and oil installations with only minor engineering modifications. Because gasifiers perform best on a uniform, dense and clean feedstock, DBF may be preferable to coal or green biomass.

Other potential uses of DBF include fueling residential, commercial or industrial central heating systems; fueling airtight wood stoves; firing external combustion engines; fueling fireplaces and outdoor grills; and producing pyrolysis oil and high-density charcoal. In summary, the process of densifying biomass holds the promise of providing a dry, uniform, easily stored and conveniently shipped fuel from the wide variety of residues produced by forest, agriculture and food processing industries.

CONCLUSION

The Committee feels that there are definite advantages to be gained from increased exploitation of Canada's wood resources and that one of the ways of making wood a more attractive and versatile fuel is by densification.

RECOMMENDATION

As the technology for biomass densification is available now and is being used in some loca-

tions, the Committee recommends that development of the wood densification industry should be encouraged in Canada. This means that increased emphasis in R&D should be placed on improving combustion technologies for densified biomass fuels and on developing end uses and markets for the densified biomass product.

Some environmentalists are expressing concern about the growing popularity of residential, as opposed to industrial, wood burning. Carbon monoxide, particulate matter and polycyclic organic matter (POM) are all emitted from wood stoves and fireplaces, and a draft paper prepared by Battelle for the Environmental Protection Agency in the United States concerning industrial and commercial wood combustion, stated that

> ...low-temperature wood-burning units tend to produce more undesirable atmospheric emissions than do the larger units which operate at higher temperatures and with greater turbulence ... it may be that the small residential wood-burning units are capable of producing larger quantities of POM emissions than the commercial/industrial-size wood-burning boilers... (Budiansky, 1980, p. 770)

Thus there is a danger that increased residential use of firewood may have detrimental effects on the environment. The POM emitted by wood stoves and fireplaces contains benzo [a] pyrene and other known or suspected carcinogens and may represent a significant health hazard and cancer risk in certain locations.

> Wood is now recognized as a serious source of air pollution. Vail, Colorado, and many communities in New Hampshire and Vermont (particularly in valleys susceptible to particulate haze) have already been forced into coming to grips with the smoke and haze resulting from the residential wood-stove boom. (Budiansky, 1980, p. 769)

CONCLUSION

The Committee sees increased use of firewood for home heating as a means of substituting a renewable energy source for oil and as a good way of making people aware of how they use energy in their lives. This may help Canadians develop a personal feeling for the importance of conservation. Nonetheless, the Committee is concerned about the increased use of firewood in homes, particularly in urban areas.

RECOMMENDATION

The Committee recommends that a study of how the increasing combustion of wood in urban areas will affect air quality should begin immediately. Such a study should be completed before expanded use of firewood is recommended for urban centres.

RECOMMENDATION

Fire safety regulations should be reviewed and strengthened so that the installation and use of wood stoves and fireplaces does not lead to a tragic increase in the incidence of fires in homes using fuel wood.

B. GASIFICATION

When wood is exposed to heat it first begins to lose moisture then decomposes (pyrolyzes) into a variety of compounds depending upon temperature, the rate of heating and the presence or absence of oxygen. The wood itself does not burn, rather it is the products of pyrolysis which do. In the presence of ample supplies of oxygen, these products combust completely to form predominantly carbon dioxide (CO_2), water and ash. In the absence of oxygen, the main gaseous pyrolysis products are carbon monoxide (CO), hydrogen (H_2) and some CO_2, collectively known as synthesis gas.

Gasification of wood under pyrolytic conditions is a highly useful process because it converts a bulky and difficult to handle raw material into a flexible fuel. The synthesis gas produced can be piped easily; it can be used to fire fossil-fueled systems; or it can be combusted to generate electricity. In addition, the chemical composition of this gas can be adjusted by adding hydrogen to give the proper ratio of carbon to hydrogen to allow efficient synthesis of methanol.

RECOMMENDATION

The Committee believes that the technology of biomass gasification should be funded on a priority basis in biomass R&D. It has the potential of allowing greater use of wood (and other biomass feedstocks) to fire systems which traditionally have used fossil fuels. It is perhaps the last part of the technology of methanol synthesis from biomass which must be improved upon to assure commercialization of this alcohol fuel option.

4. PEAT

A. THE NATURE OF PEAT

Peat is partially decomposed organic matter which is made up principally of decayed *Sphagnum* moss, although a minor component may be contributed by other aquatic plants, grasses or sedges. It is formed very slowly by the decay of this dead vegetation under anaerobic (oxygen deficient) conditions. All Canada's peat bogs have developed since the last glacial epoch, some 10,000 years ago.

Peat bogs differ from other types of wetlands in that they are nourished almost entirely from rainwater. Their surface is a continuous carpet of *Sphagnum* moss which supports a layer of grass and shrubs and, occasionally, trees. In Canada peat bogs may be as large as tens of kilometres across but are generally much smaller.

A peat bog is made up of a number of layers. The top level is living bog vegetation. The second consists of very young peat which is characterized by a loose open structure that clearly shows the form of the dead vegetation from which it is derived. The third layer is of varying thickness but becomes darker and denser with depth until the black colour and putty-like consistency of mature peat is encountered.

At all its different stages in development, peat contains a very high proportion of water, usually averaging around 95% by weight. This means that, perhaps surprisingly, there is less solid matter in peat than there is in milk. This high water content has always been the main barrier to the extensive exploitation of peat as an energy source.

Because peat occurs on the Earth's surface and extends only to relatively shallow depths, its removal is unlikely to cause environmental problems as severe as those associated with strip-mining. However, great care should be exercised during and after peat excavation to ensure that harvested bogs do not turn into muddy wastelands. Fortunately, peat has been mined for years in other countries and there is a wealth of experience in reclaiming bogs. In fact, with proper management, depleted bogs can be used for agricultural land or for energy plantations (Figure 6-9). It is essential then that peat harvesting only be permitted with the assurance of proper reclamation after excavation.

Harvested peat can be marketed in three different forms. Sod peat is made by a large cutting machine which dredges peat from all depths of the bog, mixes it and forms it into sods. They are therefore all of similar quality and can compete in the marketplace with other industrial fuels. Milled peat is scraped from the surface of the bog in the form of a coarse powder. After drying this material can be either burned in power stations or processed into briquettes. Briquettes are small tightly-packed blocks of milled peat, the quality of which is carefully monitored because the briquetting process can tolerate only small variations in density, moisture and ash content. About one-fifth of the energy in the peat is used to produce the briquettes and this product is used primarily for home heating.

Development of a Peat Bog for Energy Production

Peatlands have to be developed before they can produce utilizable peat and a great deal of preparation, usually taking several years, is required before production can proceed. First, the bog must be surveyed to determine how much peat there is, what its quality is, how it can best be drained and how access routes to the resource can be set up by rail and road.

The second step is drainage. Since peat is approximately 95% water, it cannot support heavy machinery and removal of as much moisture as possible is essential. A network of drainage ditches is dug to begin the process of dewatering and, as the bog consolidates, these drains are deepened to facilitate further water removal. This stage normally takes five to seven years to complete and reduces the bog's moisture content to approximately 90%. This may seem a trivial improvement but, in fact, it is very significant as it represents removing more than half the water contained in the peat. At 95% water content the ratio is 1 part solid to 19 parts water; at 90% the ratio is 1 part solid to only 9 parts water.

After draining the bog is levelled. This is done to facilitate drying of the peat and to allow mechanical handling to take place with maximum efficiency.

The final step involves establishing a network of light railways over the surface of the bog for the handling and transportation of the peat. All these steps plus the fact that only a few inches of peat are harvested annually mean that a bog may be commercially exploited for several decades.

B. INTERNATIONAL AND CANADIAN DEVELOPMENT

World peat resources over 50 cm thick are estimated to total some 145 billion tonnes dry weight, having an energy equivalent to about 63.5 billion tonnes of oil. Much of this total is located in the U.S.S.R. but large quantities are found in other countries as well, with Canada ranking second in terms of resource size (Table 6-5).

Finland has a number of power stations which utilize peat to produce electricity, and steam and hot water for district heating. The Finns expect to derive from 5 to 10% of their total energy requirements from peat in the future.

Figure 6-9: BOGS OF TODAY ARE FARMLANDS AND ENERGY PLANTATIONS OF THE FUTURE

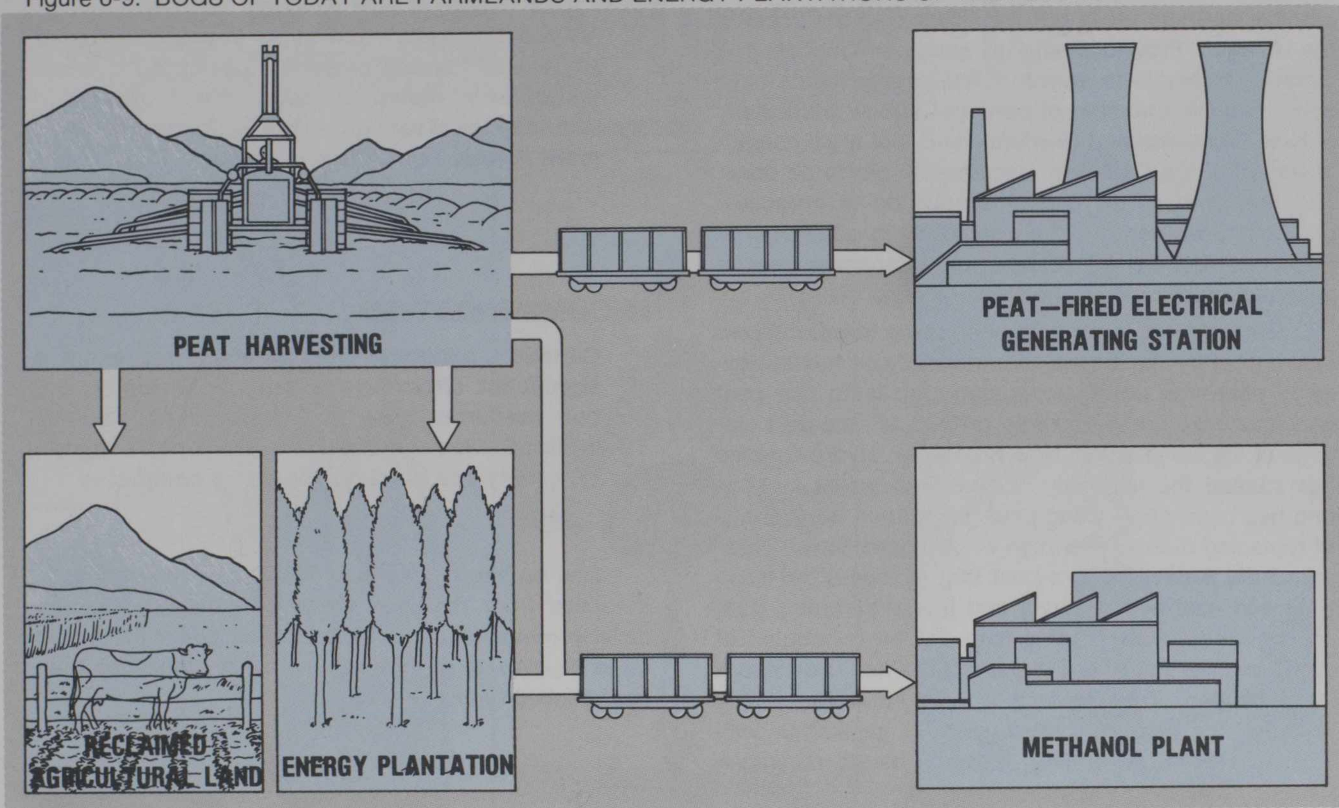


Table 6-5: WORLD PEAT RESOURCES

Country	Billions of Tonnes at 40% Moisture Content
U.S.S.R.[a]	147.4
Canada[b]	22.7
Finland	16.3
United States	12.7
Sweden	8.2
Poland	5.4
West Germany	5.4
Ireland	4.5

[a] Investigated resources; probable resources are about 200 billion tonnes.
[b] Now regarded as underestimated.

Source: "Peat Facts", 1977.

In the U.S.S.R. it is estimated that an electrical generating capacity in excess of 6,000 MW is peat-fired. (By comparison, Churchill Falls generates 5,225 MW and supplies about 6% of Canada's electrical power.) In addition, perhaps 4.5 million tonnes of peat are produced annually for home heating.

Ireland presently operates seven peat-fired electrical generating stations. These installations consume approximately 56% of Ireland's harvested peat (about 5 million tonnes annually) and produce about one-third of the country's thermally-generated electricity. If peat were not used as an energy source, the cost of supplying that electricity with imported oil would be some £60 million. Moreover, exports of peat (predominantly horticultural peat) currently pump £70 million a year into the Irish economy.

Irish research is currently directed towards studying the conversion of depleted bogs into energy plantations and experiments with fast-growing hybrid clones of several tree species are being actively pursued. The most promising species so far examined are willows, poplars and alders. It is estimated that the energy output per unit area from a biomass plantation will only be some 1/7th or 1/8th of that derived from milled peat production.

Peatlands cover approximately 12% of Canada's land surface, an area 12 times that of the Island of

Newfoundland. Much of the resource is located in inaccessible northern areas but significant deposits occur in the Atlantic Provinces and in southern Quebec and Ontario. Attempts to inventory the peat resource have been made in a number of parts of Canada, particularly in New Brunswick and Newfoundland, but a full characterization of the Canadian resource has yet to be done. The use of peat for energy production is attractive, particularly in areas that are deficient in other energy resources, but at the present time Canadian peat is recovered exclusively for horticultural purposes.

Recently there has been increasing interest shown in fuel peat by Canadians and one study on the feasibility of peat-fired power generation concluded that peat was economic compared with oil-fired or coal-fired stations of the same size in New Brunswick. Hydro-Québec has studied the feasibility of peat-fired power stations and has been considering peat gasification as a means of replacing diesel generation on Anticosti Island. Newfoundland is developing a peat bog to assess the feasibility and cost of harvesting and transporting fuel peat on the Island. Peat burning tests will be conducted at the Grand Falls pulp and paper mill of Price (Newfoundland) Limited. The Province is also interested in the potential for displacing diesel-electric generation with small peat-fired generating units in isolated communities.

Perhaps one reason peat development has been slow in Canada derives from the fact that very little peat expertise exists in this country. This is in contrast to many European nations where much peat R&D and the teaching of peat-related studies at the university level takes place. The technology of harvesting and utilizing peat is well developed elsewhere although it is strange to Canada.

CONCLUSION

As peat deposits often occur in less developed regions of Canada and since peat production is a labour-intensive activity, development of Canada's peat resources could provide employment as well as produce energy.

RECOMMENDATION

Canada's extensive peat deposits represent a significant alternative energy opportunity, but our resource base has been only partially outlined. An accurate assessment of its quantity, quality and location should be completed.

One option for peat use which may be particularly attractive from the point of view of helping Canada develop methanol as a portable liquid power fuel would be to develop an expertise in methanol production from peat-derived synthesis gas.

RECOMMENDATION

The Committee recommends that peat R&D encompass the development of an efficient technology for the gasification of peat. This would allow Canada to broaden its resource base for the production of the alternative liquid transportation fuel methanol.

Coal Technologies

1. COMBUSTION TECHNOLOGIES

A. FLUIDIZED BED COMBUSTION (FBC)

Fluidized bed combustion is a technology which promotes more efficient burning than that achieved in traditional boilers, using a variety of fuels, with less expensive equipment and causing fewer environmental problems. Since the design of an FBC boiler is to some extent independent of fuel characteristics, it is possible to fabricate large-capacity, packaged units in shops with little assembly required on site.

A boiler is a system in which a fuel is burned to produce steam. In all boilers (excluding those in nuclear powerplants) the fuel is burned with air and the resultant heat is used to vapourize and superheat a working fluid, which is almost always water. The steam produced may be used to generate electric power or to provide heat for industrial, commercial or district heating applications. The fuel is burned in a furnace which serves three purposes, namely those of reaction chamber, cooling chamber and ash disposal area — three functions which often conflict with one another. In a conventional boiler, for example, the high temperatures which promote efficient burning are incompatible with the effective cooling of combustion gases. Similarly, ash collection is easier when the fuel is burned in large pieces, but efficient combustion is promoted by fine grinding. In a fluidized bed boiler the design is such that there are no fundamental conflicts between complete combustion, gas cooling and ash collection.

A fluidized bed is a layer of solid particles which is agitated by passing a column of gas through it vertically. The gas, usually air, moves with sufficient velocity to vigorously agitate the solid particles without causing them to be blown upwards out of the bed. When in this state, the bed shows many of the characteristics of a liquid, hence the term *fluidized.* Fuel is added to and burned within the fluidized bed, and a significant fraction of the combustion heat is extracted by heat transfer surfaces in direct contact with the bed.

Hot gases from combustion may be used to drive gas turbines for electrical power generation. The combustion chamber itself may be kept at atmospheric pressure (Atmospheric Fluidized Bed — AFB) or pressurized (Pressurized Fluidized Bed — PFB). The latter option is technically more complex but it reduces the size of the combustion chamber and hence capital costs. Tests have suggested that PFB units allow greater sulphur removal than AFB systems. Finally, the use of a gas turbine in a combined gas-steam system is more efficient with a PFB.

FBC offers a number of distinct advantages over conventional boiler technology.

- Sulphur dioxide (SO_2) emissions can be reduced at lower cost than with any available alternative by adding limestone to the bed.
- Nitrogen oxides (NO_x) emissions are reduced because of the lower combustion temperatures characteristic of FBC units.
- Coal and other fuels burn more rapidly in a fluidized bed and heat transfer to the boiler tubes is more rapid and uniform than in conventional boilers.
- The positioning and closely-spaced arrangement of the boiler tubes makes fluidized bed units more compact.
- FBC boilers can burn almost any size or type of coal and a wide variety of other fuels such as wood chips, combustible garbage, municipal sludge, agricultural wastes, oil shale and petroleum fractions as well.
- Capital costs are competitive with conventional solid fuel boilers.

The principles of FBC technology are well established, and its advantages and problems are fairly well understood. Pressurized fluidized bed boilers for electrical power generation are in the advanced pilot plant stage, and there seems to be no doubt that they will prove to be technically feasible. In North America, FBC is used today in commercially available atmospheric pressure boilers, dryers and incinerators.

In Britain, interest in FBC was sporadic until 1974 when, following a major study of the national coal industry, the government authorized the National Coal Board to implement a "Plan for Coal" that will increase annual output to 136 million tonnes with the aim of displacing oil and gas in the national energy mix. Renewed impetus was thus given to the development of FBC and by 1980 several demonstration/prototype boilers using FBC were in daily use at industrial sites.

In the United States research into FBC is at an advanced stage and the Johnston Boiler Co. of Ferrysville, Michigan is already licensed to sell boilers incorporating this technology. A recently commissioned 12.6 kilogram/second (100,000 lb/hr) FBC steam generator at Georgetown University, Washington, D.C., was designed and manufactured by Foster Wheeler Energy Corporation. This unit has been burning high sulphur coal in a densely populated area since mid-1979 and has met strict pollution emissions regulations.

The United States Department of Energy is sponsoring research into both atmospheric and pressurized fluidized bed boilers. Under this program, a 20 MW AFB pilot plant has been operated by Monangahela Power Co. at Rivesville, West Virginia since 1976. The project is aimed at developing an environmentally acceptable process for burning high-sulphur coals. Five other contracts have been let by DOE to design, build and test FBC boilers or heaters using AFB combustors. In PFB research, the Department is sponsoring the Curtiss-Wright Corp. in designing, constructing, operating and evaluating a 13 MW coal-fired pilot plant. In Fiscal Year (FY) 1980 Federal funding of FBC research amounted to over $50 million and in FY 1981 funding is to exceed $68 million.

In West Germany, a full-scale demonstration of FBC technology is underway at the Flingern power station at Dusseldorf. The 35 MW installation was designed, built and commissioned by companies of the Deutsche Babcock Group. Planning began in early 1978 and trial operations began in late 1979.

As part of the activities of the International Energy Agency, the United Kingdom, United States and West Germany are cooperating in the construction of a PFB combustor in Grimethorpe, Yorkshire, England. The facility was started in fiscal year 1977 and was to be completed in FY 1980.

The People's Republic of China is perhaps the most advanced country in terms of the practical application of FBC. Research began in the early 1960s and the first FBC boiler was put into service in Mouming in 1969. In 1980 there were more than 2,000 FBC boilers operating in China, with capacities ranging up to 50 tonnes/hour. They are used for district heating, industrial applications and power generation, and burn a wide variety of fuels including such low-grade energy sources as shale fines, coal washery wastes, stone-like coal and lignite.

Simple fluidized bed combustors have been available commercially in Canada for close to 15 years. The Department of Energy, Mines and Resources (through CANMET, the Canadian Centre for Mineral and Energy Technology) supports a demonstration program intended to promote FBC technology at an increasing scale in commercial applications specifically suited to exploit its advantages; and to reduce risk to a level at which private sector funding can be rationalized.

Special objectives of the EMR demonstration program are to: provide the industrial market with an alternative to oil and natural gas; provide a means of burning high sulphur coal with control of SO_2 emissions; provide a technology for utilizing low-grade fuels which have a combination of high moisture, high ash, and low reactivity; and provide more efficient coal-to-electricity cycles (Friedrich, 1980a, p. 8). The main elements of this program are summarized in Table 6-6.

As indicated in Table 6-6, two fluidized bed boilers are being installed at a Canadian Forces Base heating plant at Summerside, Prince Edward Island. These boilers will use 5% sulphur coal from Cape Breton Island. Construction will begin in 1981 with the first unit to be commissioned in 1982. In industrial applications an FBC boiler an order of magnitude larger than the one planned for Summerside would be needed. The Department of Energy, Mines and Resources has offered financial and technical support for the construction of such a boiler by a team of designers, manufacturers and users at a suitable industrial location. For electrical power generation, an FBC boiler perhaps ten times the size of an industrial boiler would be needed. The obvious place for such a utility-sized boiler would be in the Atlantic region, with its local supply of high-sulphur coal and its dependence upon foreign oil. Under the Oil Substitution Agreement between the Governments of Canada and Nova Scotia, the Department of Energy, Mines and Resources has sponsored studies into the best location for a 150 MW unit, with completion targeted for 1988.

Western Canadian coal must be washed and dried before it is exported. In the past the drying process has used natural gas heating. However, Alberta Government regulations now require new coal dryers to be coal-fired. With FBC, this could be accomplished using the coal rejects from washing, not high quality coal. This means that some 6.4 million tonnes (7 million tons) of washing rejects produced in Alberta and British Columbia every year, which presently represent a waste disposal problem, could be utilized to fire a FBC drying unit. EMR has a contract with coal suppliers in Alberta to study the design and economic feasibility of a FBC drying facility using these coal rejects.

Table 6-6: CANADIAN DEMONSTRATION PROJECTS IN FBC

Project	Status	Completion Date	Unit Size
1. HEATING PLANT (CFB Summerside) Coal & Wood	Design 1st Unit 2nd Unit	1981 1982 1985	20 Tonnes Steam/Hour
2. INDUSTRIAL STEAM PLANT Coal & Possibly Wood	Site Proposal	1981 (Est)	100 Tonnes Steam/Hour
3. THERMAL POWER PLANT (Nova Scotia Power Commission) Coal	Site Study Design Demo	1981 1984 (Est) 1988 (Est)	150 MW(e)
4. COAL DRYER (Luscar Ltd.) Coal Washery Rejects	Study Demo	1981 1983	
5. PFBC COMBINED-CYCLE Thermal Power Plant (B.C. Hydro) Coal	Design Demo	1983 1988 (Est)	70 MW(e)
6. R&D PROGRAMS In-house and Contract	Continuing		Pilot and bench-scale experiments and mechanistic studies of combustion, emissions and metallurgy

Source: Lee *et al*, 1980, p. 63.

Manpower and funding for the above activities are being allocated through CANMET. For FY 1980-81, 7.75 person-years have been allotted and funding for R & D and Demonstration projects amounts to $218,000 in direct expenditures and $1,255,000 in contracts. Under the National Energy Program, Federal Government expenditures on new coal technologies are projected to amount to "$50 million over the period 1980-83, with the provision of a further $100 million in 1984-85" (Kelly, 1981, p. 76). The bulk of the funding is assigned to the demonstration of FBC in thermal-electric power generation in Nova Scotia.

CONCLUSION

Fluidized bed combustion technology offers the best approach to minimizing emissions of sulphur and nitrogen oxides from coal-fired boilers and for allowing the efficient combustion of a wide variety of low-grade fuels.

RECOMMENDATION

The Federal Government should undertake a thorough analysis of the opportunities and benefits of fluidized bed combustion in the Canadian context, and of the funding levels necessary to exploit the technology to maximum advantage. Topics which should be addressed in the analysis include the choice between various FBC technologies from economic and environmental standpoints, the use of fuels other than coal, and the nature of regional opportunities.

B. COAL-OIL MIXTURES (COMS)

The rapidly escalating cost of petroleum has sparked renewed interest by governments and utilities in burning slurries of coal in oil (coal-oil mixtures or COMs) in oil-fired thermal-electric generating stations. This can be accomplished with only minor modifications to power stations, whereas conversion to coal firing only requires extensive alterations. A recent study by Montreal Engineering Company on behalf of the Canadian Electrical Association showed that 5.25 million barrels of oil per year (14,400 barrels per day) could be saved by converting 11 oil-fired utility boilers in the Maritime Provinces to 50% COM (Montreal Engineering Company, 1979). The use of coal-oil mixtures is also worth considering in other applications in which oil alone is commonly used as boiler fuel, including industrial and commercial plants, district heating complexes, and ocean-going ships.

The Department of Energy, Mines and Resources, through the CANMET Energy Research Program, actively supports COM research in Canada. The COM program has been in formal existence since 1977 when a demonstration program was begun at Chatham, New Brunswick with the New Brunswick Electric Power Commission. A project is also underway to demonstrate the use of coal-oil mixtures in blast furnaces. CANMET's research and development is carried out in cooperation with a number of other agencies, including the Canadian Electrical Association, the International Energy Agency, Nova Scotia Technical College, the Ontario Research Foundation and the Saskatchewan Research Council. The total value of contracts issued by CANMET under the program to the end of fiscal year 1980-1981 amounts to approximately $1,099,000, and planned expenditures under contract for FY 1981-82 are $400,000.

A novel advance in COM technology has been made by Scotia Liquicoal Ltd. of Halifax, Nova Scotia. The company is producing COM at bench scale using a spherical agglomeration process developed by the NRC and under license to Scotia Liquicoal. Water forms up to 20% of the mixture and stabilization is achieved by ultrasonic agitation. The product is more stable, less viscous and more easily burned than conventional COMs. The company has committed over $1.1 million to bring this process to the point of commercial exploitation by late 1981.

Spherical Agglomeration in COMs

Spherical agglomeration is a means of separating ground coal from water and solid impurities. Water and oil are added to the input coal and vigorously mixed; oil coats the coal particles, which then adhere to one another forming spherules which can be separated from the impurities and most of the water by screening.

The benefits of pursuing COM technology in the Atlantic Region today are obvious. Such a strategy is of less interest in Central and Western Canada where generating alternatives allow oil-fired stations to see limited duty.

RECOMMENDATION

Canadian RD&D in coal-oil mixture technology should be accelerated where feasible. A heavy emphasis should be placed on the rapid deployment of this technology in the Maritime Provinces.

2. CONVERSION TECHNOLOGIES

Coal contains more highly complex organic molecules and has a higher carbon/hydrogen ratio than petroleum. In coal conversion, therefore, the goals are two-fold — to break down the complex molecular structure and to lower the carbon/hydrogen ratio. The former objective is accomplished by the application of extreme heat; the latter is achieved either by removing carbon from the coal or by adding hydrogen to it. Coal conversion can produce either gaseous or liquid fuels.

Coal gasification is an established technology which has been applied at various times in many countries. Progress has been made recently in developing techniques for economically gasifying coal *in situ* for delivery to surface pipelines. Since Canada's coal resources are concentrated in Western Canada where extensive reserves of natural gas are also found, it will not make economic sense to pursue coal gasification in this country.

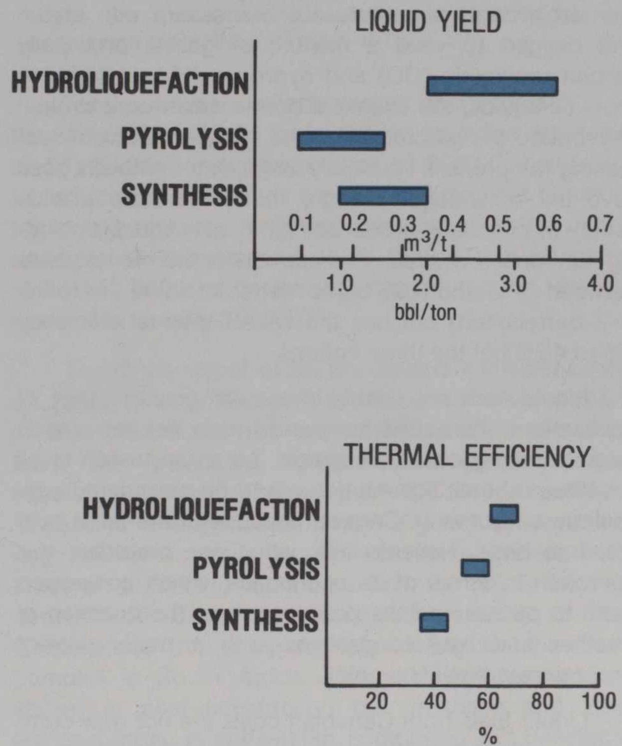
CONCLUSION

For at least the remainder of this century, Canada's resources of natural gas obviate the need to pursue coal gasification as an energy alternative.

The large-scale derivation of liquid fuels from coal in Canada is another matter, however, and one worthy of serious consideration as a medium-term energy strategy. Coal liquefaction by synthesis after gasification has been proven technically feasible, most recently at the SASOL I and SASOL II Complexes in South Africa. Various other hydroliquefaction processes are at the pilot plant stage of development. In general, the technical feasibility of coal liquefaction is well established. There are three main processes by which coal liquefaction can be achieved — hydroliquefaction, pyrolysis and synthesis — but no single technological route for the process has emerged as being clearly superior.

Hydroliquefaction takes place in a slurry under conditions of high temperature and pressure and in the presence of a catalyst. Hydrogen is added directly to the mixture or "donated" by a hydrogen-rich solvent to yield a liquid product which can then be distilled to produce a variety of fuels. The choice of catalyst determines to some extent the liquid produced; high gasoline yields, for example, are possible using zinc chloride. Whatever the catalyst, the process has a major drawback, however, as impurities and the large, heavy molecules in the coal itself quickly contaminate the catalysts, which are both difficult to regenerate and expensive to replace. As shown in Figure 6-10, the process yields between 0.35 and 0.65 cubic metres of liquids per tonne of coal (2-4 barrels/ton) with thermal efficiencies in the range of 60-75%. It is apparent that if the technological problems in hydroliquefaction can be solved, the process is the best of those available in terms of both liquid yield and thermal efficiency.

Figure 6-10: TYPICAL LIQUID YIELDS AND THERMAL EFFICIENCIES IN COAL LIQUEFACTION PROCESSES



Note: Thermal efficiency is the percentage of energy stored in the coal input which is recovered in the liquid products.

Source: Taylor, 1979, p. 14.

In the pyrolysis process, liquefaction is achieved by concentrating carbon in the input coal residue rather than by adding hydrogen. This is accomplished through destructive distillation; that is, the coal is heated in the absence of air until chemical breakdown occurs. A carbon-rich coke or char is left behind and hydrogen-rich tars, oils and gases are released which are suitable for upgrading to fuels. The process is used now in the production of metallurgical coke and the resultant tars and oils used as petrochemical feedstocks. Not all coke is suitable for metallurgical use, however, and the residue from pyrolysis (at least half the feed coal) has no present industrial application. The liquid yield is lowest of the three coal liquefaction processes, between 0.1 and 0.28 m^3/tonne (0.5-1.7 barrels/ton), but the thermal efficiency is intermediate between hydroliquefaction and synthesis at about 50-60% (Figure 6-10).

In synthesis technology the coal is first gasified and the produced gases are then synthesized into liquids.

The process was pioneered in Germany before World War II and is that used at the only commercial coal conversion plant in the world, the SASOL (South African Coal, Oil and Gas Co.) complex in South Africa. Coal is reacted at high temperature and pressure with steam and oxygen to yield a mixture of gases, principally carbon monoxide (CO) and hydrogen (H_2). In order to produce liquids, the chemical bonds which were broken to produce the gas must now be partially reassembled, making the process inherently inefficient. Synthesis does have the advantage, though, that it can use a wide variety of coals and produces high quality liquids, including methanol if desired. This coal conversion route yields between 0.18 and 0.36 cubic metres of liquid per tonne (1-2 barrels/ton) but has the lowest thermal efficiency (35 to 45%) of the three options.

Liquid fuels are usable in a much greater range of applications than solid fuels and herein lies the reason for considering coal liquefaction. As an approach to oil substitution, coal liquefaction might be considered particularly attractive in Canada because of the large coal resource base. Nevertheless, when one considers this approach in terms of its economics, which conversion route to pursue and the product range, the question of whether and how to proceed with a major project becomes extremely complex.

Liquid fuels from Canadian coals are not now competitive with those derived from crude oil or oil sands. This situation is not likely to change for the simple reasons that bitumen available from oil sands is closer chemically to the desired end product than is coal, and the extraction process is cheaper than coal mining on the same scale. Furthermore, Canada has an enormous oil sands resource, sufficient to supply domestic needs for liquid hydrocarbons for several hundred years even at current rates of consumption.

Coal liquids contain more impurities than conventional oils but often contain less sulphur, so that refining them and burning the products might be environmentally less hazardous than is the case with conventional fuels. Such a statement cannot be made with confidence, however, because an assessment of environmental impact would require knowledge of the liquefaction process to be used, and the physical and chemical nature of the coal feed for the process.

The large-scale mining of coal to supply a liquefaction plant could have a profound environmental impact on the area to be mined, especially if strip-mining were done. By 1975, a total of about 16,000 hectares (40,000 acres) of land in Canada were disturbed by strip-mining for coal, of which only about 20% was slated for reclamation. In 1979, Canada produced an estimated 33 million tonnes of coal, or an average of approximately 90,400 tonnes/day. A coal liquefaction plant of optimum size — considered to be one producing about 16,000 m^3/d, or 100,000 barrels/day, of liquid products — would consume roughly 30,000 tonnes/day of coal. This would require a major boost in Canadian production and a consequent increase in the rate at which land would be strip-mined. Strip-mining for coal results in better worker health and safety, a higher percentage of coal recovery and lower production costs than is the case with underground operations. Nevertheless, problems of land reclamation and acid mine drainage would have to be faced if the decision were made to proceed with coal liquefaction on a large scale.

South Africa is the only country in the world operating commercial coal liquefaction plants. The SASOL I complex delivered its first coal liquids in 1951 and presently produces about 8% of the country's gasoline at a cost of around $2 per gallon. A second plant, SASOL II, was opened in 1980, and SASOL III is planned to begin production in 1983. The three plants together will consume 28.8 million tonnes of coal annually and will meet at least half of South Africa's petroleum needs. The project is reported to be marginally profitable in the South African context, partly because of the low cost of labour in that country, but it seems doubtful whether a similar operation could be profitable in Canada without much higher petroleum prices.

In the United States intensive research into coal liquefaction is being carried out under the auspices of the Department of Energy, with the objective of establishing a synthetic liquid fuels industry. Environmental studies into the impact of coal conversion processes are proceeding as well, and results indicate that all processes include the necessary technology to meet existing emissions standards. All of the conversion routes appear to be commercially feasible and the choice of which process to go with will depend largely upon the products desired. Department of Energy funding for coal liquefaction projects amounted to $218 million in FY 1979 and will rise to over $500 million in 1981. Nonetheless, the U.S. program has encountered considerable difficulties in trying to develop more efficient, "second generation" coal conversion technologies. Project costs are much higher than originally anticipated and progress has been slower than expected.

Plans for commercial coal liquefaction plants in West Germany should be finalized by late 1981 according to the Federal Ministry for Science and Technology. The intention, however, is to establish a world technological lead in the field rather than to make extensive use of liquefaction in Germany, because of the high expense of extracting large tonnages of German coal. The construction of 14 coal-refining pilot plants at a cost of over $2 billion is under study but it is anticipated that, in 1990, oil and gas derived from coal will satisfy only 3% of the country's needs.

Coal Liquefaction Research in the United States

The objectives of the U.S. program are to: (1) demonstrate the technical capability to commercially produce clean liquid and solid fuels from coal by at least four direct liquefaction processes (SRC-I, SRC-II, H-Coal, EDS) by the late 1980s; (2) develop improved indirect liquefaction processes to produce liquid fuels from synthesis gas made from coal by the late 1980s; and (3) promote the development of more advanced third-generation coal liquefaction processes which can be demonstrated to be commercially viable in the 1990-2000 time frame (U.S. Department of Energy, 1980a, p. 74).

The four processes referred to under item 1 above are hydroliquefaction techniques. Solvent Refined Coal (SRC) processes I and II are being tested in 6 tonnes/day and 50 tonnes/day (coal) pilot plants that are now in operation. Technical demonstration plants of 6,000 tonnes/day size (one for each process) are in design stages. H-Coal is undergoing current development in a 600 tonnes/day pilot plant which began operation in FY 1980. Exxon Donor Solvent (EDS) is undergoing development in a 250 tonnes/day pilot plant which also began operation during FY 1980. As a contribution to research in the derivation of coal liquids by synthesis, design and construction of a small (100 barrels/day) methanol-to-gasoline pilot plant based on a Mobil process is underway.

In Great Britain, the National Coal Board (NCB) recently recommended the construction of two coal liquefaction pilot plants with capacities of 24 tonnes per day of coal. The $100 million cost of this project will be shared among the NCB, British Petroleum and the Department of Energy. Its goal is to accomplish nearly 100% conversion of coal into high quality transport fuels, plus some liquid petroleum gas and synthetic natural gas.

Canada's commitment to coal liquefaction research has been limited in manpower and funding compared with American, West German and British efforts.

> The federal government, through CANMET, initiated an ongoing coal conversion contracting-out program in 1976 to study various ways to process coals into other energy forms. The liquefaction studies have included assessment of the applicability of various processes in Western Canada, bench-scale studies with Nova Scotia coals and Saskatchewan lignites, investigation of electrode coke production for the aluminum industry by the solvent refined coal process, and other more fundamental studies at various universities and research establishments. The work has served to expand Canada's technical knowledge base and to build Canadian expertise. Experimental facilities are also under construction for bench-scale research at CANMET. (Taylor, 1979, p. 30)

Total in-house expenditures on coal liquefaction to the end of FY 1980-81 under the program are estimated at $1,065,000 and expenditures of $230,000 are projected for 1981-82. Total funds contracted out to industry, public research institutes, consultants and universities from 1976 to the end of FY 1980-81 are estimated at $1,418,000 and projected expenditures for 1981-82 amount to roughly $600,000.

The Government of British Columbia is establishing an Office of Coal Research to stimulate Provincial R & D in coal liquefaction. In the meantime, B.C. Research leads the Province's technical development of coal liquefaction under monitoring by B.C. Hydro. In June 1980, the Energy Development Agency entered into negotiations to issue a contract for a pre-feasibility study on producing liquid fuels from the Hat Creek coal deposit and subsequently awarded the study to Fluor Corporation, the company responsible for the Sasol complex in South Africa. This work followed interest shown in coal liquefaction by Japanese and West German firms. A consortium comprising BC Resources Investment Corporation, Petro-Canada and Westcoast Transmission is also investigating constructing a coal liquefaction plant in the Province. The Federal Government has encouraged potential investors by indicating that it will permit the export of some of the end products.

In 1979 the Alberta Research Council, together with the Alberta Department of Energy and Natural Resources, established a task force which recommended a long-range plan for provincial research into coal and oil sands. Coal research will include studies in liquefaction, underground gasification and fluidized bed technology. Part of the work will be contracted out to the private sector.

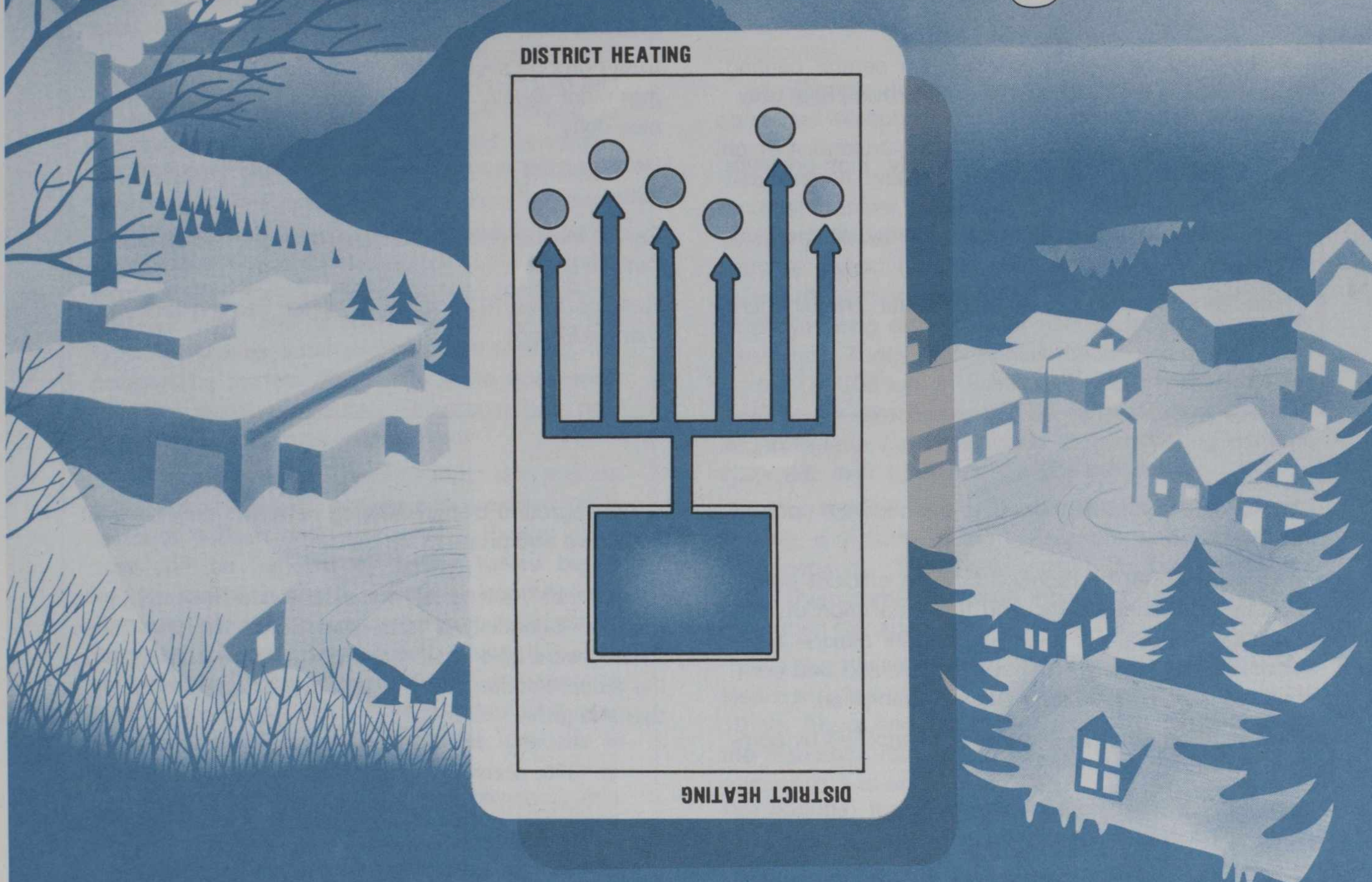
CONCLUSION

Coal liquefaction is incompatible with the Committee's long-term objective of eliminating hydrocarbon fuels from the Canadian energy mix. Furthermore, Canada's requirements for synthetic liquid fuels in the 1980s and 1990s will be more economically met, with less environmental damage, using resources in the oil sands of Western Canada and alternative energy sources.

RECOMMENDATION

Coal liquefaction should not be adopted as a long-term energy option for Canada. In the shorter term, however, a limited number of coal liquefaction projects aimed primarily at export markets could be accepted — with stringent environmental safeguards — to earn foreign exchange, to generate skilled employment and technological expertise, and to provide a supplementary source of synthetic fuel for domestic use in an emergency.

District Heating



District heating is a technology which allows residential, commercial or industrial space heating to be carried out from a central location. A heat source and a distribution system are the two basic elements in a district heating scheme, and either hot water or steam serves as the medium for delivering heat to the consumer. The heat source may range from a conventional boiler through a garbage incinerator to a nuclear powerplant. The distribution network consists of pipes which can be either buried or, in permafrost areas, housed aboveground in "utilidors". (In hot climates, district cooling is technically possible by circulating cold water to customers.) Heat may be delivered directly from combustion or reclaimed as a by-product of electrical power generation, with the latter "Combined Heat and Power" (CHP) type of scheme being termed co-generation in North America.

District heating technology in North America and in Europe has evolved along different lines (Table 6-7). The North American choice of providing steam heat from central plants using fossil fuels is the less expensive district heating option for supplying heat alone in small systems. For larger-scale applications the European approach of using hot water from co-generating systems is the preferred option.

District heating will often be cheaper than individual unit heating because of lower overall capital costs and greater combustion efficiency (even further efficiencies can be achieved with co-generation). Other factors which contribute to the attractiveness of district heating are:

- The cost of producing heat decreases as the size of a district heating plant increases, offering important economies of scale.
- Low-grade coals or combustible municipal wastes can be used to fire the boilers (most efficiently in fluidized

Table 6-7: COMPARISON OF NORTH AMERICAN AND EUROPEAN APPROACHES TO DISTRICT HEATING

North American	*European*
Single-purpose system employing a central heating plant usually fired with gas or oil to provide heat only	Dual-purpose system employing a CHP (co-generating) plant usually fired with coal to provide heat and electricity
Heat transfer medium is generally high-pressure steam or high-temperature water	Heat transfer medium is generally lower-temperature water
Serves institutional customers primarily, at premium cost	Serves institutional and residential customers at competitive costs
Handles about 1 to 2% of space heating requirement in North America	Handles from 10 to 40% of space heating requirement in Europe

Source: After Farkas, 1975, p. 2.

bed combustors), thus reducing dependence upon oil for heating.

- Air pollution can be reduced through efficient burner design and maintenance, and the installation of anti-pollution devices. For example, sulphur dioxide emissions can be largely eliminated in fluidized bed combustors using limestone for sulphur absorption.
- Fuel handling and ash disposal are simplified by comparison with dispersed heating units.
- Space in district heated buildings is not required for furnaces, fuel tanks and so on.
- Fuel costs may be reduced by bulk purchase and delivery.
- Heat can be derived from energy-efficient co-generating plants.
- Condensation in dwellings is minimized because combustion is carried out elsewhere.
- Domestic fire hazards are reduced because no fuel is stored or burned where the heat is used.

Whether district heating is competitive with unit heating, however, can only be determined by taking political, economic and social constraints into consideration:

- In planning and administering district heating schemes, the involvement of several levels of government could prove to be an impediment to efficient development.
- The cost of restructuring an area to install district heating is, in general, prohibitively high. District heating is widespread in Europe as a result of postwar reconstruction, but in the North American context, large-scale application of this option may be restricted to new construction.
- Aboveground district heating networks may be unattractive and prone to vandalism.

District heating is an established technology in Europe, Scandinavia and the Soviet Union. These nations were able to start district heating systems during the reconstruction after World War II and add to them as demand grew.

> In 1978, according to rough estimates, 600 companies distributed more than 10 [million tonnes of oil equivalent] of heat through about 1,000 district heating networks, comprising a total length of almost 9,000 km of mains. Somewhat more than one-half of this heat was used in the Federal Republic of Germany; a little less than a third went to Denmark; the remainder is divided between France (10%), the Netherlands (3%), Belgium (2%), Italy and the United Kingdom (0.2-0.3%).
>
> Total capacity, connected to district heating schemes in the [European Economic] Community, is presently of the order of 50,000 MW. The capacity per million inhabitants is, with some 2,000 MW, in Denmark, the highest of the Western World. In the Federal Republic of Germany connection density reaches about one-fifth of the Danish value. In the remaining Community countries densities are below 100 MW/million inhabitants. (Davis and Colling, 1979, p. 57)

District heating has gained in importance in Scandinavia since Sweden commissioned the first plants during the 1950s. In 1978, Sweden had 53 built-up areas served by district heating systems, 12 of which incorporated power generation plants (co-generation). The total installed district heating capacity (1978) was about 10,000 thermal megawatts or about 1.25 kW per capita for the entire population. The Stockholm district heating system is particularly noteworthy, being one of the largest co-generating systems developed in the free

Operation of District Heating Systems

In practically all district heating schemes, heat is transferred using hot water, although steam has been the medium of choice in North America. Water is inexpensive, non-toxic and has a high specific heat, meaning it can store large amounts of thermal energy compared with many other liquids. Water boils at 100°C at 1 atmosphere pressure (1 bar), but the boiling temperature rises when the water is pressurized. In modern European-style district heating applications, water temperatures and pressures rarely exceed 180°C and 10 bars, and temperatures of 130°C are typical. Because water expands with heating, the pressurizing system must be able to accommodate the increased volume. This capacity is normally provided by an expansion tank.

These pressurized systems must also provide adequate safeguards against either excess pressures or sudden depressurizations. Excess pressure can be handled by safety valves but a sudden pressure drop is a more serious concern. Pressure loss due to accidental ruptures must be localized by emergency shutoff valves. It is also desirable to exclude oxygen from the system to reduce corrosion, and soft water should be used to minimize the formation of scale deposits in boiler and distribution pipes.

Heat in the circulating water is transferred to residential or commercial users by heat exchangers such as conventional radiators. Water returning to the boiler has been cooled by some 40-60°C during circulation.

While a flat rate may be charged by a utility to a residential or industrial consumer, this offers little incentive to conserve; consequently most consumers are metered for their heat use. European research has led to the conclusion that metered customers experience average economies of 15-25% compared with flat-rate customers. A district heating meter performs much the same function as an electricity meter but it measures and records both the temperature and volume of water used. This dual function makes metering more expensive and more prone to error.

world. It comprises three subsystems with heat sources ranging from temporary and permanent conventional boilers to refuse incinerators.

Nearly 20% of Finland's buildings are serviced by district heating in 20 large communities. In 1977 the district heat demand of the Helsinki Metropolitan Area was 1,920 thermal megawatts, with thermal power plants producing 810 MW by co-generation and regional hot water boilers supplying the remainder. In Denmark, district heating is even considered an economically viable option for small communities and individual farmhouses.

In France, district heating accounts for 3% of the combined institutional, commercial and residential heating requirement. In contrast to other European countries, French systems generally use superheated water for heat transfer (although the use of steam is widespread in Paris). The West Germans are considering a national district heating grid, anticipating that by the turn of the century technology will permit the transfer of heat over long distances for use up to six hours after generation. Today, Italy boasts the longest district heating line, at 106 km. In Austria, Vienna and Salzburg are serviced by district heating in co-generating systems, and in Prague, Czechoslovakia, district heating is a civic utility with over 1,000 km of mains installed.

The U.S.S.R. is the world's largest user of district heating, with 50% of the installations and 85% of the total capacity. The Soviets claim that co-generation saves them some 36 million tonnes of coal per year — more than Canada's annual production.

In the United States, district heating systems using steam satisfied about 1% of the demand for heat in the 1970s. About half this amount was sold by utilities, and the rest was produced at government facilities, college campuses and so forth. Parts of downtown New York, Philadelphia, Boston, Detroit and other cities are supplied with steam heat from boilers and from condensing steam turbines.

District heating is not practiced on a large scale in Canada and, with the exception of a pilot hot-water system in Charlottetown, all plants distribute steam. Perhaps the oldest system is the one established in Winnipeg in 1924 where a standby coal-fired electrical plant was used to generate by-product heat. This system was expanded in the 1950s and again in the 1960s, and is now operated by the municipally-owned utility Winnipeg Hydro. In 1964, natural gas became available in Winnipeg and the plant lost its competitive edge in supplying heat. In 1978, the plant serviced 232 customers in the downtown area.

In the early 1970s, the City of Toronto began to integrate the steam heating systems of the University of Toronto, the Government of Ontario, the local Hospital Steam Corporation and its own Pearl Street plant. The project was inspired by the need to reduce air pollution by the Pearl Street plant, the idea being to phase out this old facility and finance a new one with revenues generated from an expanded downtown market. The integration is proceeding and planning is underway to include a municipal refuse incinerator for heat generation.

Smaller district heating plants operate in downtown Montreal (Canadian National Railways), Ajax, London, Ottawa (Parliament Hill), Vancouver, Charlottetown, Yellowknife and Inuvik. The Inuvik scheme is of particular interest because steam is piped aboveground in utilidors totalling 8 km in length.

Canadian research into district heating was sponsored by the Office of Energy Conservation, EMR, which funded a number of consultants' studies in 1976 and 1977. Other studies to assess the feasibility of expanding district heating facilities or installing new ones have been undertaken in Vancouver, Regina, Sarnia, Montreal, Halifax, Edmonton, Toronto, London, Charlottetown and Summerside.

In January 1981 the Governments of Canada, Ontario and the City of Ottawa agreed to undertake a demonstration project for the district heating of 197 homes to be built in LeBreton Flats. The heating plant will operate initially on natural gas but other fuels may be substituted at a later time. Heat will be distributed by hot water rather than steam and, while the cost of the heat will be shared equally by tenants, each home will have its own flow and temperature meters. The City of Ottawa will own and operate the district heating utility, and startup is scheduled for late 1981.

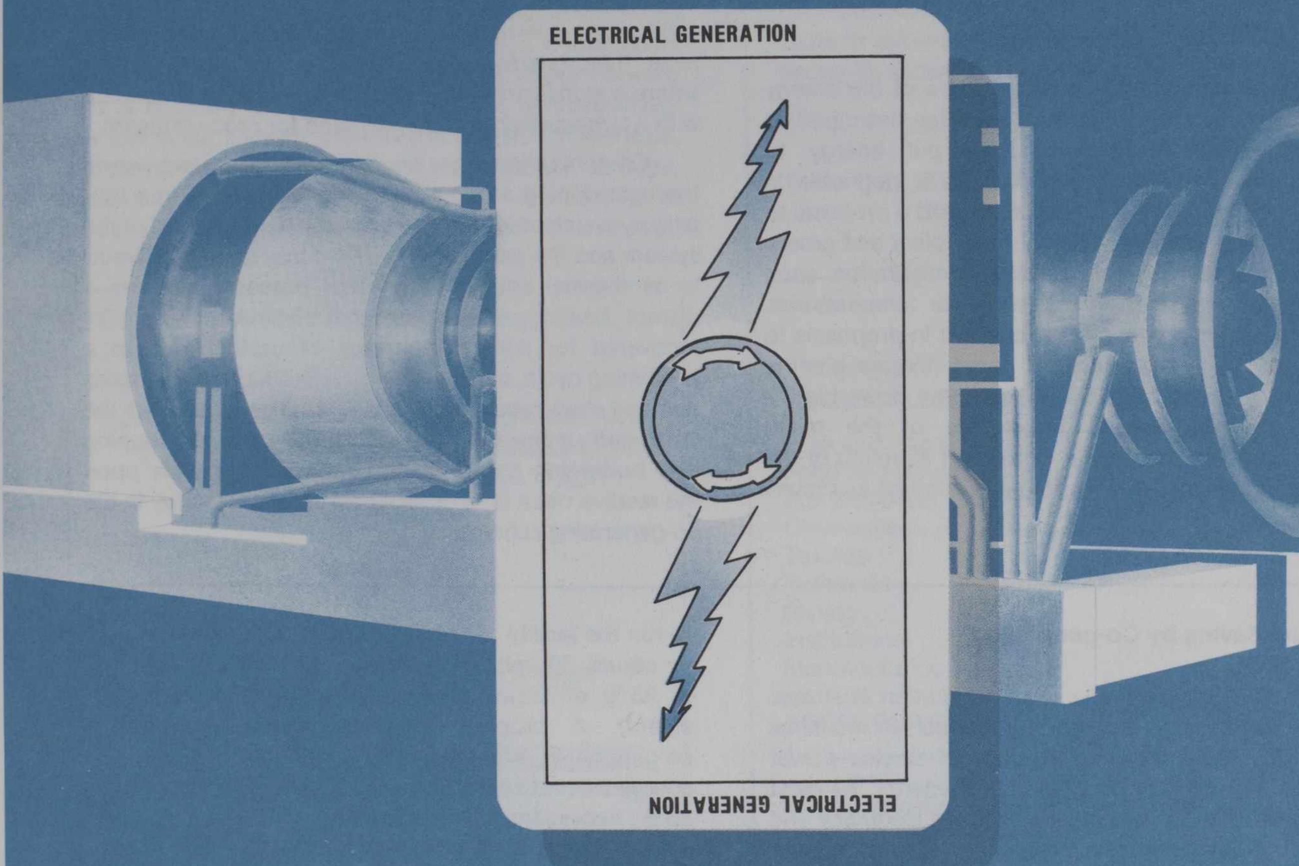
CONCLUSION

District heating will have limited application in Canada as the costs of installing such systems in built-up areas are prohibitively high. This technology may, however, make economic sense in regions of new construction.

RECOMMENDATION

The Committee recommends that district heating should be considered as an energy-conserving technology for new subdivisions, communities and industrial parks.

Electrical Generation



1. COMBINED-CYCLE GENERATION

A. INTRODUCTION

In the large thermal-electric generating stations of today's utility systems, the intent is to produce electricity with maximum efficiency in converting thermal energy into electrical energy. A modern, fossil-fuelled, central power station will succeed in this endeavour with an efficiency of roughly 35% over its operating lifetime, with the remaining two-thirds of the thermal energy exhausted to the environment as "waste heat". Nuclear-electric stations do even less well, with the Pickering Generating Station demonstrating a conversion efficiency of about 30%. Accounting further for energy losses in transmission lines, transformers and the distribution grid, one finds that only 25 to 30% of the energy contained initially in the powerhouse fuel is delivered to the point of use as electricity. At today's fuel prices and with the longer term prospect of petroleum scarcity, this is not a happy situation.

Combined-cycle generation is an approach to achieving maximum *energy* efficiency, typically in industrial settings, as opposed to the central power station concept of maximizing *electrical* efficiency. Combined-cycle systems usually involve the simultaneous production of heat and electricity. In this configuration such systems are termed co-generation in North America and combined heat and power (CHP) in Europe. Occasionally, combined cycles are employed to produce electric power alone.

Various names for more energy-efficient industrial systems are appearing in the literature, sometimes to describe schemes which are rather old in practice. A *total energy system* refers to one which supplies all the electricity at a site (either in isolation or with backup from a utility) and which also handles all or part of the heating and cooling loads of the site. While new in name, such installations were actually common early in this century in industrialized countries.

Systems which make sequential use of the energy input to perform a series of tasks are often described as *cascading systems*. Such systems put energy to progressively less demanding uses as it degrades in quality. For example, the Committee heard a proposal to link a generating station, a heavy water plant and greenhouses in a cascading, energy-using configuration, each step utilizing heat at progressively lower temperatures. Energy cascading is the central element in proposals to create *energy centres* around large thermal-electric generating stations, capitalizing upon the powerplant's rejected thermal energy. Regardless of the name applied, however, the goal is to convert as much of the energy of a fuel into useful work as is possible in a given situation.

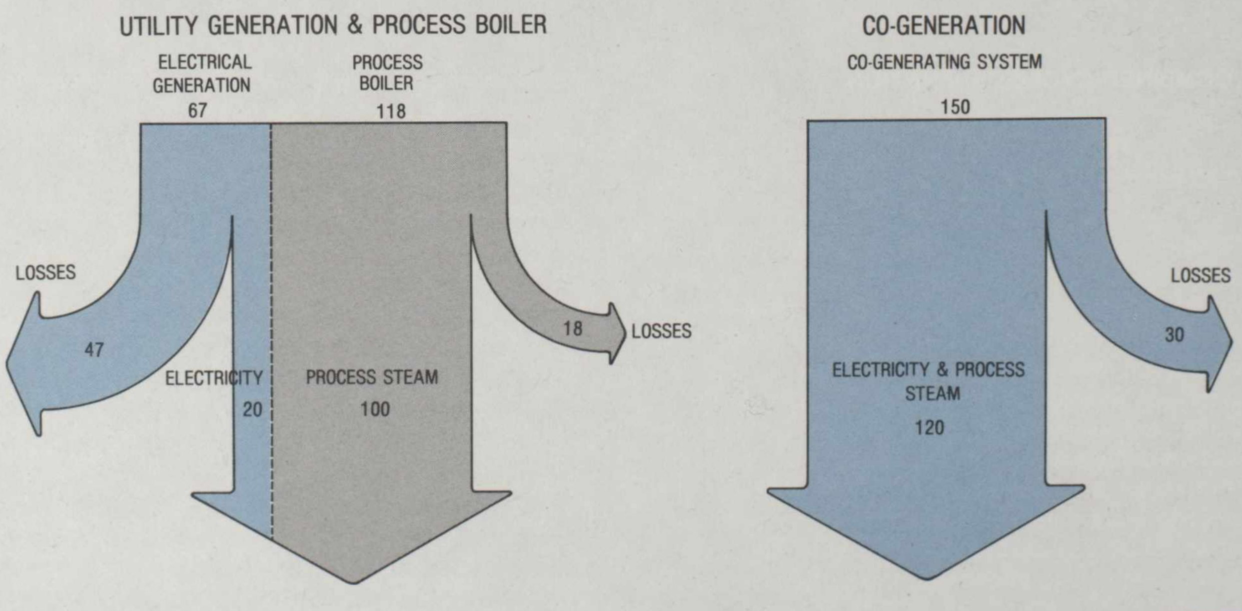
B. CO-GENERATION

A co-generating system produces electricity and heat (and sometimes mechanical energy) in tandem, with reclaimed heat from one part of the system being used as an energy source for the other. Such systems have their greatest potential in an industrial setting where a significant requirement for electricity is coupled with a large and continuous demand for process steam.

Co-generation can be approached in two ways, through topping and bottoming configurations. In a topping cycle, electricity is generated at the front end of the system and the exhausted heat is either delivered directly as thermal energy to another process (such as a district heating scheme or an industrial process) or recovered for some other form of useful work. In a bottoming cycle, thermal energy is produced for process use and then recovered for electrical generation at the back end of the system. The choice between topping and bottoming cycles in co-generation depends upon the relative need for electricity and thermal energy in the co-generating scheme.

Fuel Saving by Co-generation

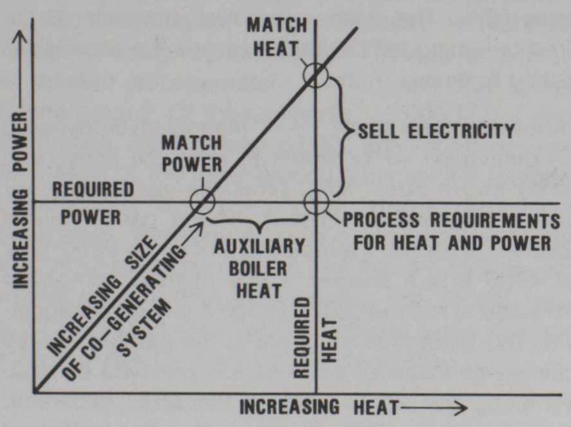
A simple example of co-generation illustrates the value of the approach. Consider an industrial development requiring 20 units of electric power and 100 units of process steam energy. At most locations today a utility supplies the electricity and an on-site process boiler makes the steam. Assuming an efficiency of 30% in the system delivering the electricity and an efficiency of 85% for the boiler system, 185 units of fuel are required to run the facility (67 units of fuel at 30% efficiency equals 20 units of electricity; 118 units of fuel at 85% efficiency equals 100 units of process steam). A properly matched, steam turbine co-generating system might handle these same energy needs with an overall efficiency of about 80%, necessitating a fuel input of 150 units (150 units of fuel at 80% efficiency equals 120 units of electricity and process heat). The co-generation system described thus saves 35 units of fuel for a fuel-saved ratio of 35/185 or 19%.



Despite the advantages in fuel saving, the percentage of industrial electricity derived from co-generation has fallen during the twentieth century. In the United States, industrial co-generation accounted for one-third or more of industrial electricity use in 1900; it represents less than 5% today. The explanation is straightforward and is basically a matter of economics. With relatively low fuel costs, steadily improving conversion efficiencies, increasing powerplant size and the reliability of large, multi-unit systems, the utilities could offer industrial power at lower rates than industry could achieve itself

Co-generation and Process Matching

Figure 6-11: A HYPOTHERICAL CO-GENERATING SYSTEM WITH EXCESS ELECTRICAL GENERATING CAPACITY



The illustration above represents a co-generation scheme where the ratio of power to heat exceeds that required at the site. The sloped line beginning at the origin and rising to the right represents a co-generating system of increasing size. Reflecting the power/heat ratio, the slope of the line is characteristic of the system in question and is a function of the temperature at which heat is required in the process.

In this example, if the co-generating system is selected to match the power requirement, then the system does not produce enough heat and an auxiliary boiler must be installed to make up the deficiency. If the system is designed to match the heat requirement, on the other hand, more electric power is generated than required at the site and the excess power must then be sold to a utility.

Industrial Co-generation in Canada

A recent study has estimated that the technical potential for industrial co-generation in Canada exceeds 4,000 megawatts, distributed by sector as shown in Table 6-8.

Table 6-8: THE POTENTIAL FOR INDUSTRIAL CO-GENERATION IN CANADA

Sector	Potential in Electrical Megawatts
Pulp and Paper	1,613
Food and Beverage	211
Iron and Steel	149
Chemicals	593
Textiles	26
Refineries	880
Mining	134
Institutional	196
Manufacturing	224
TOTAL FOR CANADA	4,026

Source: Canada, Department of Energy, Mines and Resources, 1980a, p. 51.

Some 1,100 to 1,400 MW of this potential has already been developed, notably in the pulp and paper industry and in heavy water production, and an additional 1,400 MW is considered economically exploitable (under conditions prevailing at the time of the study in 1977). Compared with Canada's total generating capacity of more than 77,000 megawatts, the opportunities to pursue co-generation now and in the future are modest but not inconsequential.

Companies such as Dow Chemical and Suncor already operate major co-generation schemes. The Nova Scotia Power Corporation owns two such systems, both supplying process steam to heavy water plants, and the New Brunswick Electric Power Commission owns a unit supporting a newsprint mill. Most co-generation schemes in Canada today use natural gas or oil as the fuel, a situation which will change with time. Coal, petroleum coke and hog fuel (waste wood in the forest industry) are other fuels presently being used.

through co-generation. Industry was also facing rising costs for utility backup to co-generation schemes, increased co-generation costs because of new environmental regulations, and capital costs of co-generation plants rising to prohibitive levels. While utilities can justify an extended depreciation period for equipment, industry looks for a more rapid write-off on co-generating systems. Combined heat and power production, despite its fuel savings, simply did not pay.

Given today's rising fuel prices, one can expect a reversal in this trend. Nonetheless, difficulties remain. For example, utilities have often charged rather stiff rates for backup services while offering low prices for excess power produced in co-generating systems. This is an important point from the perspective of industry since only rarely can a co-generation plant precisely meet the site requirements for both electricity and heat. Such barriers may prevent this energy-conserving technology from re-establishing itself in the industrial sector at anything more than a modest pace.

The barriers to co-generation today are not technical, although the technology will continue to evolve, and previously important economic barriers are shrinking as the price of conventional fuel rises. The prime obstacle to industrial co-generation is now an institutional or attitudinal one.

CONCLUSION

Co-generation is an energy-conserving technology whose importance in the post-war period has diminished, largely for economic reasons. Utilities have not been interested in promoting co-generation because, until recently, there was little reason for them to be involved in such schemes. Low electrical rates for large users have also discouraged co-generation.

RECOMMENDATION

The Committee encourages Canadian utilities to look more favourably upon co-generation and to devise means for promoting the broader use of this technology, possibly through joint ownership of such systems with industrial partners.

C. ALTERNATIVE CYCLES FOR PRODUCING ELECTRICITY

New approaches to converting heat into electric power are under investigation as the pressure mounts to combat escalating fuel prices. Most of these technologies would be incorporated in combined-cycle systems and thus warrant brief consideration here.

The *steam turbine* cycle is the most highly developed system for power generation, with more than a half-century of work behind it. Pushing development further will result in much higher capital costs and reduced reliability because of system complexity, suggesting that a practical limit has been approached. Efficiencies of 40 to 45% have been achieved with extremely high boiler pressures (some 300 times atmospheric pressure) and temperatures (more than 600°C or about 1150°F), incorporating two stages of reheating in the boiler system. Unfortunately, such extreme conditions degrade system reliability and more conservative (and less efficient) designs usually prevail.

Gas turbines operating in a combined cycle can achieve efficiencies about equal to the best steam plants but coupling a gasifier to a combined-cycle turbine system might stretch the overall thermal efficiency to nearly 50%. This poses a problem, however, as the required operating temperature exceeds the capabilities of existing turbines.

Another technology — *magnetohydrodynamic (MHD) generation* — promises to raise the conversion efficiency above 50%. MHD produces electrical power directly in a generator without moving parts. Heated combustion gases (at a temperature of some 2600°C or about 4700°F) are seeded with a metallic compound and directed at high velocity through a powerful magnetic field. This generates a current in the partially ionized (electrically-conducting) gas which is removed by electrodes along the inside walls of the MHD generator. Given the high exhaust temperature of such a system, it will be used as a topping cycle in combined systems.

Although there are still problems to overcome, MHD technology has advanced to the stage of engineering development in the U.S.S.R. and the United States. Both countries are planning commercial powerplants using coal for fuel. The Soviet Union expects to bring a 250 MW gas-fired topping unit (coupled with a 250 MW bottoming unit) into operation in 1985 and coal-fired MHD units will be introduced in the 1990s. The United States is planning a 200 MW coal-fired MHD generator which may be operational by the end of the decade. A number of other countries are also showing interest in MHD generation but their programs are well behind those of the U.S.S.R. and the United States.

Other generating cycles are being studied which offer efficiencies equal in theory to that of MHD generation and which may prove to be less technically demanding. None of these, however, will see broad commercial application for some time.

CONCLUSION

Individual utilities can best identify the opportunities for incorporating advanced energy conversion cycles in their systems as the technology becomes available. It should be sufficient for the Government of Canada to monitor developments in this technical area.

2. LOW-HEAD AND SMALL-SCALE HYDRO-ELECTRIC GENERATION

Through a blend of old and new technologies, low-head and small-scale hydro-electric generation offer some potential for increasing electrical generating capacity in Canada. This can be done by renovating or retrofitting existing facilities and by installing modern, small-scale equipment at locations where the stream flow and gradient are not adequate for conventional (large-scale) hydro-electric development.

Current estimates suggest that some 122,000 MW of conventional hydro-electric capacity is technically and economically developable in Canada and that of this amount approximately 44,000 MW has already been harnessed. Of the remainder, 15,000 MW is under construction, leaving some 63,000 MW for future exploitation. Most of this undeveloped potential will eventually be harnessed by conventional large-scale projects. Nevertheless, there are numerous opportunities for low-head, small-scale, mini-hydro and micro-hydro projects, particularly in remote communities not served by an electrical grid but where an appropriate hydro site could be used to replace diesel-electric generation.

Defining Small Hydro-electric Development

Generally speaking, an installation with a capacity below 100 kW is called a *micro-hydro* project; one between 100 and 1,000 kW is known as a *mini-hydro* project; and one whose installed capacity ranges between 1,000 and 15,000 kW is called a *small-scale* hydro development.

Hydro head is the difference in height between water levels immediately upstream and downstream of a turbine.

In the southern and more populous parts of Canada, the competition for water resources may limit the small-scale hydro potential. For instance, water demand for irrigation, for recreation and for maintaining natural stream flows conflicts with storing water for power generation. In addition, many abandoned reservoirs have deteriorated beyond the point where it is economically feasible to renovate them.

When choosing a site for small-scale hydro development, a number of considerations must be taken into account. For example, the hydro head determines the water pressure available to drive the turbines and helps determine the unit cost of electricity produced. The size of reservoirs, the rate at which they are replenished and the cost of their construction also influence the cost of the electrical output. The environmental impact of reservoir flooding must be evaluated before development and efforts made to ensure that construction does not adversely affect water quality and wildlife. Economics will favour the isolated community where it would cost more to link it to an existing grid than to develop a local, small-scale hydro site. The Committee visited one such site near Hay River in the Northwest Territories.

The Federal Government and many provinces have expressed interest in low-head and small-scale hydro developments and surveys of likely sites have taken place in the Maritimes, Quebec, Saskatchewan and British Columbia. Initiatives that have gone beyond the study and planning stages are currently underway in Newfoundland, Nova Scotia and Ontario.

Newfoundland signed an agreement with the Federal Government in September 1978 to construct a 400 kW mini-hydro demonstration project near Roddickton, a small community about 75 km south of St. Anthony on the Island's Great Northern Peninsula. The project commenced operation in the fall of 1980, some six months ahead of its completion date of 1 March 1981, and an appraisal of its practicality and benefits are now underway. This appraisal will attempt to identify opportunities for simplified construction, installation, control, operation and maintenance of equipment suitable for small-scale hydro development in isolated communities across Canada. Efforts will also be made to establish standard techniques for simplifying site selection. A design manual will be prepared for use by any provincial government interested in constructing a similar facility. The $1,200,000 cost of the demonstration (of which the Federal Government agreed to pay 90%) emphasizes the comparatively high cost ($3,000 per kilowatt) of small-scale projects, although their economics will improve as the price of oil continues to rise.

In Nova Scotia there are undeveloped hydro sites in the 50,000 to 100,000 kW range where large volumes of water flow with relatively low heads. To date, it has not been feasible either technically or economically to develop them. As discussed in the section entitled Tidal Energy, a 20 MW demonstration project is under construction near Annapolis Royal to test a large straight-flow (Straflo) turbogenerator with potential tidal and low-head river applications. Unlike conventional units, the turbine and generator are integrated, with rotors attached to the tips of the turbine blades. If the demonstration is successful, low-head waterways across Canada may become exploitable for energy.

In the Province of Ontario, Ontario Hydro has taken a somewhat different approach to small-scale hydro power, emphasizing micro and mini "packaged plants". These can be transported to isolated communities and the design is simple enough that they can be assembled locally with a minimum of outside help. A Port Colborne company recently introduced two sizes of hydro-electric systems, known as "tin can powerhouses", which have been designed to operate with a head of eight metres (25 feet) or less. This represents a considerable advance over conventional equipment which requires a minimum head of some 16 metres (50 feet) to function efficiently. The smaller of the two, called the micro-hydel (hydro-electric) unit, can generate between 15 and 50 kilowatts of power depending upon the site. It includes a turbine, a generator, a gear box, a governor and control circuitry. The larger unit, the mini-hydel station, can generate between 100 and 1,000 kilowatts. Both units have been designed with ruggedness, reliability, transportability and ease of maintenance in mind.

To test the mini-hydel unit, a prototype has been installed by Ontario Hydro on a small dam at Wadsell Falls on the Severn River in southern Ontario. This plant is an ungoverned unit with a maximum capacity of 145 kW. Its output is fed directly into the southern Ontario grid. The use of a siphon penstock to draw water over the top of the pre-existing dam and direct it onto the runner of the unit reduced the cost of the installation. The Wadsell Falls project will establish the economics of installing a small-scale powerhouse in a built-up area. It will also help establish the potential of the mini-hydel power station for use in isolated communities and indicate whether or not it can compete for sales in international markets.

The mini-hydel unit has control and safety features which make it particularly attractive and a number of countries have expressed interest in the technology. Although testing continues, the Port Colborne company considers the program far enough advanced to accept orders for generating units of up to 750 kilowatt output.

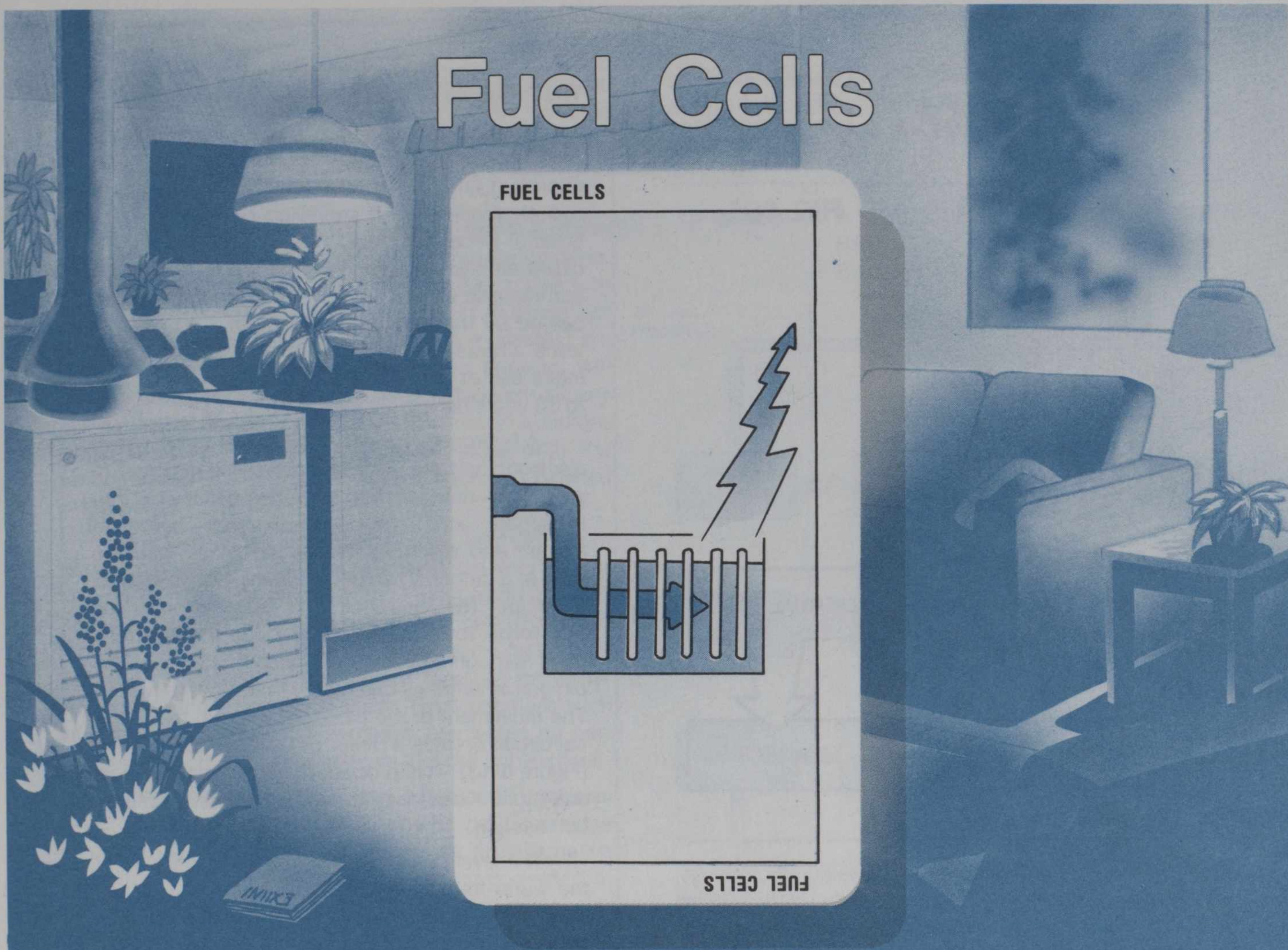
CONCLUSION

Continued increases in the prices of fossil fuels are making small-scale and low-head hydro look increasingly attractive. There are clear economic advantages in installing small-scale units in isolated communities which rely on diesel-electric generation and which have little likelihood of integration into an electrical network for a number of years. Since these same conditions prevail in many developing countries, the technology offers considerable export potential.

RECOMMENDATION

The Committee recommends that financial assistance be extended to isolated communities which rely upon diesel-generated electricity to enable them to install small hydro units where an appropriate site exists. The Committee further recommends that this technology be vigorously promoted for its export potential.

Fuel Cells



1. FUEL CELL TECHNOLOGY

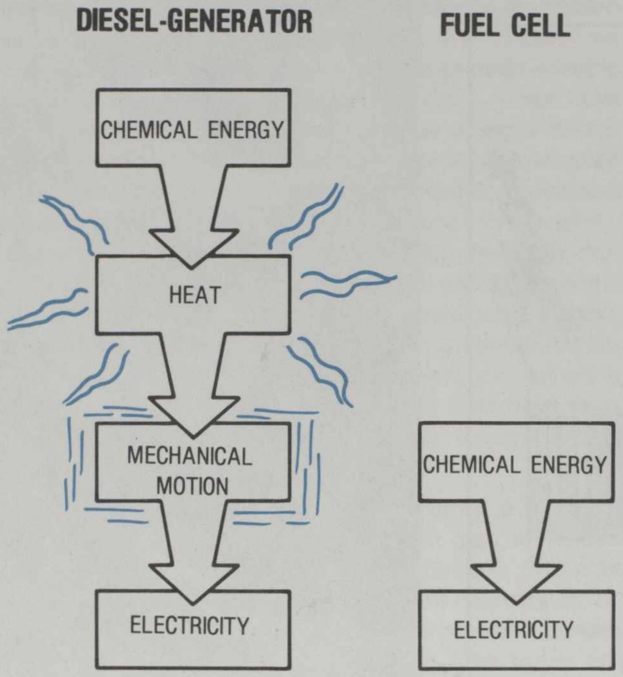
A fuel cell works like a dry cell or car battery in that chemical energy is converted directly into electrical energy with no intermediate combustion step. Unlike batteries, however, which undergo a chemical change in releasing stored energy, fuel cells convert the chemical energy of a fuel supplied from outside the cell into electricity and undergo no material change. A fuel cell can produce electricity with a greater efficiency than that achieved in conventional thermal generation because fewer energy conversions are involved and there is little waste heat produced. Figure 6-12 displays the one-step conversion to electricity in a fuel cell, contrasted with the three conversion steps required in diesel-electric generation.

At the present state of development, a fuel cell is approximately 40 to 45% efficient in converting chemical energy to electricity. This compares with a typical efficiency of about 35% achieved in modern central power stations. In applications where the heat released by a fuel cell can be recovered, as in home heating, the efficiency of a fuel cell energy conversion system can approach 100%. Fuel cells developed for transportation use will not be readily able to reclaim this heat.

The fuel cell was invented by Sir William Grove in 1839 but was not developed until required for non-polluting, on-board power generation in the Gemini and Apollo spacecraft. These first cells were small and costly but the technology has come a long way since then and Consolidated Edison recently installed an experimental 4.8 MW fuel-cell-powered electrical generating plant in Manhattan.

A variety of reactants can be used to power a fuel cell, but typically the power generating reaction involves the combination of hydrogen and oxygen to produce

Figure 6-12: COMPARISON OF ENERGY CONVERSION PROCESSES IN A FUEL CELL AND IN A DIESEL GENERATOR



Source: Crowe, 1973, p. 3.

water. Fuel cells of the *direct* type utilize pure H_2 and O_2 which have been produced independently whereas cells of the *indirect* type are combined with a hydrogen-generating unit which can produce hydrogen from a wide variety of fuels.

2. ADVANTAGES AND DIFFICULTIES IN USING FUEL CELLS

In addition to the high efficiency and hence energy-conserving character of fuel cells there are other features which make them attractive as well. Being very clean in operation, they represent an environmentally appealing means of generating power and can be used in urban settings with little worry about emissions. In fact, the only emissions from fuel cell operation other than air and water are from the operation of the fuel processor which is used to generate hydrogen.

Another attractive characteristic of fuel cells is that they are modular in form and can be assembled in one location and then shipped to the place of installation with no costly on-site building required. This feature also means that they can be added to or subtracted from existing installations as power requirements change. Used in urban settings for electrical generation, fuel cells reduce the costs of acquiring land and building transmission lines and can consequently conserve energy by

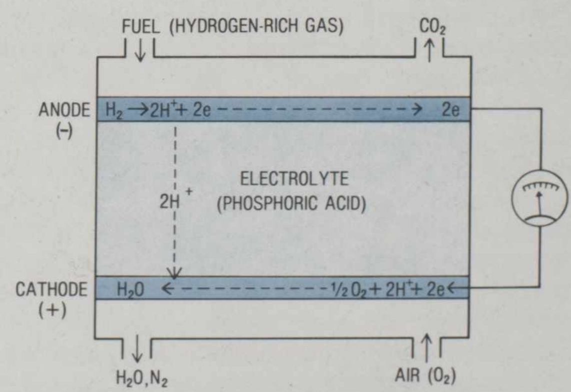
The Principle of Fuel Cell Operation

The most common fuel cell is the phosphoric acid type and it serves to illustrate the basic operating principle of these devices. It consists of two electrodes which sandwich between them a layer of phosphoric acid. The phosphoric acid is called an electrolyte, the word used to describe a non-metallic electric conductor in which current is carried by the movement of ions instead of electrons. (There are other types of fuel cells which make use of different electrolytes, but they are 5 to 10 years behind in development.)

A hydrogen-rich gas passes over the negative electrode and the positive electrode is exposed to an oxygen-rich gas. The hydrogen gas is split into hydrogen ions (positively-charged hydrogen atoms) and electrons at one electrode with the help of a catalyst, usually a noble element such as platinum. The hydrogen ions pass through the electrolyte towards the oxygen and the electrons flow through an external circuit towards the oxygen where they chemically react to form water. The movement of the electrons through the external circuit creates a direct or DC electrical current (Figure 6-13). This process of converting chemical energy into electricity is termed an electrochemical reaction.

The level of current depends upon the rate of the water-forming reaction and upon the surface area of the electrodes where the reactions take place. To increase voltage to utilizable levels, individual cells are assembled into stacks and by connecting stacks in series or parallel, the amount of power which can be generated is further increased.

Figure 6-13: SCHEMATIC REPRESENTATION OF A FUEL CELL



Source: After Fickett, 1978, p. 72.

eliminating the losses which are inherent in electrical transmission. Finally, having no moving parts, fuel cells are virtually noiseless in operation making them attractive for use in the transportation sector, particularly in urban areas.

Despite these advantages, however, the cost of this technology must be further reduced to make it competitive. The development of less expensive electrodes with a longer operating life is a major factor in reducing fuel cell costs. Emissions associated with fuel processing are unlikely to cause environmental concern because sulphur removal equipment must be a subsystem of any fuel processor supplying hydrogen to a cell. Precautions would of course always have to be taken with the various acidic or alkaline electrolytes which can be used in fuel cells.

Fossil fuels (in particular natural gas, light petroleum fractions or liquefied petroleum gases) are very adaptable for use with fuel cells, but they must all be converted into a hydrogen-rich gas to feed the cell. This could limit the use of fuel cells which operate on fossil fuels because the processing equipment required for utility-sized installations would be costly. Synthetic fuels such as hydrogen, methanol or synthesis gas would be particularly attractive for smaller-scale fuel cell applications.

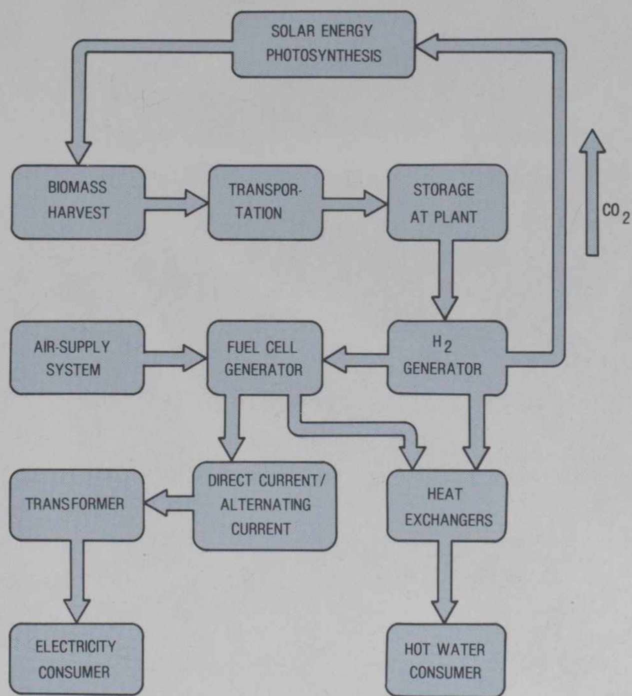
One attractive option for fuel cells used in vehicles is to run them on methanol, which the Committee recommends developing in Canada as an alternative liquid transportation fuel. Methanol can be converted to hydrogen easily and storing H_2 in this form overcomes some of the problems encountered in designing on-vehicle, hydrogen-carrying systems.

3. INTERNATIONAL AND CANADIAN DEVELOPMENT

Numerous programs are established in the United States to study fuel cell design, operation and application but research seems aimed primarily at developing a technology which can be used for utility-size electrical power production. Some experiments for motor vehicle and space research application are being done as well, but these are limited.

Sweden has no natural gas or oil so its interest is directed primarily at developing fuel cells which can utilize hydrogen derived from biomass or peat feedstocks. The Swedes believe that fuel cells offer an attractive alternative energy technology in their country because the high reactivity of biomass in pyrolysis/gasification processes (see section on Biomass) permits easy generation of a hydrogen-rich gas which can run the cells. Moreover, the modular character of fuel cells makes them adaptable to a widely-dispersed resource base like biomass. Figure 6-14 schematically represents a fuel cell electrical generating system employing biomass (including peat) as a feedstock.

Figure 6-14: A FUEL CELL ELECTRICAL GENERATING SYSTEM EMPLOYING BIOMASS AS A FEEDSTOCK



Source: Lindström *et al*, 1979, p. 1178.

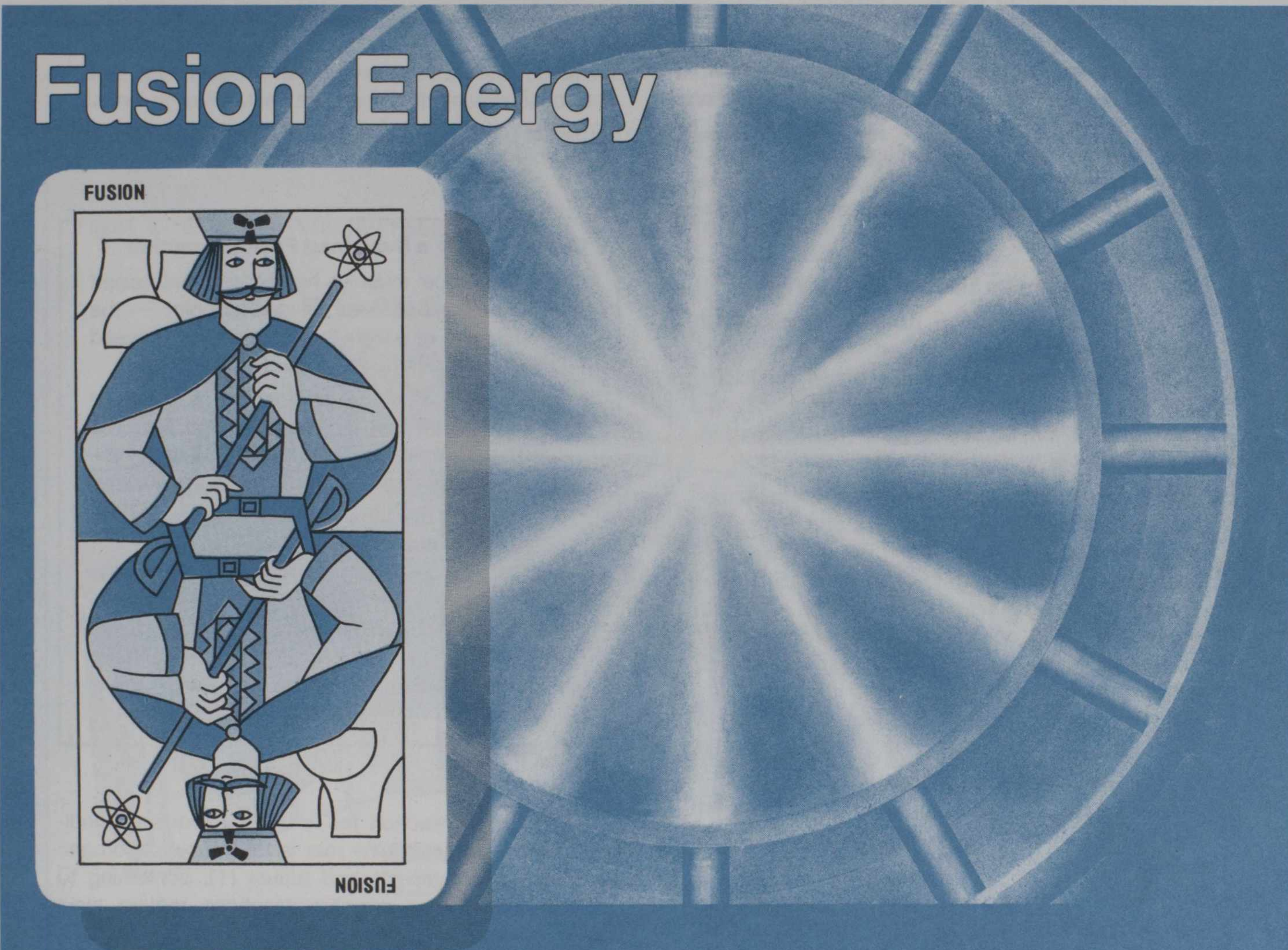
CONCLUSION

The Committee recognizes that the high efficiency of fuel cells makes them attractive as an energy-conserving technology and that they hold the potential for allowing an increased use of Canada's biomass and peat resources.

RECOMMENDATION

The Committee recommends that research on fuel cells be funded as part of a commitment to developing a hydrogen economy for Canada. In particular, the development of fuel cells for the transportation sector should be given high priority as their use promises to substitute for transportation fuels, to reduce vehicle exhaust emissions and to develop a market for hydrogen.

Fusion Energy



1. THE NATURE OF FUSION ENERGY

The stars, our sun included, are powered by nuclear fusion. In these gargantuan reactors, hydrogen is the fuel and helium is the ash. Once the physical processes operating in the deep interior of stars were comprehended by scientists, speculation began on whether controlled fusion could be achieved in the laboratory. If it could, the prospect of an essentially inexhaustible source of energy lay before society.

Two contrasting nuclear processes — fission and fusion — are accompanied by the release of energy. In the *fission* process, heavy elements such as uranium are split apart. The resulting fragments have a combined mass slightly less than that of the original system, and the missing matter appears as energy. In the *fusion* reaction, the nuclei of light elements such as hydrogen combine (fuse) to form a heavier element. Again the conversion results in a mass decrease which appears as energy. To date, only the fission reaction has been harnessed to meet man's commercial energy requirements.

Fusion can be accomplished only under extreme conditions because of the strong repulsive forces between positively charged nuclei. In the fusion reactors of man, temperatures well in excess of those thought to exist in the interior of the sun will be required. Thus the central problem in fusion research is how to establish and contain a reaction proceeding at a temperature of 100 million degrees Celsius. Solving the containment problem has been so difficult that some scientists, in the 1960s particularly, questioned whether the effort would ever succeed. Today, however, a strong sense of optimism pervades fusion research as a result of major advances made during the last decade.

At extremely high temperatures, atoms are completely ionized and the resulting mixture of bare nuclei and free electrons is termed a plasma. Most of the known universe, with minor exceptions like the Earth and other planets, is a plasma. For such a conglomeration of charged particles to sustain a fusion reaction, however, special requirements of temperature, density and confinement time must be met. Thus to create a "miniature star" in the laboratory, scientists must establish a unique environment.

Atoms and Isotopes and Other Such Things

Atoms are made up of three fundamental particles. Positively charged *protons* and uncharged *neutrons* comprise the atom's nucleus which is orbited by negatively charged *electrons.* Virtually all of the atom's mass is concentrated in the nucleus.

Atoms in their normal state possess equal numbers of protons and electrons and are therefore electrically neutral. When suitably excited, however, an atom can lose or gain electrons, thereby acquiring a net electrical charge. Charged atoms are called *ions* and radiation which is capable of stripping electrons from atoms is termed ionizing radiation. Ionizing radiation is not good for one's constitution (nor for one's descendents).

The number of protons in the nucleus determines the atomic species. An atom containing one proton is hydrogen. An atom with 8 protons invariably is oxygen, and one with 92 protons is uranium. Electrons determine the atom's chemical character.

Although the number of protons in an element is fixed, the number of neutrons is not. To take a simple example, hydrogen can exist in three forms with either zero, one or two neutrons in the nucleus. The first two variants, or *isotopes,* are called protium and deuterium. Tritium, the third variant, is unstable and reverts to helium over a number of years.

There exist in nature some elements that spontaneously decay, or disintegrate, into lighter ones, accompanied by a release of energy. Such elements are said to be *radioactive.* Man has added to naturally-occurring radioactivity in detonating nuclear devices and in operating fission reactors. Whether naturally occurring or man-made, radioactive elements decay at a fixed rate characteristic of the element in question. The *half-life* is the time during which one-half of a quantity of a given radioactive substance will spontaneously disintegrate, forming new atomic species. For example, given four units of tritium whose half-life is 12.3 years, two units of tritium (plus decay products) will remain after 12.3 years and one unit after 24.6 years.

Conditions for a Sustained Fusion Reaction

- The fusion fuel must be heated and maintained at a temperature near its ignition point — the temperature at which the reaction will proceed without further heat input.
- The plasma must be confined for a sufficient time to ensure that the energy (heat) from the reacting fuel is greater than or equal to the energy supplied to heat and confine the plasma.
- The plasma must have a sufficient density to ensure that the ions are close enough for the reaction to occur. (The density is defined as the number of ions per unit volume of plasma.) The minimum product of time and density to achieve the fusion condition can be expressed as a threshold requirement, called the Lawson Product after its formulator, physicist J.D. Lawson.

The fusion reaction for which the required conditions can most readily be met is that of two hydrogen isotopes, deuterium (D) and tritium (T), combining to form helium. Other possible reactions require even higher plasma temperatures than D-T fusion. Material confinement of the fusion plasma is, of course, out of the question — the reactor wall would be instantly vapourized by contact with the plasma and, at the same time, chilling of the fusion fuel would stop the reaction. There are nevertheless three known physical mechanisms for containing a high-temperature plasma: gravitational confinement, inertial confinement and magnetic confinement.

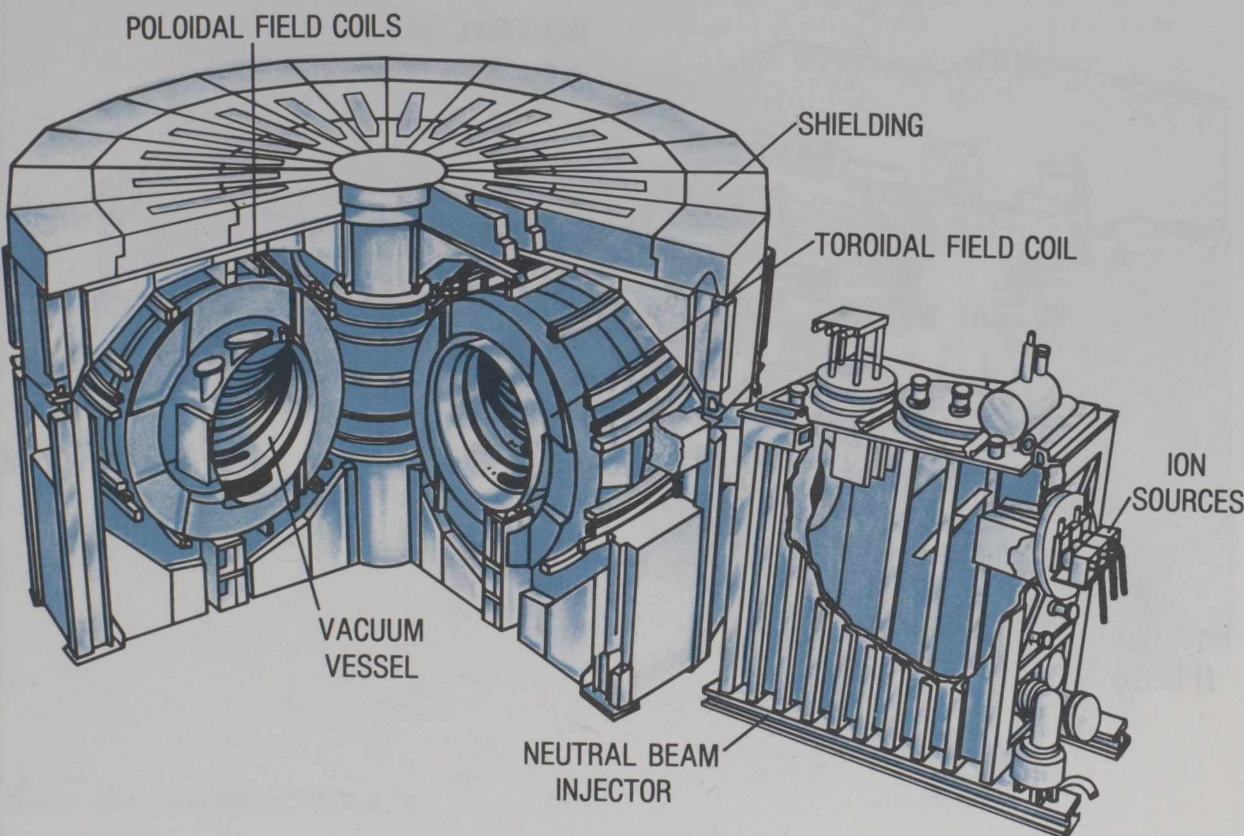
Gravitational confinement works marvelously well in the sun, so well in fact that a more difficult fusion reaction takes place at lower temperatures than face man in achieving D-T fusion. Since the Earth's gravitational field is trifling by comparison, however, this is not a relevant research approach.

In inertial confinement, the temperature and density of a plasma fuel droplet are raised so rapidly that a significant fraction of the fuel reacts before it has time to disperse. The heating is achieved with laser or particle beams dumping huge amounts of energy into the droplet in billionths of a second.

Magnetic confinement takes advantage of the fact that the plasma consists of charged particles. Magnetic fields are employed to constrain or reflect the particles

Fusion Reactor Configurations — Closed Magnetic Confinement

Figure 6-15: SCHEMATIC REPRESENTATION OF A TOKAMAK REACTOR



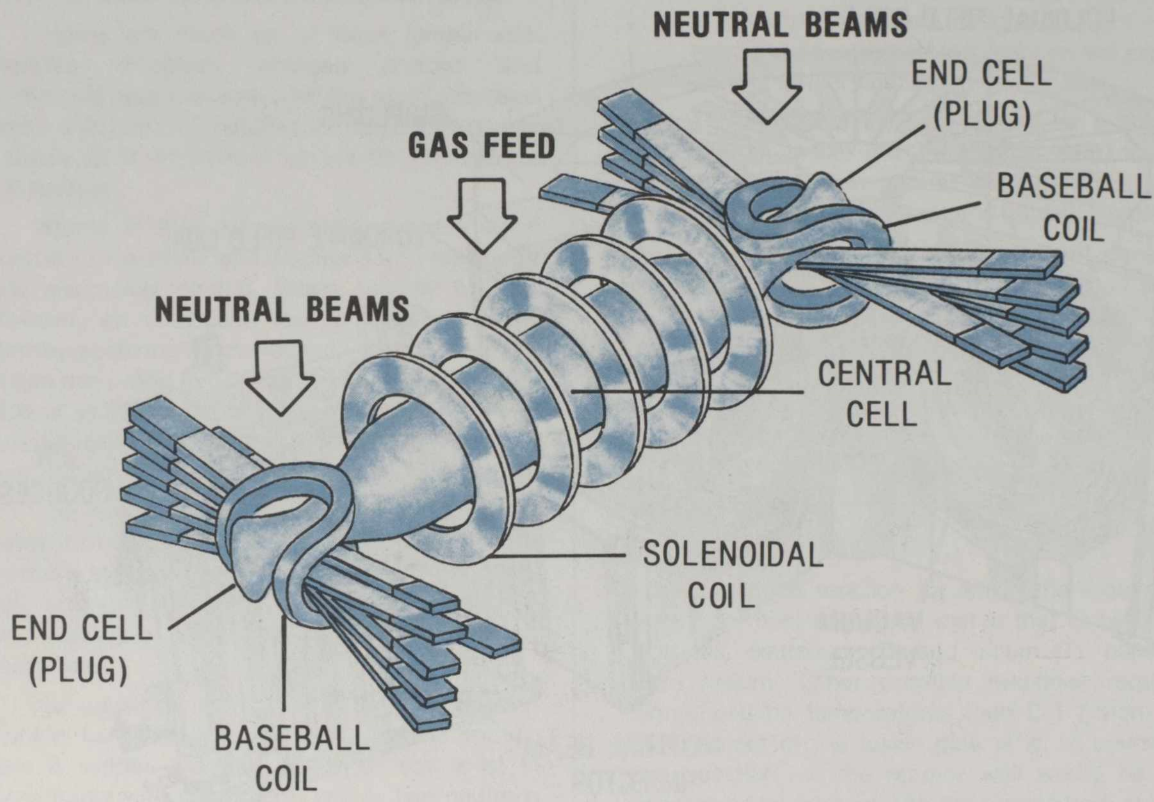
Source: After *The Princeton University Plasma Laboratory: An Overview*, 1979, p. 8.

The fusion reactor configuration with the longest history of development is the Tokamak, named after a device with which the Russians did some pioneering research on plasma stability. The Tokamak involves closed magnetic confinement of a plasma in a torus (doughnut-shaped chamber) maintained at a high vacuum. Three different magnetic fields, or sets of fields, act to confine the plasma within the torus or vacuum vessel. The toroidal magnetic field is the basic confining field, and the poloidal field forces the plasma toward the middle of the torus. To maintain plasma equilibrium and stability, a third set of magnetic fields is generated by smaller coils along the periphery of the torus.

Various means can be used to add energy to the plasma. In the Princeton TFTR (Tokamak Fusion Test Reactor) pictured above, high-energy, neutral-particle beams will carry energy into the plasma and provide the extra heat required to reach ignition temperature. To give an idea of scale, the torus or vacuum chamber for TFTR will be 1.7 metres in diameter and almost 8 metres across. TFTR is designed to achieve scientific breakeven and is scheduled to be operational in 1982.

Fusion Reactor Configurations — Open Magnetic Confinement

Figure 6-16: SCHEMATIC REPRESENTATION OF A TANDEM MIRROR MACHINE



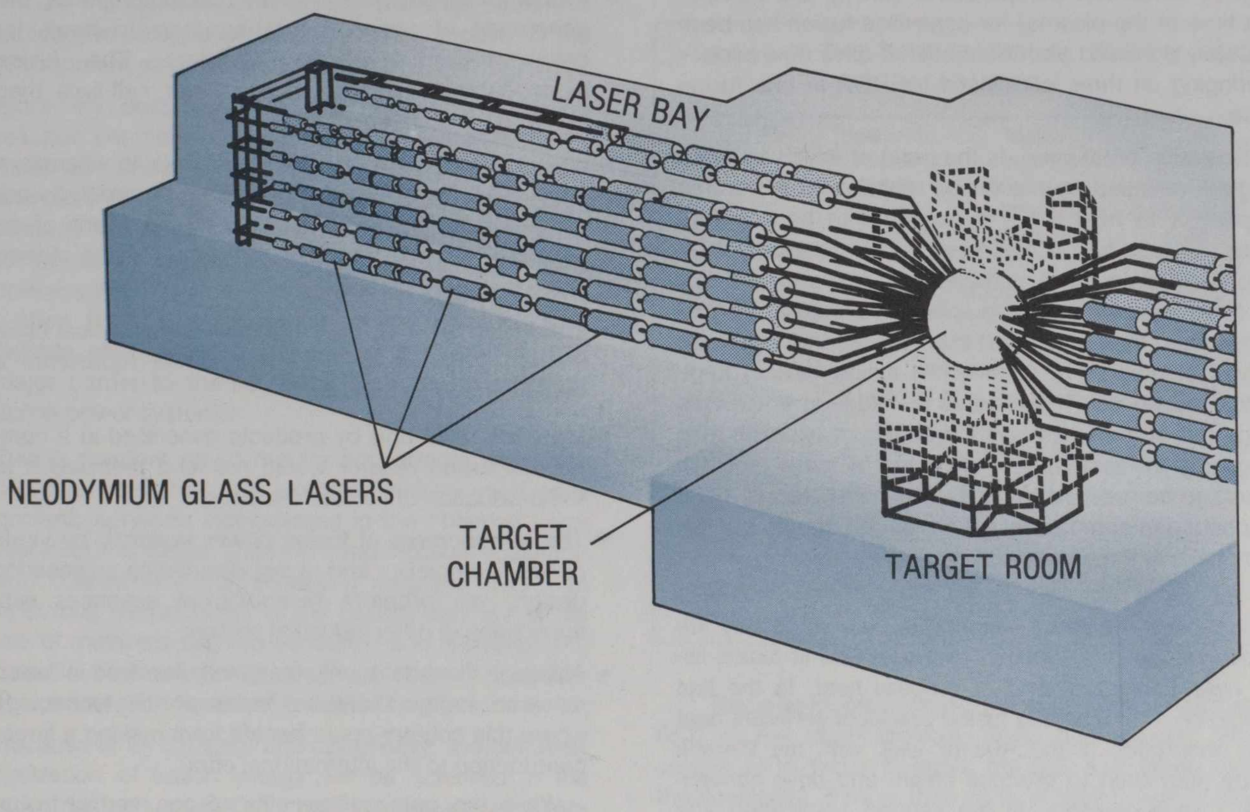
Source: After *Selected Articles on Magnetic Fusion Energy from Energy & Technology Review*, 1979, p. 13.

The other major category of magnetic confinement devices is the "open" configuration (which does not close in on itself like a Tokamak). In essence, open machines are cylindrical plasma containers with a solenoidal magnetic field around the cylinder and confining fields at the ends of the cylinder to reduce plasma losses. The end fields act as "magnetic mirrors" to reflect charged particles. At the present time, three magnetic mirror concepts are being studied: the tandem mirror (shown above), the field-reversed mirror and the bumpy torus (which links a series of simple mirrors into a circle in a hybrid design joining open and closed configurations in magnetic confinement).

A large tandem mirror, MFTF (Mirror Fusion Test Facility), is under construction at Lawrence Livermore Laboratory in California. As schematically illustrated above, energy will be added to the plasma by neutral beam injection at the end cells. To give an appreciation of scale, the cylindrical fusion chamber in the MFTF is 18 metres long. Operation of the machine is expected by late 1981.

Fusion Reactor Configurations — Inertial Confinement

Figure 6-17: SCHEMATIC REPRESENTATION OF A LASER FUSION MACHINE



Source: After "Laser Fusion", 1977, p. 13.

Apart from magnetic confinement, the other approach to containing a high-temperature plasma on the Earth is by means of inertial confinement. This latter technique seeks to intensely heat a tiny pellet of fusion fuel so rapidly that the fuel burns as a plasma before it can disperse. Extreme heating of the surface of the fuel pellet causes it to implode; the high plasma density thereby achieved allows the fusion reaction to be established for a very small fraction of a second. The problem is to deliver a huge pulse of energy to a tiny target in less than a billionth of a second. Two approaches to achieving these conditions involve heating with high-power lasers or with highly-energetic particle beams.

The device illustrated in Figure 6-17 is the Shiva laser fusion facility at Lawrence Livermore Laboratory. In this installation, 20 neodymium glass lasers deliver energy to a fuel pellet inside the target chamber. Success with the Shiva system has been such that the facility is being doubled to include a second laser bay. The expanded system, called Shiva Nova, is expected to demonstrate scientific breakeven. The Shiva laser operates at a power level of 20 to 30 terawatts; Shiva Nova will produce 190 to 285 TW of power and the expanded facility will approximately cover the area of a football field.

in attempting to confine the plasma long enough for a fusion reaction to take place.

Both magnetic confinement and inertial confinement are being vigorously pursued in a variety of reactor configurations, with spending on magnetic confinement having dominated the field to the present time. Each of the three conditions (temperature, density and confinement time of the plasma) for controlled fusion has been separately achieved and the research drive now centres on bringing all three conditions together in one fusion device.

Scientific breakeven — the point at which as much energy is released by the fusion reaction as is put into the plasma to heat it — is expected to be achieved before 1985 in fusion machines under construction at the present time. That achievement, however, will still only have demonstrated the scientific principle. Requiring solution thereafter are the engineering problems involved in deriving a commercial fusion device. Engineering breakeven — defined as the stage at which total energy out of the fusion system equals or exceeds total energy into the system — is expected by many research workers to be reached by 1990. The consensus is that a demonstration commercial fusion reactor can be operating by early in the twenty-first century.

The three possible applications of fusion energy which receive the most attention in research today are the production of electricity, of fissile fuels in fusion-fission hybrid reactors, and of process heat. In the first application, the energetic fusion products generate heat upon absorption in the reactor wall, with the thermal energy then used to produce steam and drive conventional turbogenerators. In the second application, the fusion neutrons convert fertile materials such as thorium into fission reactor fuel. Thirdly, waste heat from electrical generation in a fusion facility could be exploited, as is the case with other powerplants, for industrial process heat, for district heating or for greenhouse agriculture or hydroponics. A number of other applications have been proposed, such as the use of fusion energy in one of several ways to produce hydrogen.

2. ADVANTAGES AND DIFFICULTIES IN USING FUSION ENERGY

The potential benefits of fusion energy are perceived by some governments to be so great that more than $2 billion is now being spent annually on R&D in the United States, Europe, the Soviet Union and Japan. While the promise of almost unlimited energy from the fusion process is alluring, this energy source is the furthest from commercialization of any we have considered and by a large margin it will be the most expensive to develop.

- Fusion offers the possibility of providing a virtually limitless supply of energy based upon a fuel available to all countries. It is one of the very few energy sources with the potential to broadly handle man's energy requirements in his long-term occupation of the planet.
- Proper design of fusion reactors should reduce the generation of radioactive by-products to levels far below those of fission reactors. The fusion by-products would also have shorter half-lives than fission by-products.
- Fusion activation products are nonvolatile whereas a substantial fraction of fission activation products are volatile. Controlling radioactivity in the event of an accident should therefore be easier in a fusion reactor.
- The fusion reaction does not generate chemical combustion products and in that sense represents a benign energy technology.
- Materials used and by-products generated in a commercial fusion reactor would not lend themselves to the production of nuclear weapons.
- The development of fusion power systems, by virtue of their complexity and highly demanding engineering design, will promote technological advances with application in other industrial sectors.
- Although Canada is only marginally involved in fusion research today, there are areas of the technology where this country could benefit from making a larger contribution to the international effort.

While the potential benefits of commercial fusion energy are indeed great, there is also no other alternative energy source facing as many difficulties in its exploitation.

- The technology to exploit fusion energy on a broad commercial basis is not yet in place and many experts believe that 20 years or more will be required to reach that goal. This is a time span beyond the planning horizon of most organizations and a conventional cost/benefit analysis therefore cannot be made. It is difficult for industry in particular to commit funds on a large scale to such research when the return is so tentative.
- The cost of commercializing fusion energy will be tremendous. More than two billion dollars was spent worldwide last year on fusion research and one expert has ventured the guess that required fusion RD & D might ultimately cost some $50 billion. Progress therefore depends on heavy financial commitments by governments.
- It has yet to be determined whether chronic exposure to the powerful electromagnetic fields characteristic of

fusion reactors constitutes a health hazard for workers.

- The large-scale use of lithium for tritium breeding in what is expected to be the first commercial fusion process poses a hazard since lithium is chemically very active.
- Tritium management is a sizable challenge since this radioactive isotope of hydrogen is as mobile in the environment as common hydrogen.
- Extremely demanding vacuum requirements in the reaction chamber must be met, the reactor structure must last under intense bombardment from highly energetic neutrons, and materials must resist large stresses imposed by powerful magnets and steep temperature gradients. Despite this hostile operating environment, the various elements of a fusion power system must function with high reliability for long periods of time. Such engineering problems form a major barrier to the successful commercialization of fusion power systems.
- Fusion reactors could require appreciable quantities of scarce materials; for example, helium used as a coolant; beryllium incorporated in the "blanket" surrounding the fusion chamber; and niobium (columbium) utilized in superconducting magnets. The high operating temperatures of the reactor also favour the use of materials such as vanadium and molybdenum. Canada is fortunate though in possessing considerable resources of some of these elements.
- Because of its expense and complexity, the commercialization of fusion energy will be achieved in the industrialized world. Other nations wishing to adopt this technology will have to purchase it, making some countries technically dependent on others.
- Some observers are concerned that in the rush to harness fusion energy, the best fusion system will not necessarily be the one commercially deployed.
- Although the prospect today is that fusion energy systems will be much more environmentally appealing than fission systems, the public may nevertheless transfer its apprehension over "nuclear power" from one process to the other.

3. INTERNATIONAL AND CANADIAN DEVELOPMENT

Any one country would find the cost of developing a fusion energy system high, and fusion research has progressed with international cooperation which has enabled the sharing of technological breakthroughs. The International Atomic Energy Agency and the International Fusion Research Council are two of the bodies which coordinate fusion research and which share research results and information. Joint projects also are common: Japan is planning to invest $250 million in an American project, and the U.S. is investing $50 million in a West German program. Estimates of funding in 1980 for the major foreign fusion programs are indicated in Table 6-9.

Table 6-9: THE INTERNATIONAL FUSION R & D PROGRAM IN 1980

Country	Estimated Fusion R & D Budget (millions)	Major Magnetic Confinement Facilities Under Construction	Estimated Completion Date
U.S.A.	$ 600	Tokamak Fusion Test Reactor (TFTR) at Princeton	1981-82
U.S.S.R.	$1,000	T-15 Experimental reactor	1984
European Community (EURATOM)	$ 500	Joint European Torus (JET)	1983
Japan	$ 400	JT-60	1984

Source: Personal communication, National Research Council, 1981.

These amounts indicate the active pursuit of fusion R&D in the technologically developed nations. When compared to fission budgets, the U.S. and Japan spend the equivalent of more than 25% of their fission budgets on fusion, the European Community about 10% and Great Britain 11%. Other nations including Australia, South Africa, Spain, Brazil and Argentina are also becoming involved in fusion R&D.

Four projects in the construction phase today are expected to establish the scientific feasibility of the magnetic confinement approach to fusion power: TFTR in the United States, JET in Europe, T-15 in the Soviet Union and JT-60 in Japan. These experimental machines should provide conclusive information on how to achieve ignition in a D-T plasma. This generation of magnetic confinement machines must then be followed by one or more experimental reactors dedicated to establishing the technological feasibility of fusion power and then by demonstration reactors to assess the economic practicality of fusion.

In 1978, the International Atomic Energy Agency proposed an international project to tackle the next phase of technological feasibility. The result was the INTOR (International Tokamak Reactor) Workshop, with the parties to the Workshop being the European Community (through Euratom), the United States, the USSR and Japan. The Workshop established the specifications of such a fusion device and recommended that it be constructed and put into operation by the late 1980s or early 1990s. INTOR was to require 200 electrical MW of power to operate and was to produce a total fusion power of about 620 thermal megawatts. Controlled plasma burn was to extend for at least 100 seconds.

For a while there was speculation that INTOR might be built in Canada but the Soviet invasion of Afghanistan appears to have killed the project. The United States has been reexamining its own program in the light of this development to see how it should best proceed to the technological feasibility stage.

Canada spent $1.9 million on fusion R&D in 1979-80. This sum comprised $0.3 million from the Federal Government for the 1979-80 National Fusion Program and $0.9 million for the in-house Laser Fusion Group at NRC, augmented by $0.7 million from Provincial Governments and utilities. International groups involved with the development of fusion energy do not consider this level of support to be a serious contribution to the international fusion research effort.

The National Research Council has proposed a budget for a Canadian National Fusion Program which it considers to be just sufficient for Canada to attain international recognition as making a significant effort in fusion research. Details of this funding are presented in Table 6-10. The recommended program is intended to develop scientific and technological expertise in Canada, permitting access to international work and allowing Canadian industrial participation in the development of commercial fusion power systems. The spending program outlined includes funding by both the Federal and Quebec Governments for the new Tokamak facility at Varennes.

The Federal Government did not support fusion R&D at the recommended level of $4.2 million in fiscal year 1980-81. Although the NRC Laser Fusion Group did receive $1.2 million, only $1.3 million was forthcoming for the National Fusion Program, of which $1.0 million represented the initial Federal contribution towards constructing the Varennes Tokamak. Consequently only $300,000 was available in the National Fusion Program last year to support project definition studies, to promote work in the particularly important area of materials research, and to support Canadian scientists in getting hands-on experience with fusion machines abroad. This level of funding is well below the investment being made collectively by several provinces, principally through their electrical utilities.

Table 6-10: RECOMMENDED EXPENDITURES ON A CANADIAN NATIONAL FUSION PROGRAM

All values are given in millions of 1979 Canadian dollars.

FISCAL YEAR	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88
Federal Funds for National Fusion Program	0.3	3.0	6.0	9.0	12.0	15.0	12.0	12.0	12.0
NRC In-house Laser Fusion Group	0.9	1.2	1.5	2.0	2.0	2.0	2.0	2.0	2.0
Total Federal Funds	1.2	4.2	7.5	11.0	14.0	17.0	14.0	14.0	14.0
Other Sources of Funds for National Fusion Program[a]	0.7	1.8	6.5	12.0	14.0	ü.0	3.0	3.0	3.0
Total Funding	1.9	6.0	14.0	23.0	28.0	25.0	17.0	17.0	17.0

[a] Includes provincial governments, utilities and foreign sources.

Source: Canada, National Research Council, 1980, p. 10.

The NRC has suggested that our fusion research effort would best entail a three-pronged approach because of unique Canadian resources. First, Canada enjoys international recognition for its gas (CO_2) laser research which is relevant to the inertial confinement approach to fusion systems. Second, with the Varennes Tokamak, Canada will be in a position to contribute to the magnetic confinement program. (Studies leading to commercial cycles of operation and to the coupling of a fusion facility to an electrical grid are planned for this facility.) Third, Canada should specialize in one or two carefully selected engineering technologies associated with fusion power systems. In this latter respect, particular interest should be paid to the management of tritium which will be required as a fuel for the first-generation commercial fusion plants. Ontario Hydro already has extensive practical experience in this area.

CONCLUSION

Evidence put before the Committee strongly suggests that fusion will be harnessed in commercial power systems early in the twenty-first century. Although the Committee cannot identify a time at which the Canadian energy system would require the input of fusion energy, we nonetheless anticipate that substantial benefits would flow from participation in the international program to commercialize this energy form. Those benefits will not accrue to Canada at the present level of support of fusion R&D in this country.

RECOMMENDATION

The Committee recommends that the program of expenditures proposed by the NRC Advisory Committee on Fusion-Related Research be adopted by the Federal Government. For the five-year period from fiscal year 1980-81 to 1984-85, this represents an expenditure of approximately $54 million (in constant 1979 dollars). An independent review should be carried out in the third year of the program and after five years to determine its effectiveness.

Geothermal Energy

1. THE NATURE OF GEOTHERMAL ENERGY

In its broadest context geothermal energy refers to the natural heat of the Earth. In the restricted sense of an alternative energy form available to man, it refers to useful energy that can be extracted from naturally occurring steam and hot water found in the Earth's volcanic zones, in geologically young mountain belts and in deep sedimentary basins. Several sources of internal heating have been recognized but heat generated in the decay of radioactive elements is considered to represent the principal contribution to the Earth's thermal budget.

Heat is energy in transit from a higher-temperature environment to a lower-temperature one, in this case from the interior to the surface of the planet (with subsequent radiation into space). In total, the Earth's thermal energy transfer represents an enormous ability to do work — a potential observed in such forms as earthquakes, volcanism and mountain-building. For example, the power generated by the Mount St. Helens eruption in Washington State, during the nine hours of activity on 18 May 1980, has been roughly estimated at 100 times the entire U.S. electrical generating capacity (Decker and Decker, 1981). This often distressing natural activity is not randomly distributed, however, as it tends to lie along well-defined belts, with the occurrence of hot springs and geysers also indicating an elevated temperature regime.

The explanation for the intriguing distribution of this geological activity, and hence for the location of prime geothermal prospects, is contained in the theory of plate tectonics which revolutionized thinking in the earth sciences in the late 1960s. Figure 6-18 shows that the principal active volcanoes of the world typically lie near what are termed plate boundaries, the most notable exception being the immense lava outpourings that have created the Hawaiian Islands. It is not surprising therefore that much of the emphasis on developing geothermal resources has been concentrated in these higher-energy zones of the Earth's crust, in such countries as Italy, Iceland, the (western) United States, Mexico, Japan, the Philippines and New Zealand. The principal exception to this correlation has been the exploitation by several European nations of hot groundwater contained in deep sedimentary basins.

Geothermal Gradient and Heat Flow

The term geothermal gradient refers to the rate at which temperature increases with depth in the Earth. Averaged over the planet, the geothermal gradient is roughly 25° to 30°C per kilometre (approximately 15°F per thousand feet). For this reason deep mines are hotter than shallow mines and require more elaborate ventilation systems. Similarly, drilling operations become more difficult with depth as the equipment has to withstand progressively higher temperatures.

Heat flow refers to the quantity of heat crossing a unit area of the Earth's surface per unit of time — the mean thermal flux over the Earth's continental regions is about 62 milliwatts per square metre.

Plate Tectonics

Plate tectonics is the name for a theory which considers the outer layer of the Earth to be divided into a dozen or more large plates "floating" on a viscous underlayer. These plates, which may comprise both continental and oceanic rocks, move in response to poorly understood internal forces, at rates of several to ten or more centimetres per year.

Plates may move laterally past each other along boundaries termed *transform faults* (as along the San Andreas Fault system in California), or override one another at *subduction zones* (as appears to be occurring at the deep-ocean trenches in the Western Pacific and beneath the Himalayas in Asia). Ocean ridges in this scheme are zones along which new crustal material is created, with plates moving outwards from these axes of *seafloor spreading* to be reabsorbed within the Earth along the subduction zones. Figure 6-18 displays the major crustal plates.

Earthquakes can in most cases be regarded as the result of interactions at or near plate boundaries.

The Earth's average rate of heat loss over 1,000 square metres is roughly equivalent to that amount of energy required to light a 60 watt bulb. Given this low rate of delivery of heat at the Earth's surface, man searches for regions of the crust where thermal energy exists in anomalously high concentrations. Utilizing geothermal energy thus becomes a two-component problem. Where can the highest temperatures be found at the shallowest depths? And, can useful energy be extracted at a viable rate from a given geothermal "deposit"?

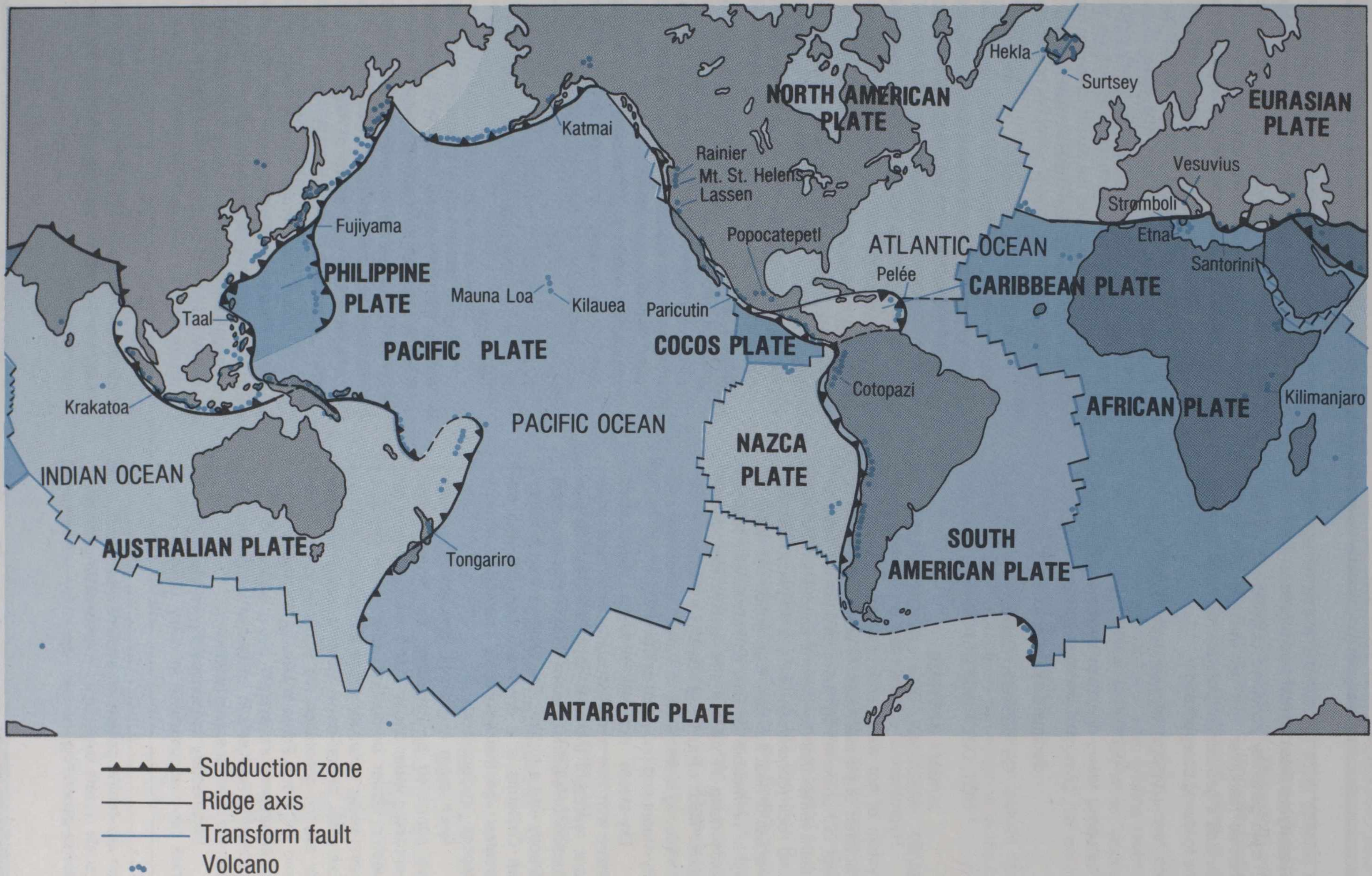
Five approaches to utilizing geothermal resources have been identified: (1) producing geothermal-electricity; (2) using lower-grade heat for space heating and similar applications not requiring the conversion of thermal energy to another form; (3) producing fresh water; (4) extracting minerals from geothermal brines; and (5) recovering methane from geopressured deposits. The first two of these applications are the subject of development tests in Canada.

2. ADVANTAGES AND DIFFICULTIES IN USING GEOTHERMAL ENERGY

Many advantages accrue to the use of geothermal energy, even considering the limited range of deposits being exploited today.

- Land disturbance is less than for most other energy alternatives and restoration is comparatively easy.
- Geothermal development does not require large quantities of materials and energy, and the entire operation is localized.
- With a moderate degree of effort, the environmental impact of geothermal development should be minor.
- Geothermal energy is available continuously and can provide base-load power, giving it an inherent advantage over such intermittent sources as solar, wind and tidal energy.
- Low-temperature heat from geothermal deposits is directly usable in such applications as space heating and crop production, providing an efficient match between energy source and end use.
- As potentially exploitable deposits occur in more diverse geological environments than does petroleum, for example, geothermal energy may afford certain countries economic and political benefits.
- The technology for geothermal development is not as sophisticated as that required for energy sources such as nuclear fission, thus it may be a more appropriate option for many developing countries.
- Geothermal powerplants are limited in size and are easier to incorporate into small electric power systems

Figure 6-18: THE LOCATION OF PRINCIPAL ACTIVE VOLCANOES AND HIGH-ENERGY ZONES IN THE EARTH'S CRUST



Source: From EARTH, Second Edition, by Frank Press and Raymond Siever. W.H. Freeman and Company. Copyright © 1978.

Classifying Geothermal Resources

No generally accepted classification of geothermal resources has yet emerged. To review Canada's geothermal potential we have adopted the following categorization:

HYDROTHERMAL DEPOSITS

- Convecting Systems
  - dry-steam systems
  - hot-water systems
- Sedimentary Reservoirs
- Geopressured Deposits

HOT, DRY ROCK DEPOSITS

MAGMA SYSTEMS

Hydrothermal deposits are any underground system of hot water and/or steam contained in fractured or porous rocks. In convecting systems, heat is transferred by the circulation of water or steam rather than by thermal conduction through solid rock (conduction being a very much slower process of heat transfer). Convection can occur in highly permeable or fissured rocks, with heated fluids rising in part of the system and denser cooler fluids descending elsewhere. Hydrothermal convecting systems can in turn be subdivided into dry-steam and hot-water systems.

Dry-steam deposits produce superheated steam with little or no associated liquid and, while rare, represent the best opportunity for the production of electricity since steam can be piped directly into a turbine. The Geysers field in northern California is a dry-steam reservoir with the greatest geothermal-electric potential of any deposit yet discovered.

Much more commonly, convecting systems are controlled by circulating hot water. Those containing water above 150°C are candidates for electric power production, with cooler deposits being better suited for space and process heating. Examples of hot-water systems being exploited for electric generation are Wairakei in New Zealand and Cerro Prieto in Mexico. An example of a lower-temperature system being tapped is that underlying Reykjavik in Iceland where geothermal water is used for space heating.

Sedimentary sequences thousands of metres thick have accumulated in many regions of the world and these reservoirs may contain huge volumes of water warmed simply by the normal increasing of temperature with depth. As water temperatures are characteristically less than 100°C, these geothermal deposits are often referred to as warm-water fields. In contrast to the fluids in convecting systems, the water in deep sedimentary reservoirs is typically slowly circulating or virtually static. Warm-water fields have been utilized in Hungary and the Soviet Union for many years, principally for space heating and in agriculture.

Geopressured systems, or reservoirs of abnormally high pressure, are also a form of sedimentary deposit. Their characteristics and potential for exploitation are sufficiently different, however, to warrant separate consideration. The presence of natural gas in certain of these deposits increases the incentive to develop them.

Hot, dry rock deposits are the second major category of geothermal resource. In some areas of the world rock masses of elevated temperature are found at shallow depths and there are two explanations for such rocks being hotter than normal. Geologically recent intrusions of molten material into the Earth's crust may have taken place with these intrusions raising the temperature of surrounding crustal rocks. Or the rock mass may contain above-average concentrations of radioactive elements. If the rocks described contain little or no water, the system is said to be dry and exploitation of the energy is made difficult because a heat transport medium is lacking. If a practical method of extracting the thermal energy is developed, the potential of this resource will be very large.

Magma systems are emplacements of molten rock in the Earth's crust, ranging in temperature from about 600° to 1,500°C (roughly 1,100° to 2,700°F). The energy contained in such systems is immense but the problems in extracting it are formidable, and exploitation of magmatic heat is still hypothetical.

Present commercial developments exploit either convecting systems or sedimentary reservoirs. Geopressured deposits and hot, dry rock deposits are expected to be utilized commercially before the end of the century, but magma systems do not hold any near-term prospect for use.

than are central generating stations where economies of scale dictate larger units. Even smaller geothermal-electric generating devices (portable, self-contained power conversion systems in the one to ten megawatt range) are being considered for operation at geothermal wellheads.

Many of the difficulties involved in using geothermal energy are technical or economic in nature. The environmental impact is generally local and may be controlled with proper planning. Impediments to geothermal resource usage are listed below.

- Drilling for geothermal resources is more difficult than drilling for petroleum because of the higher temperatures encountered, accelerated wear on equipment, increased danger of blowouts, and more frequent loss of drilling fluids.

- The lack of knowledge about the production characteristics and longevity of geothermal reservoirs makes the economic analysis of geothermal exploitation difficult.

- Land subsidence from the withdrawal of subsurface fluids can be a significant problem. (This phenomenon is well known in petroleum production and, in sensitive areas, water is reinjected to replace the oil produced, thus preventing most of the subsidence.) In New Zealand's Wairakei field, where geothermal water is discharged into a river rather than reinjected, maximum subsidence has exceeded 3.7 metres (12 feet) and an area of more than 65 square kilometres (25 square miles) has been affected.

- Geothermal development produces high noise levels locally, especially in dry-steam fields.

- Water pollution can occur in any phase of development, as toxic or highly saline geothermal fluids are capable of contaminating surface waters or the groundwater supply.

- Geothermal fluids typically contain gaseous substances which can cause serious local air pollution problems and the requirement for advanced emission control systems can make exploitation of a geothermal deposit substantially more expensive.

- Low system efficiencies (in the conversion of thermal energy to electrical energy) result in geothermal powerplants emitting large quantities of waste heat per unit of electric power generated. A typical generating unit in The Geysers, for example, requires roughly 785 megawatts of thermal energy to produce 110 electrical megawatts, a conversion efficiency of about 14%.

- Pressurized hot water can dissolve surprisingly large quantities of material which may cause rapid scaling in or severe corrosion of the plumbing in geothermal facilities. Thus maintenance and ultimate project costs are raised.

- The exploitation of geothermal energy must take place locally as the cost of transporting steam or hot water rapidly exceeds the value of their recoverable energy.

- Geothermal power provides no siting options, unlike more conventional energy technologies, because the plant must be near the reservoir. This means geothermal development may result in land-use conflicts in areas which also have recreational value or scenic appeal.

- Geothermal development for electric power production is a costly endeavour with existing technology. While electricity derived from dry-steam deposits is economically attractive today, power produced from the much more commonly occurring hot-water systems is often not competitive.

- Legal and institutional problems can impede development of this resource, as has occurred in the United States.

3. INTERNATIONAL AND CANADIAN DEVELOPMENT

Many nations are investigating the potential of geothermal energy, both for electrical and non-electrical applications, but this source is only exploited on a minor scale today (Tables 6-11 and 6-12). The U.S.S.R. makes the greatest non-electrical use of the Earth's heat while almost half of the world's geothermal-electric capacity lies in California. The contribution of geothermal resources to the world energy picture will remain small in this century, although in certain regions it promises to become quite significant.

Table 6-11: INSTALLED GEOTHERMAL-ELECTRIC CAPACITY IN 1980

Unit: Electrical megawatts.

	INSTALLED CAPACITY
United States	1,000
Mexico	153
Japan	218
Italy	455
Iceland	64
El Salvador	60
New Zealand	203
Philippines	58
U.S.S.R.	5
Republic of China	3
WORLD TOTAL	2,219

Source: Stock, 1981.

Table 6-12: NON-ELECTRICAL USE OF GEOTHERMAL ENERGY IN 1979

Unit: Thermal megawatts.

COUNTRY	RESIDENTIAL & COMMERCIAL	AGRICULTURAL	INDUSTRIAL
United States	75	5	5
Italy	50	5	20
New Zealand	50	10	150
Japan	10	30	5
Iceland	680	40	50
U.S.S.R.	120	5,100	—
Hungary	300	370	—
France	20	—	—
Republic of China	—	100	—

Source: Stock, 1981.

The United States looks to a rapid expansion of its geothermal-electric capacity in The Geysers field in the 1980s, after having encountered difficulties in the past decade. As of October 1980, there were 928 electrical megawatts of installed capacity in this field, embodied in l5 generating units and representing an investment of approximately $2 billion. The Geysers already supplies about one-half of San Francisco's electricity and ultimate generating capacity may exceed 4,000 megawatts. The Geysers represents the lowest cost new generating capacity in California today and supplies about 2% of the State's electricity. Development of geothermal deposits for both electric power production and for heat is proceeding in many western states and the 1980s will see rapidly growing use of this energy resource.

Iceland uses geothermal resources for space heating, serving most of the population. Japan makes limited use of geothermal energy for electrical power generation, for space heating, at recreational spas, and in agriculture and industry. Oil price increases have led Japan to pursue an aggressive program of geothermal exploration aimed at establishing a major geothermal-electric capacity by early in the next century.

The largest geothermal development in Latin America is the 150 megawatts of generating capacity at Cerro Prieto in Mexico, expected to reach 400 MW in 1982. El Salvador's 60 MW station accounted for nearly one-third of that country's electric generation in 1977. If numerous other Latin American projects now in the feasibility stage reach fruition, Guatemala, Honduras, Nicaragua, Argentina and Chile will also have geothermal-electric stations operating within ten years.

In New Zealand there is 192 megawatts of commercial geothermal-electric capacity installed in the Wairakei field, with another 150 MW capacity in the nearby Broadlands field expected to be operational by the mid-1980s. Declining pressure in the Wairakei field has forced a drop in generating output to about 145 MW at the present time and although this reduced rate of steam use has tended to stabilize power production, it apparently still exceeds the rate of reservoir recharge. An output of 100 MW is thought to be indefinitely sustainable. Approximately 8% of New Zealand's electrical energy is derived from geothermal sources.

France is developing warm-water fields in sedimentary basins and some 12,000 dwellings in the Paris Basin are heated geothermally with more in the planning stage. Unlike most geothermal schemes, this development has taken place in a region of average thermal gradient. France projects that 2% of its housing stock may be so heated by the turn of the century.

Extensive warm-water fields have heated parts of Budapest since the 1930s and the Hungarian Government is developing an extensive geothermal system for the entire city of Szeged. A longer-term goal is space heating of an additional 100,000 to 200,000 units. Warm water is also used in agricultural applications and Hungary today exploits more than 1,100 thermal megawatts of geothermal energy overall.

The Soviet Union is the world's largest user of geothermal energy for non-electrical purposes, the principal application being in agriculture. Geothermal space heating has been employed in the U.S.S.R. since 1947. In 1975, 28 geothermal fields were reported to be supplying heat to housing and to farming in several regions of the Soviet Union.

Interest in Canada's geothermal resources is a recent phenomenon and the role that this energy source will play here is not yet clear. The Earth Physics Branch of the Department of Energy, Mines and Resources is the lead agency for geothermal research. A Geothermal Studies Group has been in existence since 1962, but only recently has funding for this group increased significantly.

Research is directed towards defining the areas of geothermal potential in Canada, but a comprehensive publication outlining these resources across the country is still some time away. The Federal Government's approach is to identify the most promising areas and then to involve the relevant provincial government or utility in the development stage.

Investigation of Canada's geothermal potential is presently concentrating on two regions: a broad thermal anomaly extending through the southern Yukon and west-central British Columbia, and the Western Canada Sedimentary Basin. Eastern Canada appears less promising although there is a possibility that deposits of relatively low-temperature water may be found in association with rocks containing radioactive minerals.

The westernmost part of the country is a segment of the geologically active spine of North and South

America. While this zone is characterized by earthquake activity, current (or geologically recent) volcanism, hot springs and zones of high heat flow, there is a lack of the associated features (mud pots, alteration zones, boiling water) commonly found near producing geothermal fields. The geothermal potential of this region of Canada has been described as follows:

> ...The possibility of finding a dry steam field such as Larderello or The Geysers in Canada seems extremely remote. Such fields are invariably associated with surface leakage of steam or boiling water. Even the smallest surface expression of such thermal activity could not have gone unnoticed in the Canadian Cordillera where, for twenty years, an aggressive mineral exploration industry has used helicopters to scout the landscape...
>
> It seems realistic to hope for the discovery of at least one hot water field (such as Wairakei) capable of supplying enough flash steam to generate electricity ... The most promising areas of search are broadly defined by the four belts of Quaternary volcanoes that extend across British Columbia and southwestern Yukon... (Souther, 1975, p. 266)

Studies of recent volcanism have led to the choice of the Meager Mountain area north of Vancouver for the Federal Government's first demonstration of a geothermal reservoir of volcanic origin. For the past five years the Government has been working on this project in cooperation with B.C. Hydro. The investigation first concentrated on identifying the best site for deep drilling, since the reservoir is not always found directly under the surface manifestation of the geothermal resource. If the drilling program establishes a deposit with appropriate characteristics, B.C. Hydro will assume commercial development and may have a pilot geothermal-electric plant operating by the mid-1980s. Federal funding of the Meager Mountain project came to $420,000 in FY 1980-81 and is set at $325,000 in 1981-82.

No other area in the Canadian Cordillera has been studied as thoroughly as has Meager Mountain for its geothermal potential, but there are further sites of interest. Geothermal resources suitable for generating electricity may be discovered in other volcanic belts of British Columbia and the Yukon. The Mt. Edziza area in northern British Columbia looks especially promising. However, due to its remoteness, lack of a sizeable local market for the electricity and the costs involved in investigating this resource, it is unlikely that Mt. Edziza will get a high priority. This geothermal field is in Mount Edziza Provincial Park which could lead to conflicts in land use.

The other region of Canada being studied is the Western Canada Sedimentary Basin underlying most of Alberta and parts of British Columbia, Saskatchewan, Manitoba, the Yukon and the Northwest Territories. The first attempt to tap the Basin's thermal potential began when the Energy Research Unit of the University of Regina approached EMR concerning the possibility of geothermally heating a new building. The Federal Government is assisting in this venture by paying for test well drilling, in line with its objective of defining areas of exploitable geothermal potential. The heating system envisioned requires two boreholes, one to pump water to the surface and the other for its return. Results from the initial drilling were promising and the work continues. The Federal contribution to the Regina project was $17,700 in 1980-81 and is expected to be $250,000 in FY 1981-82.

To better define Canada's geothermal potential, a modest program of resource appraisal is underway, costing $592,000 in the 1980-81 fiscal year. Thus Federal expenditures in the geothermal sector in FY 1980-81 totalled slightly more than $1 million, including shared-cost projects.

CONCLUSION

The Federal Government's approach to geothermal exploitation — identifying and defining the resource while involving appropriate parties in its commercialization — is sound.

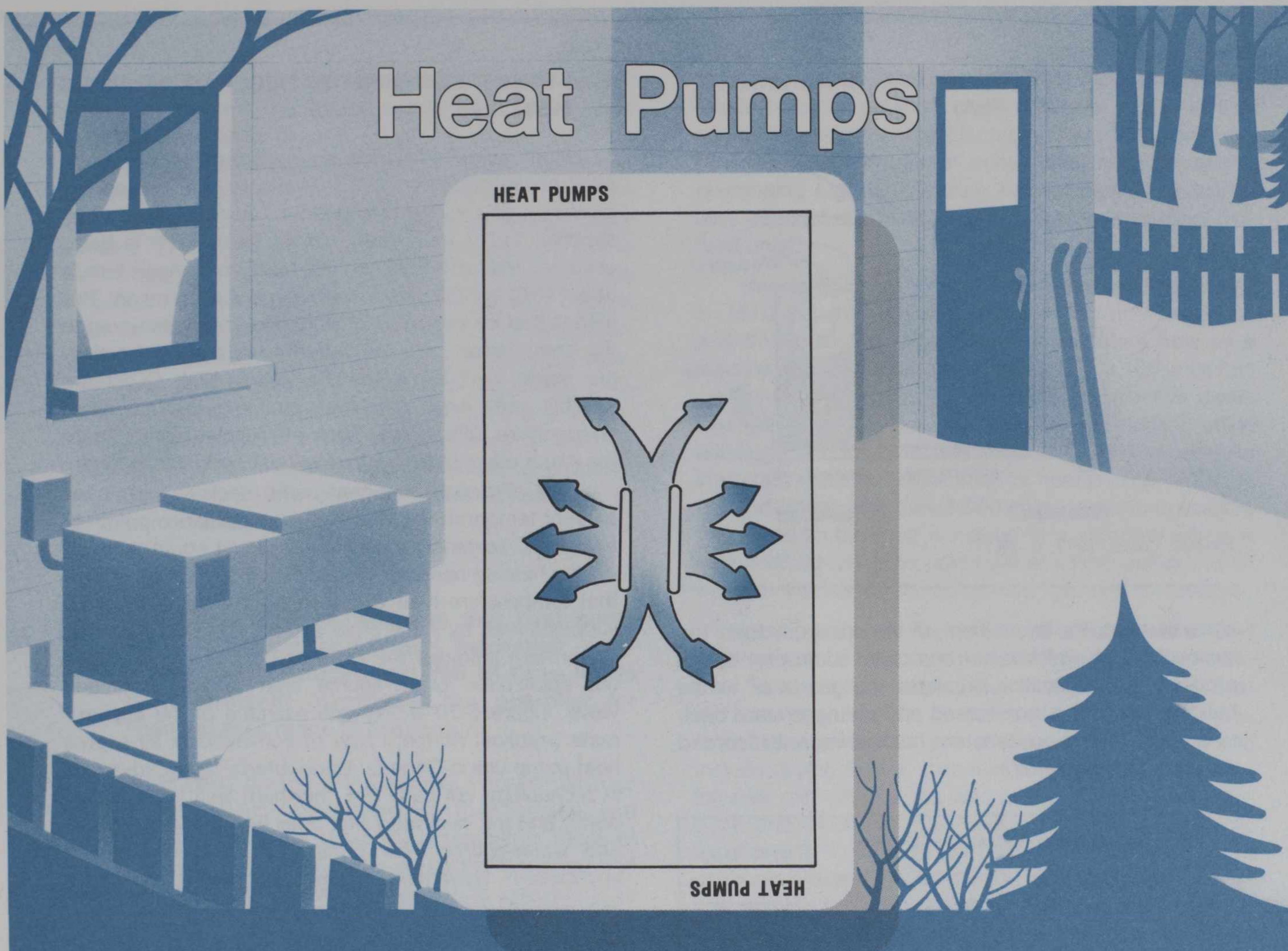
CONCLUSION

Geothermal energy will not add significantly to Canada's energy supply in this century. In the long run, however, this resource has the potential to contribute in an important way, largely in non-electrical applications, if economic extraction methods are developed.

RECOMMENDATION

The Committee recommends that Federal expenditures on geothermal energy be sufficiently large to accomplish at least the following: to define the size of the geothermal resource in Canada; to promote development of this energy form, especially for space heating; and to determine the feasibility of extracting thermal energy from hot, dry rocks.

Heat Pumps



1. HEAT PUMP TECHNOLOGY

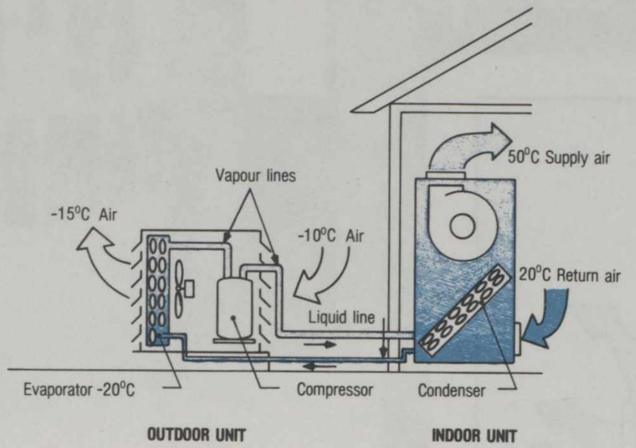
Ordinarily, heat flows naturally from warm areas to cooler ones until an equilibrium is reached, and any mechanical system that works to reverse this flow is termed a heat pump. Refrigerators and air conditioners are the most common heat pumps, but pumps designed to heat and cool households, office buildings and industrial plants have been in service for decades and are becoming steadily more popular.

Heat pumps depend for their operation upon the fact that there is always some warmth available in the air (or water or earth) surrounding a building which can be extracted and used for heating. In most installations the exterior heat exchange takes place in the atmosphere, but this method is not the most efficient and is advantageous only in that it requires a lower capital investment than the alternatives. Heat exchange in water (where freezing is not a problem) or in soil (where feasible) is preferable because these media are not subject to the wide temperature fluctuations of the atmosphere which lower the efficiency of an air-to-air unit. In rare cases, geothermal sources (such as hot springs) may be used for heat exchange.

The operation of an air-to-air heat pump is illustrated in Figure 6-19. The heat pump consists of two units; an outdoor one which absorbs heat from the atmosphere and an indoor unit which releases this thermal energy to a building's interior. The action of many heat pumps can be reversed in summer to provide air conditioning.

Generally, heat is transferred by means of a *working fluid*, or heat transfer medium, such as freon. This fluid is piped cold from the interior of a building to the outdoor unit where it is expanded in an evaporator and changes state from a liquid to a gas. In so doing, the liquid

Figure 6-19: THE ESSENTIAL COMPONENTS OF A HEAT PUMP



Source: Leslie, 1977, p. 78.

absorbs heat, its latent heat of vaporization, from the surrounding air which is in turn cooled somewhat by the process. A compressor circulates the gas back to the building where it is condensed and changes state back to a liquid, giving up its latent heat of vaporization and warming the interior air.

The Latent Heat of Vapourization

The latent heat of vapourization is the amount of energy required for a substance to change its state from a liquid to a gas. This quantity of energy is much greater than that required simply to raise or lower the temperature of the liquid. For example, to raise the temperature of one gram of water through one Celsius degree, one calorie of heat is required. To *vapourize* a gram of water at the boiling point, 540 calories are required.

This type of heat pump cycle (termed a vapour compression cycle) is by far the most common in use today. Other cycles involve the compression and expansion of air or the chemical absorption of heat and are in limited use or under development, but neither is competitive with the vapour compression cycle at present. A novel and very promising combination of a simple heat pump using water as the working fluid, with an active solar heating system using hygroscopic salts for heat storage, is discussed in the section on Solar Energy.

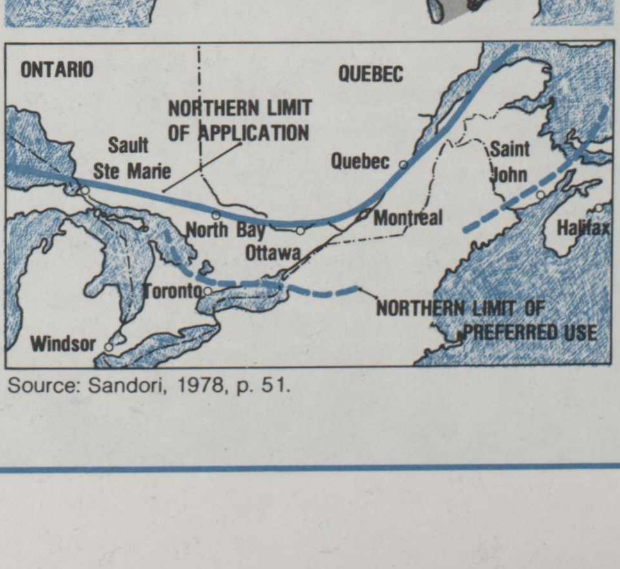
Virtually all heat pumps used today are powered by electric compressors. Alternatively, a heat engine, running on natural gas or oil, for example, can be employed to power the compressor for a heat pump, in which case the waste heat from combustion can be used to help warm the building.

2. ADVANTAGES AND DIFFICULTIES IN USING HEAT PUMPS

Heat pump efficiency is expressed by the *coefficient of performance* (COP) — the ratio of the energy delivered at the high-temperature unit to the energy supplied to the compressor. If the heat pump is being used to heat a home and the outside temperature is about 0°C, a COP of between 2 and 4 is common. This means that for every unit of electrical energy delivered to the compressor, between 2 and 4 units of heat energy are made available inside the home. High COPs are feasible with large machines pumping through small temperature differences. Such efficiencies demonstrate the major advantage in pursuing heat pump technology.

The efficiency of a heat pump declines with lower exterior temperatures, however. At a "balance point" of about 0°C (exterior) a heat pump is just equal to meeting the heating needs of the building it serves, and below that temperature heat delivered by the pump must be supplemented by some other source. It is clear then that in northern latitudes the extreme cold of winter makes the application of air-source heat pumps of limited value. Figure 6-20 shows one estimate of the approximate practical northern limit of conventional air-source heat pump use in Canada. Undoubtedly future advances in technology will push the "northern limit" line further north, and the illustrated limit does not apply to ground- and water-source heat pumps or to unconventional applications. Nevertheless, almost one-third of Canada's

Figure 6-20: NORTHERN LIMIT OF AIR-SOURCE HEAT PUMP APPLICATION IN CANADA



Source: Sandori, 1978, p. 51.

population lives in the "preferred zone", indicating that even at present the technology should be of great interest to Canadians.

Heat pumps are being used increasingly for industrial processes such as wood-drying, and the Committee anticipates that this technology will be applied more widely. The application of heat pumps is particularly advantageous where temperature differentials must be maintained within buildings. For example, heat pumps can be used to freeze the ice in skating arenas, delivering the extracted heat to warm the surrounding stands. Similarly, heat pumps may be used in community centres to warm the water of indoor swimming pools, extracting heat from the air in the building or from an adjacent skating rink. Such energy balancing probably represents one of the best short-term applications of heat pump technology.

RECOMMENDATION

The Committee recommends that heat pump use in suitable community recreation complexes be encouraged and that all three levels of government investigate the potential for financial assistance in this regard.

While heat pumps are attractive because of their energy conserving characteristics, their capital and maintenance costs are presently greater than those of other systems. Moreover, since alternative fuel costs and availabilities vary across Canada, it is necessary to evaluate the economics of heat pump systems from site to site. For example, a study by Cane (1980) suggested that gas furnaces are more economical than heat pumps for new installation and retrofit in locations where natural gas is available. Similarly, economic analyses done by other workers (Kernan and Brady, 1977; Heap, 1979; Stricker, 1980) confirm that generalizations on the applicability of heat pumps are difficult to make. Where the homeowner attaches a high value to air conditioning, however, the analyses suggest that heat pump systems are economic in all major Canadian cities.

3. INTERNATIONAL AND CANADIAN DEVELOPMENT

Progress in heat pump research and development is monitored by international organizations concerned with energy supplies, including the World Energy Conference, the International Energy Agency (IEA) and the Scientific and Technical Research Committee of the European Economic Community. The International Council for Building Research Studies and Documentation publishes reviews of current research in heat pump technology applied to buildings, and the International Institute of Refrigeration includes work on a wide range of heat pump applications in its publications.

In the United Kingdom only about 500 heat pumps are installed at present, chiefly because of the lack of suitable equipment. The Electricity Council is monitoring air-source heat pumps in commercial buildings and is developing high-temperature heat pumps for industrial use. A number of organizations are investigating gas-fired units.

Residential heat pumps were introduced to France in 1970 but their mass production has not yet begun and the spread of the technology has been slow as a consequence. By the beginning of 1977, 3,100 units had been installed, of which 2,800 were in collective dwellings. A further 150 heat pumps were in service in office buildings, 350 in stores and 200 in small businesses. An important industrial application of heat pumps in France is wood-drying with over 1,000 installations in operation. The wood to be dried is placed in a chamber which is dehumidified using the cold coils of a heat pump and air which is warmed on the hot coils is returned to the dryer.

Heat pumps are the subject of active research and development in Australia, Austria, Belgium, Denmark, Eire, Finland, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, Switzerland and West Germany. Industrial applications are widespread in Europe and include drying bricks, ceramics and noodles, evaporating milk and other foods, and concentrating sugar solutions and alcoholic beverages. A special application, used only in Europe to date, is in electroplating where separate hot and cold baths are required for the various steps of cleaning, acid treatment, preparation, plating and washing. Heat pumps provide an ideal means of maintaining the necessary temperature differences.

In the United States the first large-scale heat pump application was in the Los Angeles offices of Southern California Edison Company in 1930-31 and by 1940 there were 15 commercial installations around the country. The first experiments with ground-source heat pumps were made around 1950 and in the early 1960s domestic heat pumps gained an appreciable market in the United States. Unfortunately they went out of favour because of poor reliability. For the same reason, the U.S. Armed Forces banned the use of heat pumps in military housing in 1964, a ban which remained in effect until 1975. As reliability was improved, sales picked up again in the early 1970s with reversible units gaining favour among consumers. The Department of Energy is developing a new natural gas-powered heat pump which could be on the market in the early 1980s. This kind of unit promises to exceed by about 50% the total heat energy delivered by a conventional heat pump for the same energy input.

The international market for heat pumps is expanding. For instance, the total U.S. supply of packaged units for space heating and cooling was expected to be

600,000 in 1980. 1979 Canadian demand reached 5,000 units and in Germany an estimated 15.000 to 18,000 units were purchased in 1980 (Stricker, 1980). The relative sizes of these markets reflect the differing states of technological innovation as well as the market-specific needs in each area. North American applications are primarily residential and commercial, whereas the Europeans are more advanced in industrial applications.

Heat pumps are used at several Canadian kilns for drying hardwoods (softwoods are dried at much higher temperatures and suitable heat pumps are not yet available). R&D in Canada is not extensive, but Ontario Hydro is carrying out research aimed at lowering the balance point of heat pumps so as to make this technology useful at colder temperatures and in more northern latitudes. Much of this program is being sponsored by the Canadian Electrical Association which will be inviting proposals from Canadian manufacturers to produce the Ontario Hydro-designed pump.

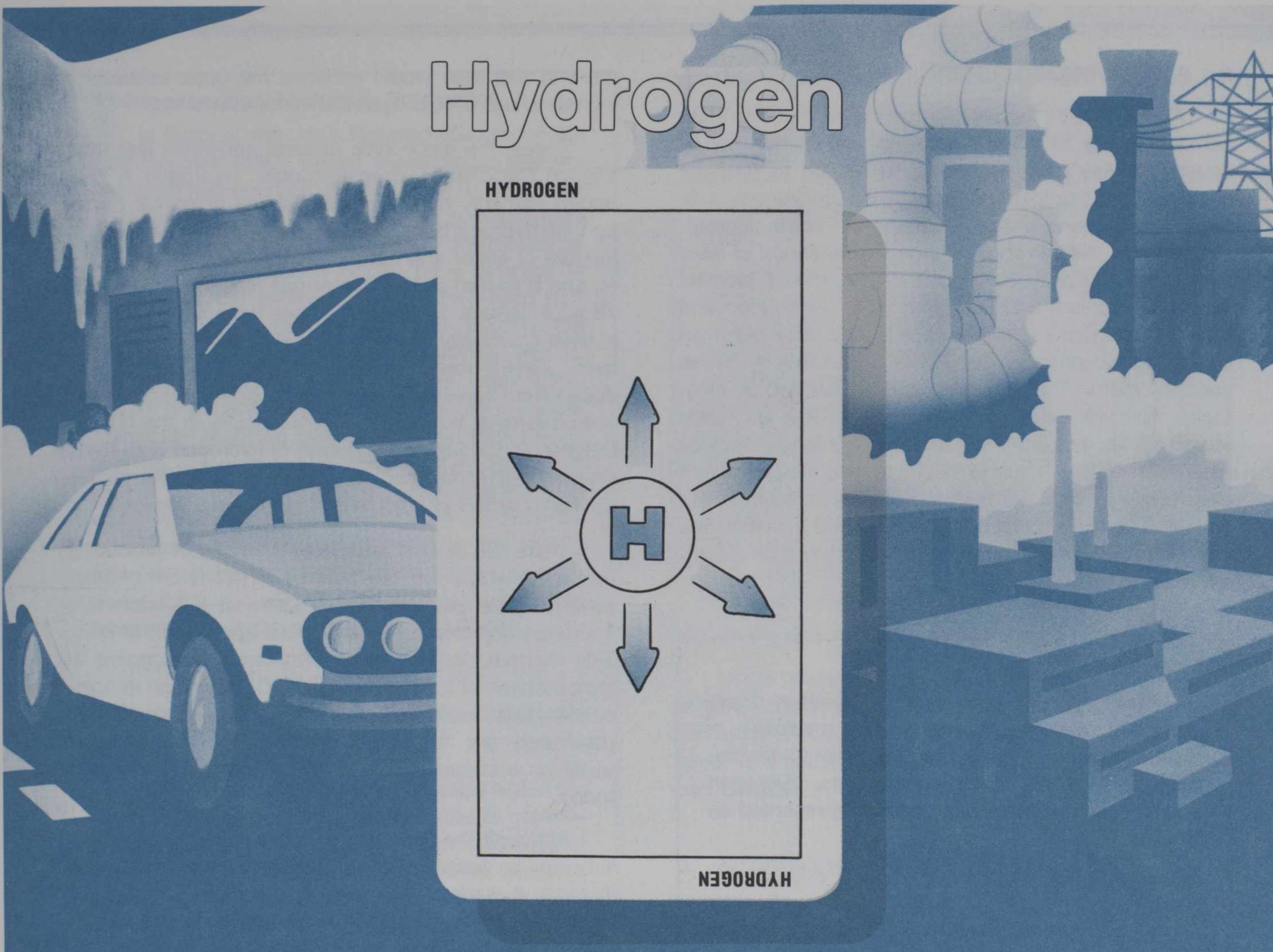
CONCLUSION

The increasing use of heat pumps in Canada is compatible with the goals of substituting for oil and conserving energy. The decision to apply heat pump technology, however, is highly case-specific.

RECOMMENDATION

Governmental and industrial R&D in Canada should continue to refine heat pump technology. Emphasis should be placed upon penetrating commercial, residential and industrial markets and upon seeking the most effective marrying of heat pumps with other energy technologies.

Hydrogen



1. THE NATURE OF HYDROGEN

Hydrogen (H_2) is the lightest and most abundant element in the universe. In its elemental form it is a colourless, odourless, tasteless gas which is easily ignited in air. On Earth hydrogen is always found combined with another element or elements. For example, water (H_2O) is a compound of hydrogen and oxygen, and natural gas (CH_4 or methane) is a compound of hydrogen and carbon. In order to obtain pure hydrogen, energy must be spent to separate it from the other elements with which it is combined and this is why hydrogen should not be referred to as an energy source. It is an energy carrier or currency, however, as it releases energy upon recombination with oxygen. Hydrogen is in fact a highly desirable energy currency since it can be produced from a wide variety of sources such as water, coal and natural gas. It can be generated through a number of processes and applied to a broad range of end uses.

The main consumer of pure hydrogen is the chemical industry which uses it as a raw material in the manufacture of everything from plastics to fertilizers. Another major consumer of H_2 is the petroleum refining industry where it is employed to upgrade oils (increase the ratio of hydrogen to carbon).

In addition to its use as a chemical feedstock, pure hydrogen is also an attractive fuel because it has the highest energy density per unit weight of any chemical fuel and because virtually the only by-product of its combustion in air is water. H_2 is already in limited use in some countries to fuel urban transit systems and it is also well suited for use as an aircraft fuel because of its high energy content. Residential heating systems, appliances and passenger cars can also be converted to use hydrogen.

2. PRODUCING HYDROGEN

As the world's supplies of fossil fuels decline, there will necessarily be a shift towards sustainable energy sources. These sources can be harnessed to produce electricity via photovoltaic cells, wind conversion systems, tidal power plants or geothermal-electric generating facilities. Add to this Canada's abundance of sites for small and large hydro-electric developments, plentiful supply of uranium and mature nuclear technology and one can foresee a future in which electricity plays an increasingly important role. Some of the energy needs currently met by hydrocarbons can be satisfied by electricity; however, electrical energy is neither as easily stored nor as efficiently transported over long distances as are fossil fuels. By using electricity and the process of electrolysis to produce hydrogen, these difficulties can be largely overcome. Thus H_2 can facilitate a shift from a fossil fuel-based energy system to one based on electrical energy.

Electrolysis

Electrolysis is a process in which a direct electrical current is passed through a solution of water and a catalyst causing the water to decompose into its elemental components, hydrogen and oxygen. This reaction can be represented as follows:

H_2O(liquid) + energy input $\rightarrow$ H_2(gas) + ½O_2(gas).

The efficiency of the electrolysis process can be expressed as the ratio of

$$\frac{\text{heating value of } H_2 \text{ output}}{\text{electrical energy input}}.$$

Commercial electrolysis plants are in use today, primarily to generate hydrogen for ammonia production. In British Columbia, Cominco Limited operates one of the largest commercial electrolyzer plants in the world. This plant consumes 90 megawatts of power and produces about 36 tons of hydrogen per day for synthesis into ammonia. The range of efficiency in the electrolysis process in such plants is typically 57% to 72%.

It may be possible to reach efficiencies of 85% or, if operated in an endothermic (heat absorbing) mode using heat from the surroundings, efficiencies in excess of 100% may be achieved in the electrolysis cycle. This should not be confused, however, with the efficiency of the entire process which includes that part of the cycle in which the electricity itself is produced. It is this factor which limits the overall efficiency and raises the cost of producing hydrogen by electrolysis. Improving efficiency in the production and use of electricity from whatever source is clearly a fruitful area for research. An improvement in this area would enhance the opportunities for increased use of hydrogen fuel in our economy.

Today, the electrolytic process generates less than 1% of Canada's hydrogen supply. Hydrogen is produced primarily by steam reformation or partial oxidation of hydrocarbons. The process involves heating a mixture of water and natural gas or crude oil to release H_2 and is known as the "water-gas reaction". Currently, 76% of Canada's hydrogen comes from natural gas and is used principally in the synthesis of ammonia for fertilizers. Twenty-three per cent of our hydrogen is produced from liquid petroleum and is both generated and used internally by the petroleum industry in the refining process. In the future, the output of hydrogen from these methods of production is unlikely to increase as the domestic supply of both oil and natural gas declines.

There are several additional methods of producing hydrogen which are the subject of research in other countries. For example, it is possible to split water into hydrogen and oxygen by the direct application of heat. This thermal decomposition can only be achieved at temperatures of 2,500°C to 4,000°C. Such high temperatures will be available in the future if fusion reactors are developed but the direct thermal decomposition of water on a commercial scale is, in practice, impossible today.

Although the direct thermal decomposition of water may not be feasible, it is possible to achieve this end through a series of chemical reactions. A reaction sequence can be devised in which hydrogen and oxygen are produced, at lower temperatures than those required for direct thermal decomposition, by applying heat to specific chemicals. Only water is consumed and all other chemical products are recycled. Thermochemical cycles have been under investigation in many parts of the world for a number of years and a bench scale system involving a sulphur cycle has been demonstrated in Europe.

Canada, the United States, the European Economic Community and seven other countries have joined together, under the auspices of the International Energy Agency, to share in research on thermochemical hydrogen production. Canada's main effort, however, should remain with the electrolytic production of hydrogen, given our abundant supply of electric power.

There are still other methods of producing hydrogen which show a great deal of promise. Most current and proposed methods of utilizing solar energy are based on the conversion of sunlight to heat, to be used directly for space or water heating, or to electricity via silicon solar cells. However, additional steps are necessary if energy storage is required. The *photochemical* conversion of solar energy is an attractive option because it offers the potential of directly *converting* and *storing* solar energy as a chemical fuel (hydrogen).

Thermochemical Hydrogen Production

In Europe, the Joint Research Centre of the Communities (JRC) began investigating thermochemical hydrogen production in 1970. The most suitable cycles are being identified and scientists are assessing their chemistry, environmental impact and production costs. By a process of elimination, the choice in Europe has been narrowed to three sulphur cycles. Of these three, the two most promising cycles are hybrids; that is, they each include an electrochemical stage (other stages are thermochemical). One of these cycles "Mark I3" (detailed below) has been operated at the laboratory stage, producing hydrogen at a rate of 100 litres an hour. (The arrows pointing in opposite directions indicate that the reactions are reversible.) It is believed that this is the world's first demonstration of a complete thermochemical water-splitting cycle. The process takes place at temperatures in the range of 500° to 650°C.

1) $SO_2 + Br_2 + 2H_2O \rightleftarrows 2HBr + H_2SO_4$

2) $2HBr \rightleftarrows H_2 + Br_2$ (the electrochemical step)

3) $H_2SO_4 \rightleftarrows H_2O + SO_2 + \frac{1}{2}O_2$

This development puts the reaction within the bounds of the operational temperature of conventional nuclear reactors, operating in the range of 540°C to 700°C. Solar power towers are also expected to deliver high temperatures which could be used in a thermochemical reaction. All other thermochemical cycles investigated have required operating temperatures beyond this level.

The most promising photochemical reaction is the production of hydrogen and oxygen by the visible-light photolysis (splitting) of water. This can be done by living organisms or in biomimetic systems (systems which, although inspired by the mechanisms of natural photosynthesis, are entirely artificial). Some of these methods retain a part of the living photosynthetic system (for example isolated chloroplasts), others use solutions of appropriate chemicals and still others constitute what are termed photoelectrochemical cells. The first approach seems least promising because chloroplasts have a very short life span outside a living cell.

One of a number of approaches being taken internationally is that of Dr. Melvin Calvin who won the Nobel prize in 1961 for his mapping of the photosynthesis of carbohydrates. He has developed an artificial chloroplast which is less complex than a natural one but which functions in much the same way (Figure 6-21). Although the system is far from being perfected and there will undoubtedly be difficult mechanical problems encountered during development, Dr. Calvin has stated that he doesn't see any fundamental scientific difficulties with his approach.

Photochemical Hydrogen Production in Solution

As in electrolysis, water is the raw material for photochemical hydrogen production. In the presence of sunlight, atoms of a catalyst such as rhodium are excited causing them to release negatively-charged electrons which react with positively-charged hydrogen ions in solution to produce hydrogen gas. In theory, as much as 20% of the energy in sunlight could be converted into hydrogen by this process. Since rhodium (which is a rare earth element) is both scarce and expensive, some research is aimed at finding alternate catalysts, tungsten and molybdenum being two possibilities.

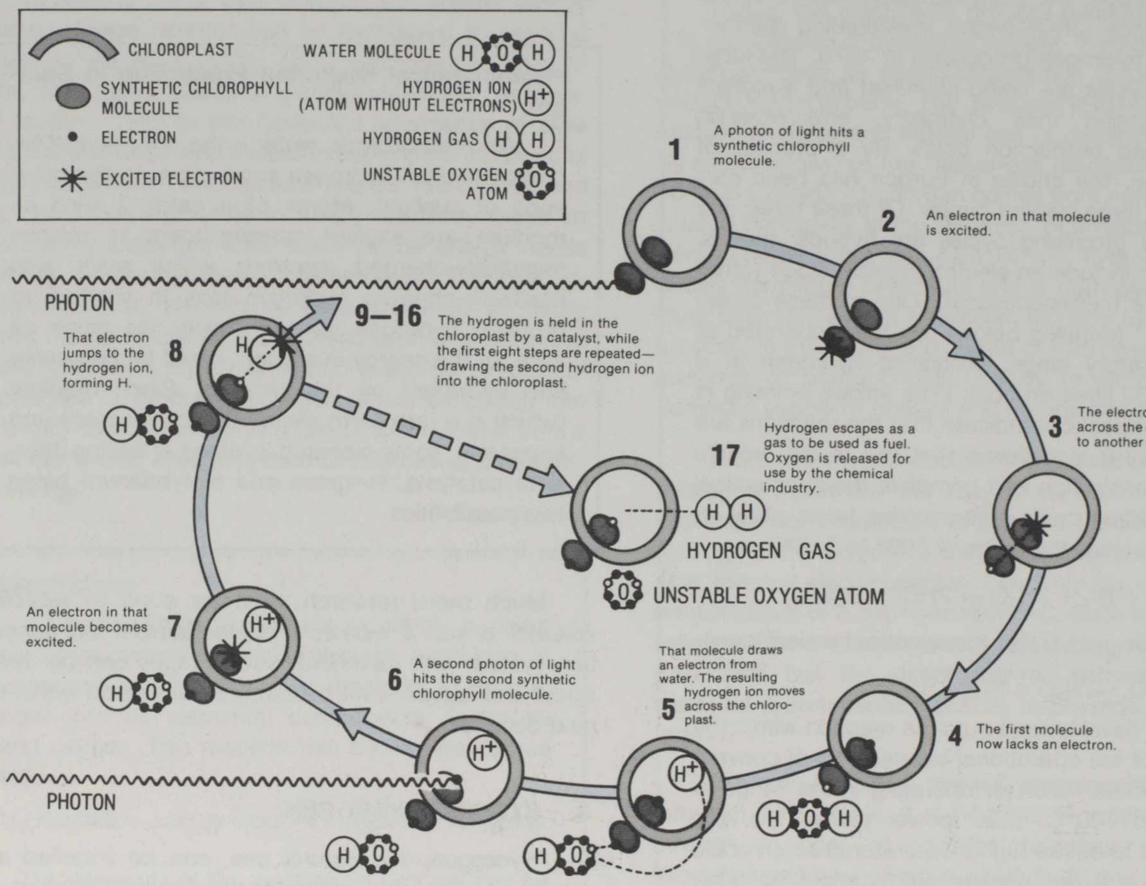
Much more research must be done to establish whether or not a workable photochemical fuel-generation system with its inherent advantages can be developed. This question will probably be answered within the next decade.

3. STORING HYDROGEN

Hydrogen, like natural gas, can be liquefied and stored at very cold temperatures (cryogenic storage). Liquid hydrogen is stored in vacuum-insulated flasks at about −250°C but this is not likely to be the favoured storage option when hydrogen comes into wider use. The cost of the insulated containers is one concern, but the most important limiting factor is the energy required to liquefy hydrogen in the first place — 25 to 30% of its heating value.

A more conventional method for storing small quantities of hydrogen is as a gas in high-pressure cylinders. This method of storage is both expensive and bulky since a large quantity of low-carbon steel is needed to contain a relatively small amount of hydrogen. The handling of hydrogen presents some technical difficulties which have to be taken into account. Embrittlement of metal can be a problem in all hydrogen systems, but especially at very high pressures. Hydrogen molecules are the smallest of all molecules and can diffuse into spaces between atoms in metals. This makes the metal brittle and can result in surface cracking which weakens the pipe or storage vessel. Furthermore, its small molecular size allows hydrogen gas to leak more easily than other gases from systems under pressure. Nonetheless, these technical difficulties can be overcome by careful design.

Figure 6-21: A BIOMIMETIC METHOD OF PRODUCING HYDROGEN



Source: After Weintraub, 1981, p. 37.

Since storage as a liquid or as a compressed gas is only suitable for comparatively small quantities of hydrogen, underground storage may represent the best approach for inexpensively containing large quantities of the gas. This seems technically feasible as natural gas has for many years been injected into depleted oil or gas reservoirs and stored until required. Any such reservoir would have to be judged on its individual characteristics. Aquifers can be used in a similar manner by displacing water with injected hydrogen. In England, Imperial Chemical Industries Limited is storing 95% pure hydrogen in solution-mined caverns in a salt deposit.

The main disadvantage of underground storage is that it is limited to locations with suitable geology. This is not a serious problem, however, since H_2 can be transported by economical means to the point of use.

Cryogenic storage and pressurized storage are appropriate for the present industrial uses of hydrogen, and underground facilities allow safe storage of large quantities of H_2. But neither of these methods is suitable for use in moving vehicles or where a combination of compactness and large hydrogen-holding capacity is required. There are alternative storage methods which show considerable promise for application in these special situations.

Most metals will, on contacting gaseous hydrogen, form a compound known as a metal hydride. Metal hydrides are attractive because they can bind a large quantity of hydrogen. For instance, it is possible to get more hydrogen into a given volume in the form of a metal hydride than into the same volume as a liquid. The metal is normally prepared in the form of small particles to provide as much surface area as possible with which the hydrogen can react. As one might expect though, there is a difficulty with this approach too and the major concern here is the weight of the system.

The most promising hydride examined to date is a ternary hydride (that is, two metals plus hydrogen), the two metals being iron and titanium. This system has a relatively low cost, a low dissociation pressure and a

Hydrogen Storage in Metal Hydrides

The reaction of a metal with hydrogen can be expressed as follows:

M (metal) + $H_2 \rightleftarrows MH_2$ (metal hydride).

This is a reversible reaction. If the ambient pressure is above a certain level (equilibrium pressure), the reaction proceeds to the right producing a hydride. Below this equilibrium pressure, the hydride will dissociate into hydrogen gas and the metal.

moderate controlling temperature. Its disadvantages are its weight and its sensitivity to contaminants (ultrapure hydrogen must be used). An iron-titanium hydride is already being used in several prototype vehicles in the United States and in Germany.

The high storage density and the inherent safety of hydride systems (they release hydrogen only slowly upon rupture) have made them an attractive subject for research. In instances where mobility, compactness and weight are not factors, such as in the on-site storage of hydrogen from off-peak power, metal hydride storage compares favourably with other methods. It seems likely that such storage will gain in importance as hydrogen fuel becomes more widely used.

In applications where mobility and weight are important, such as in automobiles, *liquid* hydride storage may hold the answer. A liquid hydride is any liquid compound which contains hydrogen as a major element. Water (H_2O) is of course the most abundant liquid hydride, but gasoline, propane and methanol are examples of liquid hydrides as well. In addition to these natural hydrogen carriers it is possible to create a variety of synthetic liquid hydrides. Such compounds could provide an answer to the problems of storing and carrying H_2 in a form suitable for use in mobile applications. Methanol from biomass, for example, could well become an important hydrogen carrier in this country as we increase our production of this alcohol.

4. TRANSPORTING HYDROGEN

Most commonly hydrogen is transported over long distances in the form of a liquid. This is done in double-walled, evacuated, insulated containers mounted on trailer trucks, rail cars or barges. Small quantities of hydrogen are moved as compressed gas in thick steel cylinders. Both of these methods will continue to be used in the future for small volumes but, in a "hydrogen economy", H_2 will most likely move to market via pipeline.

There is already a considerable amount of experience in the transmission of hydrogen by pipeline. In the United States, the National Aeronautics and Space Administration and the private company involved in the liquid-hydrogen rocket engine program have successfully operated very short high-pressure pipelines for both liquid and gaseous hydrogen. These high pressures and the use of liquid hydrogen pipelines are unlikely to be implemented for the large-scale movement of hydrogen fuel, but this experience has shown what can be achieved.

Of greater interest are the commercial or "merchant" hydrogen pipelines operating in several countries, which demonstrate the feasibility of pipeline transmission of hydrogen gas. In the United States, Air Products and Chemicals Incorporated of Houston, Texas operates a 96-kilometre (60-mile) underground pipeline. This system has worked so well that plans are underway to construct a further 104 kilometres (65 miles) of pipeline to serve additional customers in the area.

Perhaps the most impressive hydrogen pipeline system is that belonging to the Chemische Werke Hüls AG in the Ruhr Valley of West Germany. This 210 km-long underground pipeline network handles 95% pure hydrogen at a pressure of 1.5 megapascals (210 pounds per square inch). There are four separate injection points and nine different users. No significant problems have been encountered during the 40 years that this pipeline has been in operation.

The cost of hydrogen compared with current petroleum prices precludes its use as a fuel today. This means no large-scale hydrogen pipeline is likely to be built soon. On the other hand, present natural gas pipelines and, more importantly, natural gas end uses are compatible with adding up to 20% H_2 to the gas. Thus in the long term, as natural gas becomes less abundant and the supply of hydrogen gas increases, pipelines could be modified to carry H_2. The major alteration required would be the installation of larger compressors. The heating value of H_2 is only one-third that of natural gas for an equal volume. Larger compressors are therefore required to move three times the volume of hydrogen in order to maintain the same rate of energy delivery (if the system is converted to carrying H_2 alone).

5. A HYDROGEN-BASED ENERGY SYSTEM FOR CANADA

Switching Canada's energy system from one based primarily on nonrenewable hydrocarbons to one based on a wide variety of sustainable energy sources with hydrogen as the major currency will be neither quick nor inexpensive, but it is nonetheless desirable.

CONCLUSION

The Committee believes that Canada should develop a hydrogen-based energy system.

RECOMMENDATION

The Committee recommends that an energy system based upon hydrogen and electricity as the principal energy currencies be adopted by the Government of Canada as a long-term policy objective.

There are numerous reasons for concluding that a hydrogen-based energy system makes sense for Canada. The large reserves of bitumen and heavy oil in Alberta and Saskatchewan will necessarily form part of our energy supply for many years to come. These reserves require the addition of hydrogen for upgrading to usable oils. Today hydrogen used for this purpose comes from natural gas and conventional crude oil, but in the future the hydrogen could be produced by electrolysis. The first step towards a hydrogen-based energy system might therefore be made in extending Canada's supplies of hydrocarbon fuels. Although this appears to be an expensive approach, it would allow hydrogen production capability to parallel rather than track the development of end uses for hydrogen in our economy. A further benefit of this approach could be a smooth transition out of the petroleum era.

In the Biomass section the Committee recommends construction of a methanol plant using biomass and natural gas as feedstocks. The natural gas is added to the synthesis gas produced from biomass to increase the hydrogen to carbon ratio and thereby raise methanol yields. Electrolytic hydrogen could eventually replace natural gas as the hydrogen source in this type of facility.

In still another application, electrolytic hydrogen could be produced using off-peak electricity, increasing the efficiency and reducing the cost of utility operation. The hydrogen so produced could subsequently feed a fuel cell to produce electricity for peaking requirements, much as pumped storage is utilized today. However this conversion from electricity to hydrogen and back to electricity is only about 35% efficient and the energy lost in first producing the electricity has also to be accounted for. Thus it would make more sense to mix the hydrogen with natural gas and deliver it by pipeline to consumers or to ship it directly to industrial users.

Canada has potential sites for large hydro-electric generating stations which have not been developed due to their distance from markets. If electricity produced in these remote areas were used to electrolyze water into hydrogen and oxygen, these two gases could be piped to distant consumption points. It was estimated by witnesses before the Committee that for distances over 500 km it would be cheaper to go this "hydrogen route" than to transmit the power by high-voltage transmission lines, provided that the hydrogen were not to be reconverted to electricity. If nuclear energy were to be used, the remote siting of nuclear power stations, with a hydrogen pipeline link to markets, could help allay public concern over the location of such stations near population centres.

Hydrogen produced by electrolysis has distinct advantages over liquid fuel options because it can be produced from most energy sources through the medium of electricity. Therefore, Canada could begin now to develop the infrastructure for a hydrogen-based energy system knowing that no matter which long-term energy option ultimately proves to be our major source of supply, the hydrogen infrastructure would remain the same.

CONCLUSION

The Committee believes that hydrogen is the best fuel for a non-carbon-based energy system.

RECOMMENDATION

The Committee believes that hydrogen will be an important element of Canada's future energy system and recommends that we begin now to develop the technology and infrastructure for hydrogen production, distribution and use.

The speed with which a hydrogen energy system is introduced will probably depend more upon political and environmental concerns than upon economics or the depletion of hydrocarbon resources. Canada, nevertheless, is in a unique position to become a world leader in electrolytic hydrogen production technology. We already have an abundant supply of electricity from non-fossil fuel sources and we have the potential for producing electricity from a number of renewable sources. We are also fortunate in that the world's leading manufacturer of electrolysis equipment is a Canadian company. It thus appears that with this lead Canada should be in a position to develop a complete hydrogen system. The missing element is end uses for the increased hydrogen production. Suggestions have been made to the Committee that the development of a low-cost fuel cell for use in ground transportation would complete the system. In addition to helping replace oil in the transportation sector, this system would provide excellent opportunity for the export of technology to other countries.

RECOMMENDATION

The Committee agrees that the early demonstration of a hydrogen-based urban transportation system is required in Canada and recommends that research into this use of hydrogen be supported with the aim of rapid commercialization.

While we already know a certain amount about the production, storage, transportation and use of hydrogen, much research remains to be done before hydrogen plays a major role in our energy system. Many other countries have acknowledged the potential benefits of a hydrogen-based energy system and are working to overcome the remaining problems surrounding its economic production and use.

CONCLUSION

Canada has a momentary advantage, possessing all of the essential elements for developing an electrolytic hydrogen system. What is missing is a commitment to taking full advantage of our position.

This is made clear by the fact that the current Federal RD & D program for hydrogen is funded to the level of only $1 million per year -- a sum which must cover all RD & D on the production, storage and use of hydrogen.

CONCLUSION

Federal funding of hydrogen RD&D is totally inadequate to allow Canada to gain, or maintain for long, a position of world leadership in any area of hydrogen technology.

Having decided that a hydrogen-based energy system should be implemented in Canada, the Committee sought the opinion of experts in the field of hydrogen energy as to what steps would be necessary to achieve this long-term objective. The response indicates that such a system will only evolve in this country if there is a strong political will to make it happen. Without a firm commitment on the part of the Federal Government, it will be many years before hydrogen makes a significant contribution to our energy system. Once a commitment to such a course of action was made, the rate of development would depend to a great extent upon the amount of money dedicated to the effort. In order to attract and keep top research scientists well versed in the fields of hydrogen production, storage, transportation and use, a major, long-term financial commitment is a necessity.

If Canada decides to pursue a purely RD & D program over the next five years, with no provision for commercialization, funding in the tens of millions of dollars would be required. This would ensure that steady, if slow, progress was made in hydrogen RD & D but it would not enable us to begin developing a hydrogen-based energy system. If, on the other hand, Canada chooses to pursue the rapid development and commercialization of a complete hydrogen-based energy system, the investment required would be in the order of hundreds of millions of dollars over the next five years.

CONCLUSION

The Committee believes that Canada has a unique opportunity to become the world leader in hydrogen technologies if we follow an ambitious route to the early establishment of a hydrogen-based system.

It is important to note that the Committee is not simply recommending the introduction of another supply option — we are talking about the development of an entire energy system. Technologies for the production, storage and transportation of H_2 must be refined and costs reduced; the infrastructure necessary for the widespread distribution and use of H_2 needs to be put in place; and end-use technologies require basic RD & D. The Committee believes that Canada has an opportunity to act decisively and quickly to establish this country as a world leader in hydrogen energy technologies. Canada currently spends billions of dollars on large energy supply projects. The next tar sands plant is expected to cost about $10 billion and the Darlington nuclear generating station will probably exceed $7 billion in construction costs. Each of these large projects offers only one energy commodity — one supply option. A hydrogen-based system can involve a wide variety of energy sources and an equally wide variety of non-polluting end uses. Certainly such a system is worth funding at the same order of magnitude as conventional energy supply projects.

RECOMMENDATION

The Committee recommends that the Federal Government be prepared to spend up to $1 billion over the next five years to foster the broad development of a hydrogen-based energy system and to establish Canada as a world leader in hydrogen technology.

The task of developing appropriate hydrogen energy technologies will be an enormous one. The Committee believes that such development will require the guidance of a mission-oriented agency — an agency charged with orchestrating the research, development, demonstration and commercialization of hydrogen energy systems. No such agency is currently in place.

RECOMMENDATION

The Committee recommends that a Commission, to be known as Hydrogen Canada, be

established to act as the lead agency for hydrogen RD&D and commercialization in Canada. This Commission should report to the proposed Minister of State for Alternative Energy and Conservation.

RECOMMENDATION

The Committee recommends that the proposed Minister of State for Alternative Energy and Conservation begin a review of the progress and accomplishments of Hydrogen Canada after eighteen months, with the review to be completed within six months. A further review should be conducted after the fourth year of the program, with subsequent reviews to follow at five-year intervals.

RECOMMENDATION

The Committee recommends that the results of the periodic reviews of Hydrogen Canada's progress be tabled in Parliament within three months of their completion and that, in the event that Parliament is not sitting at the time, the Minister be permitted to make them public.

Hydrogen Canada: The First Five Years

In the course of its deliberations the Committee sought advice from experts in the field of hydrogen energy RD&D in Canada. Having decided that an ambitious program, including demonstration and commercialization as well as research and development, was right for Canada, the Committee asked Dr. David Scott, Head of Mechanical Engineering at the University of Toronto to suggest, as a guide, the funding levels that he felt would be required to move Canada quickly into a clear position of world leadership in hydrogen-based energy technologies. The following five-year budget was submitted to the Committee by Dr. Scott and reviewed by Dr. J.B. Taylor of the National Research Council of Canada. Dr. Taylor concurred in Dr. Scott's assessment of the effort required to reach the stated objective.

Years 1 to 3 would be taken up primarily in establishing a lead agency for Canadian hydrogen energy RD & D and commercialization. Some research could be contracted out during the time that Hydrogen Canada's facilities were being planned and constructed. In subsequent years, when RD & D was fully underway, higher levels of funding would be required.

Year 1	Millions of Dollars
Organizational Planning and Management	2
RD & D Planning	2-4
Physical Plant Planning	2
Possible Land Acquisition	2-4
Total	8-12

Year 2	
Facility Engineering and Design	7
H_2 System and Synergy Analysis	1
Land Acquisition (and some RD & D initiatives)	40-60
Total	48-68

Year 3	
Physical Plant (to complete by year end)	30-60
H_2 System and Synergy Analysis, Demonstration of some retrofit, small user and generation technologies and establishment of H_2 superior RD & D plans	120-170
Total	150-230

	Year 4	Year 5
H_2 System and Synergy Analysis	10	15
H_2 Generation	60	60
H_2 Distribution	30	40
Fossil Resource/Reserve Extension	30	25
Biomass Resource/Reserve Extension	20	30
Small User H_2 Technologies	30	30
Retrofit H_2 Technologies	40	40
"Clean H_2" Fuel Cell Technology	30	60
Hybrid Drives (regeneration and storage batteries)	15	25
On-board H_2 Storage	10	55
LH_2 Aircraft Technology	10	13
Other H_2 Superior Technologies	20	30
Total	305	423

This schedule of funding is an indication of the financial requirement to put Canada into the lead in developing hydrogen technologies. It is provided as a guide to policymakers. As with any program of this magnitude a periodic review of the progress and direction of research and development will be required.

Nonconventional Propulsion

The demand for oil and petroleum products cannot be met by domestic supply alone; therefore Canada presently makes net purchases of some 300,000 barrels of crude oil daily from foreign sources. But over 50% of the domestic demand for oil comes from the transportation sector, and it is our seemingly insatiable thirst for gasoline which has in large part created the so-called "oil crisis". In fact, the main energy problem which must be addressed in Canada in the 1980s is the supply and availability of liquid transportation fuels.

Most liquid fuels presently used in Canada are derived from petroleum (gasoline, diesel fuel, fuel oil and kerosene), although a small amount is propane stripped from natural gas. Liquid petroleum fuels have come to dominate the transportation sector because, traditionally, they have been cheap and because they are energy dense and convenient to handle.

In the context of this report, gasoline and diesel fuel are conventional energy currencies; any other energy currency which can fuel the transportation sector is referred to as nonconventional propulsion. If Canada's long-term goal is to get away from the use of hydrocarbons as energy sources, then there must be a transition period which takes us from the present to the time when Canada utilizes primarily hydrogen and electricity as the energy currencies in its economy. This transition will be crucial in our energy evolution and it must be carefully planned and coordinated to ensure that new energy currencies and the products that use them will come on-stream at the same time. For this reason, conventional and new hydrocarbon fuels will be required for some time to come in order to give us the opportunity to develop alternatives.

A number of steps will be required in making a gradual transition to new fuels.

- Conservation of conventional fuels should be promoted by reducing non-essential travel and by keeping engines well-tuned and efficiently running.
- A wide range of new, fuel-efficient vehicles should be made available to consumers.
- The refining specifications of existing refineries should be altered to allow more gasoline and diesel fuel to be extracted from each barrel of crude.
- The use of those hydrocarbons which are presently being under-utilized for transportation purposes, such as propane and compressed natural gas, should be encouraged and gasoline supplies should be extended by mixing them with power alcohols.
- Canadians should be weaned from hydrocarbon-containing fuels altogether as soon as vehicles which can run on methanol, hydrogen or electricity become available and their fuels can be produced in quantity.

Options for nonconventional propulsion are discussed individually in the following sections.

1. PROPANE

Propane is a hydrocarbon fuel but it can nevertheless play an important role in the transition taking us from a gasoline-powered transportation sector to one powered by hydrogen and electricity. Propane is a short-chain (C_3H_8), gaseous hydrocarbon which becomes a liquid under relatively low pressure. It can be stripped from *wet* natural gas or it can be produced from oil in petroleum refineries. (Wet or raw gas is natural gas containing liquid hydrocarbons. Propane is one of the "natural gas liquids" recovered in processing wet gas.) These two sources produce about 130,000 barrels/day of propane and of this amount approximately one-half is exported. Since propane production exceeds domestic demand, the discontinuation of exports would leave a significant quantity of this alternative energy currency in Canada to be used as a transportation fuel.

Propane can substitute for gasoline in conventional engines if modifications are made to the carburetor and fuel system and if a propane storage tank is added. These changes cost from $1,200 to $1,500 and produce several advantages in addition to substituting for gasoline: the combustion efficiency of the engine rises, thereby lowering the energy demand of the engine by as much as 10%; there may be lower maintenance costs for propane-fueled engines; and engine life may be extended by two to three times.

In the Committee's view though there are factors which will ultimately limit the number of propane-powered vehicles in Canada. First, the propane resource is limited. We can make more available in Canada by limiting exports and increasing the amount of propane produced by refineries, but the amount we can expect to produce from increasingly "dry" gas fields and our petroleum resources is finite. Second, being a fossil fuel, propane is a nonrenewable source of energy, and it doesn't make sense to substitute one diminishing resource for another, except as a short-term measure to aid in the transition to sustainable energy sources. Third, the distribution system for propane is not well developed, a factor which should restrict the use of propane to fleets of vehicles which are used regularly and fueled at a central source.

CONCLUSION

Propane-powered vehicles can help Canada consume less oil and aid in the transition period during which more exotic forms of propulsion are developed and hydrocarbons are phased out as transportation fuels.

RECOMMENDATION

Propane use should be encouraged in the short and medium terms for vehicle fleets refueled at central locations.

2. COMPRESSED NATURAL GAS

Natural gas is composed predominantly of the gaseous hydrocarbon methane (CH_4). Unlike propane, it is an abundant resource which could power much of the transportation sector for a number of years to come should the decision be made to encourage its use. It is an efficient, clean-burning fuel which can be used in conventional engines if they are suitably modified — a change which costs around $1,500, or slightly more than the cost of conversion to propane use.

Natural gas can be used either as a compressed gas (compressed natural gas, or CNG) or as a liquid (liquefied natural gas, or LNG). There are, however, handling and safety problems associated with LNG which preclude its gaining widespread acceptance as an alternative transportation fuel. Thus, if expanded use is to be made of natural gas for motor fuel, it should be done by exploiting CNG.

There are limiting factors which may restrict the use of CNG-powered vehicles, however. The cars will require large, heavy fuel tanks because of the low energy density (low amount of energy per unit volume of gas) of the CNG fuel and will have only limited range. In addition, compressor stations will be required at fuel distribution centres to fill the storage tanks.

In principle, using natural gas *directly* as an alternative transportation fuel makes better *energy* sense than converting it to methanol or synthetic gasoline because the steps required to "upgrade" it necessarily consume a portion of the energy contained in the raw resource. However, it may not make better *economic* sense when other parameters are taken into consideration. There would be significant costs involved in converting large numbers of conventional vehicles to CNG use and in installing a distribution network for compressed natural gas. For these reasons, some have suggested that synthetic gasoline made from natural gas would make better economic sense as a transportation fuel than CNG. They point out that existing conventional internal combustion engines could remain in use, and that the distribution network for gasoline is already in place. They also remark that it would not be necessary to invest time, money and energy in designing and building new kinds of engines.

It is indeed unfortunate that there are no hard economic data to indicate which of the CNG or synthetic gasoline routes would be preferable. Nevertheless, there are some basic scientific principles upon which a decision can be made. The long-term objective advanced by Committee is to get away from the use of nonrenewable fossil fuels. Thus any development of CNG-powered vehicles can only be viewed as a short-term alternative which can reduce our dependence on gasoline and help us through the transition to an electric- and hydrogen-powered transportation sector.

CONCLUSION

The Committee accepts the view that CNG-powered vehicles represent a short-term option for helping Canada reduce its dependence on gasoline. Natural gas is not, however, seen as a long-term alternative fuel for the transportation sector since this would not be in keeping with the strategy of reducing Canada's dependence on fossil fuel as an energy source.

RECOMMENDATION

The Committee recommends that compressed natural gas be encouraged for use as a fuel in large fleets of vehicles which travel limited distances and are fueled at central filling stations.

3. SYNTHETIC GASOLINE

Mobil Oil has developed a method of making synthetic gasoline from methanol using natural gas as the primary feedstock. It has been called the Methanol-to-Gasoline (MTG) synthesis and, recently, New Zealand decided to use this process to produce synthetic gasoline from its abundant natural gas resources. This makes eminent good sense for a country with no petroleum and plenty of methane. It may not make sense for Canada with its host of alternative energy resources.

New Zealand chose the American Mobil process (for producing gasoline from fossil fuel-derived methanol) over an adaptation of South Africa's version of Fischer-Tropsch synthesis, for a variety of reasons. For a given feed rate of natural gas, the Mobil process has a higher yield of liquid hydrocarbon products than has either of the two commercial versions of the Fischer-Tropsch process. The high selectivity in product formation which is characteristic of the Mobil process results in a better overall thermal efficiency (56-58%) than that achieved by the Fischer-Tropsch route (44-53%), although it is less than that achieved for methanol synthesis alone (60-64%). Finally, the capital investment required for an MTG process plant is less than that required for a Fischer-Tropsch, Sasol-type installation.

The MTG process produces a gasoline which contains few impurities and has a boiling point range similar to that of premium gasoline. With suitable additives, synthetic gasoline has passed tests for carburetor detergency, emulsion formation, filterability, metal corrosion, and storage stability. Vehicle tests have shown the product to provide performance similar to that derived from premium unleaded gasoline.

Summary of the Mobil Methanol-to-Gasoline (MTG) Process

In the Mobil Methanol-to-Gasoline process, methanol is converted to gasoline over a zeolite catalyst. Methanol is first reversibly dehydrated to dimethylether, then these two oxygenates dehydrate further to yield light olefins which in turn react to form heavier olefins. In the last of the sequence of reactions, the heavy olefins rearrange to form paraffins, cycloparaffins and aromatics (i.e., synthetic gasoline).

$$2CH_3OH \rightleftarrows CH_3OCH_3 + H_2O$$

$$\downarrow$$

$$\text{light olefins} + H_2O$$

$$\downarrow$$

$$C_5 + \text{heavier olefins}$$

$$\downarrow$$

$$\text{paraffins} + \text{cycloparaffins} + \text{aromatics}$$

(synthetic gasoline)

Due to the peculiar three-dimensional structure of the zeolite catalyst used in the process, few hydrocarbons larger than C_{10} are produced. This is an important feature of the MTG process since no distillation or refining of the synthetic gasoline is required to remove heavy hydrocarbon compounds.

Source: After Lee, W. *et al*, 1980.

With these considerations in mind, some observers suggest that the production of synthetic gasoline from Canada's large, and at the present time surplus, natural gas resources represents a golden opportunity for making large quantities of liquid transportation fuels. However, the Committee has already stated that weaning Canadians from fossil fuels should be the major objective of an alternative energy strategy and it would not be consistent with this philosophy for us to recommend the production of a hydrocarbon transportation fuel from a nonrenewable resource. For this reason methanol is favoured to help us through the transition to a hydrogen- and electric-powered future.

Some claim that synthetic gasoline makes better economic sense than methanol because existing internal combustion engines could remain in use and because the distribution network for gasoline is already in place, neither being the case for methanol. Furthermore, if large supplies of synthetic gasoline were made available, it would not be necessary to undergo the undeniably costly endeavour of designing, testing, building and distributing new methanol-fueled automobile engines. While there are insufficient data to determine which route would be preferable, there are some fundamental considerations which can point us in the right direction — and that direction is towards methanol, not synthetic gasoline.

First, no matter how efficient the synthesis can be made, some energy will be required to convert methanol to gasoline. Second, the Mobil process involves deliberately converting a readily biodegradable and water-soluble compound (methanol) into a toxic, less clean-burning, more explosive and non-water-soluble substance (gasoline). Third, the technology for methanol production is considered to be available "off-the-shelf" whereas the Mobil synthetic gasoline step is as yet commercially unproven. Fourth, the MTG step involves a capital investment approximately 25% larger than that required for methanol synthesis. Fifth, the continued availability of gasoline will hinder the development of new types of engines. Sixth, and perhaps most important, a large commitment to synthetic gasoline production from the Mobil process would merely substitute one nonrenewable resource (gas or coal) for another (oil) as a source of gasoline. This would completely ignore the concept of basing our energy system on sustainable energy resources and would worsen the serious environmental problems already developing as a result of the accelerating use of hydrocarbons as sources of energy.

RECOMMENDATION

Because synthetic gasoline does not reduce hydrocarbon usage and because its production is nonconserving in nature, the Committee recommends that the production of synthetic gasoline from fossil fuel resources should not be viewed as an alternative energy solution of major importance for the transportation sector.

4. ALCOHOLS

Two alcohols have generated worldwide interest as alternative liquid transportation fuels or as extenders for gasoline. They are ethanol (ethyl alcohol, grain alcohol, C_2H_5OH) and methanol (methyl alcohol, wood alcohol, CH_3OH). They can both be used pure in specially designed alcohol-burning engines or they can be mixed in varying proportions with gasoline to form gasohol. The United States markets gasohol as a 9:1 mixture of gasoline and ethanol (10% ethanol) and Brazil markets a gasohol composed of approximately 20% ethanol. In Canada, Mohawk Oil has refurbished a distillery in Manitoba to produce two million gallons of ethanol a year for blending with gasoline.

In addition to extending supplies of gasoline (and diesel), the use of alcohols as power fuels can provide other benefits as well. Ethanol and methanol can be produced from a variety of feedstocks and they are biodegradable and water-soluble. This means that spills of alcohols in the environment are much less damaging than spills of gasoline or other petroleum products. Alcohols can be quickly broken down by living organisms and they can be easily diluted to non-toxic concentrations with water. Because alcohols contain no highly volatile fractions, alcohol fires do not start as easily as gasoline fires and, when ignited, they give off much less radiant heat and can be extinguished with water.

Emissions of carbon dioxide, carbon monoxide and hydrocarbons from alcohol-powered vehicles may be reduced compared with gasoline engines but there is still some controversy over the health hazard of aldehyde emissions which would be produced by alcohol engines. If research indicates aldehyde emissions from uncontrolled engines do pose a serious health hazard, however, oxidation catalysts can be 80 to 90% effective in aldehyde removal. Nitrous oxide emissions are significantly reduced in alcohol engines because the fuel is burned at lower temperatures than in gasoline engines. (Lower combustion temperatures mean that less of the air's natural content of nitrogen is converted to NO_x during combustion.) Alcohols can replace tetraethyl lead as an octane booster in low-quality gasoline, thereby reducing knock, ping and run-on.

There are some disadvantages in mixing alcohols with gasoline. They must be anhydrous for mixing to be permanent; if water is present, the alcohol and gasoline rapidly separate, much like oil and vinegar separate after shaking — a phenomenon called phase separation. In this regard methanol is considerably less tolerant of water than is ethanol. Gasohol evaporates more easily than either gasoline or alcohol alone and problems with vapour lock may consequently arise, although this has not been the case in the Brazilian experience. There may be problems with cold temperature starts in vehicles using straight alcohols or gasohols (more so with methanol than ethanol) but these difficulties have been solved in Brazil by starting engines with gasoline in cold weather and then switching to alcohol when the engine is sufficiently warm. Further research and development will be required to develop start-up systems which are dependable in the Canadian environment.

The use of *pure* alcohols for fuel would eliminate problems of phase separation which are characteristic of gasoline/alcohol blends. It would also eliminate the problem of making the alcohol anhydrous, as straight alcohol engines can tolerate water (although it lowers power output).

Much concern has been expressed about the fact that alcohols do not have the lubricating properties of petroleum compounds. Nevertheless, experience in Brazil has indicated that accelerated wear of engine parts is not a problem with ethanol-powered vehicles.

Certain components of conventional automobiles (the fuel tank, fuel pump, numerous plastic parts and so forth) can be more or less susceptible to attack by alcohols depending upon their composition. These obstacles have, however, been overcome by materials substitutions in ethyl-alcohol-burning engines such as those being built in Brazil, and experts in the automotive industry state that similar problems with methanol can be similarly solved. In fact, a number of American, European and Japanese auto manufacturers are already producing methanol and dual-fuel (alcohols or gasoline) engines for testing.

CONCLUSION

A great deal of experimentation is being done worldwide on alcohol engines and on dual-fuel engines which can use either gasoline or alcohols. The ethanol engine has already been perfected and is being mass-produced in Brazil. Internationally, a number of automobile manufacturers are also producing prototype methanol and dual-fuel (methanol/gasoline) engines. These are still being tested but as no market exists for methanol cars, no manufacturer is making a commitment to large-scale vehicle production. On the other hand, no potential methanol fuel producers are yet involved in commercial alcohol production because no market exists for the fuel.

RECOMMENDATION

To develop a truly alternative vehicle fuel option for consumers, the Committee recommends that the Government of Canada urge automobile manufacturers to produce methanol and dual-fuel engines in Canada. Through this action and the development of a methanol-fuel-producing industry, Canada could become a world leader in methanol production and utilization.

RECOMMENDATION

The Committee recommends that ethanol produced in this country should be used for extending supplies of gasoline through the production of gasohol. We do not recommend the use of ethanol-powered cars as a major alternative transportation option.

5. ELECTRIC AND HYBRID VEHICLES

The era of the electric-powered automobile has been very slow in arriving. About 100,000 electric vehicles of myriad design, utilizing numerous different energy storage systems, are on the road around the world — a quantity approximately equal to the number of conventional cars produced daily. But without being unduly critical, they could be described collectively as slow, inefficient and expensive. They certainly hold great promise for the future but, to date, there have been severe problems in developing electric vehicles with the performance and range people have come to expect through experience with gasoline-powered cars. Moreover, manufacturers have not yet managed to make electric vehicles economically competitive with cars powered by internal combustion engines.

Electric vehicles are ideal for urban use because they are quiet, exceptionally clean in terms of operation and emissions, and can be "re-fueled" simply, if slowly, using existing technology. Electric cars would reduce the need for petroleum, provided that the electricity they used was not generated at oil-fired power stations.

The main problem with developing a practical and competitive electric vehicle has been the inability to produce inexpensive, reliable, lightweight, energy-dense and durable batteries. A large variety of battery systems is presently being tested but none has emerged which completely overcomes all of these difficulties. Analysts continue to say a quantum leap in battery technology must be made before electric vehicles become competitive with conventional cars in the automobile market.

Ford has been experimenting with at least four battery systems, including a high-temperature sodium-sulphur battery, but has met with little success so far. General Motors is committed to a nickel-zinc battery which can store two-and-one-half times as much energy per pound as the lead-acid batteries which have traditionally been used in electric cars but admits that range and performance need to be improved. It proposes marketing electric vehicles as early as 1985, however, and predicts that sales of electric cars will reach 200,000 units by 1990. American Motors is producing a limited number of electric jeeps and Chrysler is not in the electric car game at all. The U.S. company Gulf and Western Industries recently announced development of a zinc-chlorine battery which it believes will revolutionize the electric vehicle industry and projects sales of 1.3 million units annually by 1990.

A particularly interesting approach to battery development was introduced to the Committee during its visit to the Lawrence Livermore National Laboratory in California. The Laboratory has been named by the U.S. Department of Energy as the lead institution in developing an aluminum-air battery. What is most exciting about this as yet unproven technology is the fact that the battery system promises acceleration, range and refueling times comparable to today's autombiles. Costs are projected to be equivalent to those of conventional automobiles when gasoline prices reach the range of $2 to $3 per (U.S.) gallon.

It was suggested to the Committee that a prototype vehicle powered by an aluminum-air battery could be developed by 1987, assuming that the Department of Energy gives the research a fairly high priority. Experts at Lawrence Livermore believe that these vehicles could be available as early as 1985 if a crash development program were authorized.

Electricity is produced in aluminum-air power cells by reacting aluminum metal with atmospheric oxygen in the presence of an electrolyte. The product of this electrochemical reaction is an aluminum compound which can be recycled at an aluminum manufacturing plant. Aluminum battery plates, with their high energy to weight ratio, thus provide a particularly attractive link between the source of electricity and the transportation sector (Figure 6-22). As far as air pollution is concerned with this particular battery technology, emission control systems would be required only at aluminum production plants and at electrical generating stations.

Aluminum-air batteries are non-rechargeable in the conventional sense, as the battery is replenished mechanically by replacing exhausted plates with new ones. Given the battery's high energy density, a vehicle may be driven up to several thousand kilometres on one set of plates but vehicle range is determined by the necessity to add water to the battery, probably every 400 to 600 kilometres. When water is added to the battery, the waste aluminum compound formed during operation is removed for recycling.

The Committee also learned of Canadian interest in developing such a battery system. The Defence Research Establishment in Ottawa has investigated the aluminum-air battery for military applications. A company in Toronto is interested in the battery's commercial development and has an arrangement with Lawrence Livermore for the exchange of R & D information.

Since the United States is already proceeding with an active program to develop the aluminum-air battery for automotive applications, the Toronto company proposes to investigate other, more specialized uses of such battery systems in remote communities, at isolated telecommunications facilities, in navigational aids, in the household, in recreational settings, in mine vehicles, and for emergency purposes. This company does not intend to develop the aluminum-air battery for an automotive application but instead plans to import that technology from the United States.

CONCLUSION

Although the development of the aluminum-air battery is still in its early stages and remains a risky venture in a commercial sense, its potential for application in Canada looks very promising considering our abundant hydro-electric resource and our large aluminum smelting capability.

RECOMMENDATION

The Committee recommends that the Federal Government closely monitor the development of the aluminum-air battery system and that it support commercialization of this power system in Canada.

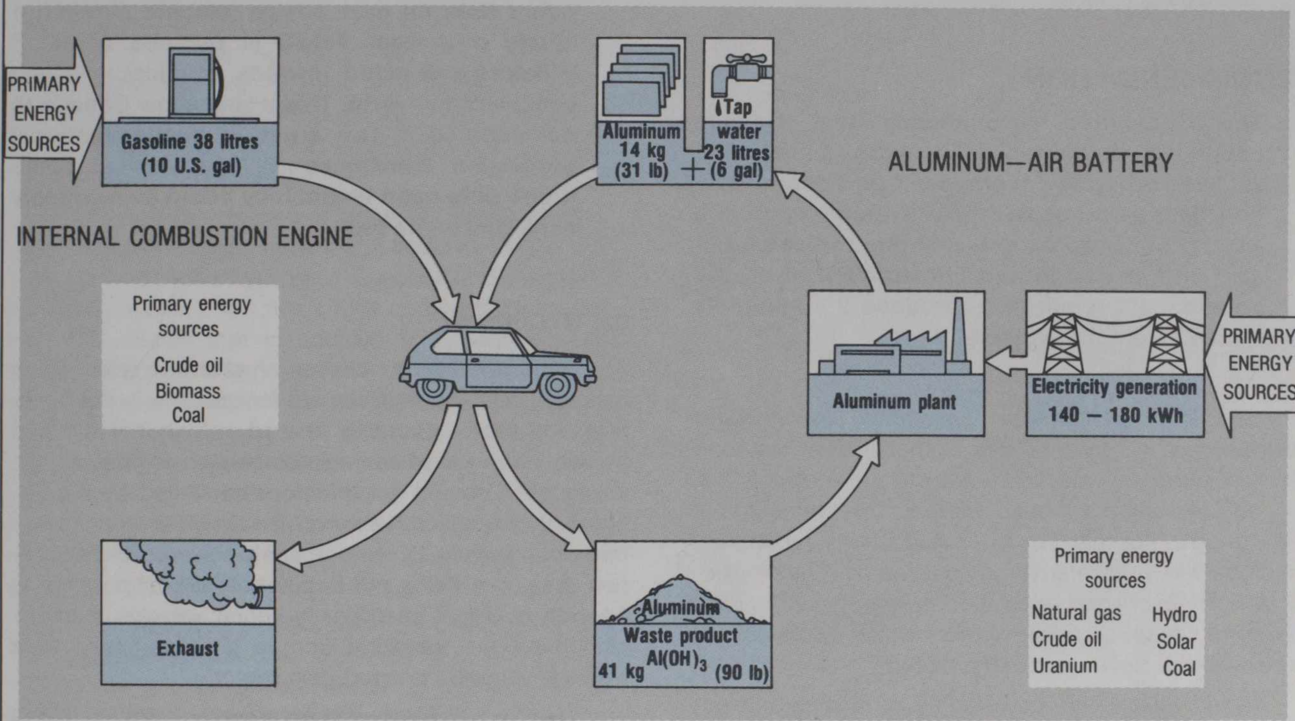
As well as in the United States, research on electric vehicles is being carried out in the United Kingdom, France, West Germany and Italy, and a large commitment to electric vehicle RD & D has been made in Japan. Interestingly enough, these countries are all relatively small and densely populated and the interest in electric cars may derive as much from environmental concern as it does from worry about petroleum supplies.

Very little electric vehicle research is yet being done in Canada but one company in Montreal has produced two types of vehicles powered by lead-acid batteries. A 1978 report on Canadian electric vehicle production stated that practically all the resources required to develop an electric vehicle industry exist in Canada and that most of the components for a complete vehicle can be produced by Canadian companies already supplying parts for vehicles under the Canada-U.S. auto pact.

CONCLUSION

The Committee recognizes that if Canada is going to direct its efforts towards developing a

Figure 6-22: A COMPARISON OF THE ALUMINUM-AIR BATTERY AND THE INTERNAL COMBUSTION ENGINE



A New Approach to Automobile Propulsion

The aluminum-air battery provides electrical energy by reacting aluminum metal with atmospheric oxygen in the presence of an aqueous electrolyte. The reaction product is aluminum trihydroxide which can be recycled to produce more battery plates. Thus the reusable aluminum provides the link between any source of electricity and the transportation sector.

The Car

— 5-passenger vehicle weighing 1260 kilograms (2800 lb)
— Propelled by a 63.4 kilowatt (85 horsepower) engine
— Travelling a distance of 400 kilometres (250 miles)

Its Energy Requirements[a]

Aluminum-air battery

14 kilograms of aluminum produced with 140-180 kWh of electricity, derived from—
- 0.27 barrel of crude oil,
- 72 kilograms of coal, or
- 4 grams of uranium oxide.

Internal combustion engine

38 litres of gasoline, derived from —
- 0.25 barrel of crude oil,
- 90 kilograms of coal, or
- 180 kilograms of biomass.

The above data suggest that vehicles powered by aluminum-air batteries are not many years away from economic viability, if the RD & D program at Lawrence Livermore Laboratory lives up to its promise.

[a] The numbers quoted are characteristic of the U.S. energy system, and might differ in detail in the Canadian context.

Source: After "The Aluminum-Air Battery for Electric Vehicles: An Update", 1980, p. 3.

hydrogen and electric energy future, it must also ensure that there are markets available for these energy currencies as they come on-stream.

RECOMMENDATION

The Committee recommends that Canada become much more actively involved in electric vehicle research, development and demonstration. This effort should be a systems approach which concentrates not only on propulsion but also on the design and construction of all the components required to produce a completely Canadian electric vehicle.

One fear expressed by those who favour the development of electric vehicles is that in the headlong rush to develop alternatives to gasoline, the electric car may be bypassed because battery development has been so slow. For this reason, some feel an intermediate option between the internal combustion and the all-electric vehicle — a *hybrid* vehicle — represents a promising area for research and development which would continue to keep the electric car in the picture.

Hybrid vehicles are powered by combining an electric motor with either a fuel cell or a gas or diesel engine. In the latter type, the heat engine cuts in during periods of high power requirements, such as during acceleration, and the battery meets the lower demand for power which is characteristic of cruising at one speed. In the case of the fuel cell/battery hybrid vehicle, the opposite would probably hold true — the fuel cell would meet low power requirements and the battery would switch in when extra power was needed.

Hybrid propulsion systems could appreciably reduce gasoline consumption by meeting some of the transportation sector's energy demand with electricity. At the present time, however, a vehicle powered in this fashion would be significantly more costly than a conventional one because it would require two power-generation units and a more sophisticated driver-control and power-management system than is presently required. A further disadvantage of hybrid vehicles is that it may be necessary to reduce engine performance expectations to make the cost of hybrid vehicles competitive.

CONCLUSION

Hybrid propulsion systems are costly and, by definition, transitional between conventional and electric vehicles. Much work must be done to perfect such systems and at least a decade would be required to introduce hybrid vehicles in significant numbers.

RECOMMENDATION

The Committee believes that RD&D in this country should concentrate on all-electric vehicles rather than on heat engine/electric hybrids. If hybrid propulsion RD&D is pursued at all, it should be directed towards developing a fuel cell/electric hybrid. This would allow Canada to do research in two areas of nonconventional propulsion simultaneously, so that at some future date each technology could be profitably exploited on its own.

6. HYDROGEN

Hydrogen has a number of characteristics which make it a suitable replacement for gasoline in the transportation sector. Certainly one advantage is that it can be used in modified internal combustion engines and its introduction should not therefore be limited by the turnover of conventional automobiles. In other words, while the infrastructure to support a H_2-powered transportation system is being put in place, it will be possible to operate dual-fuel gasoline/hydrogen vehicles, perhaps smoothing the transition from a gasoline-based to a hydrogen-based transportation sector.

There are also environmental reasons why hydrogen is a better fuel than gasoline. The combustion of pure hydrogen releases only water and nitrogen oxides, while burning gasoline releases CO, CO_2, nitrous oxides, hydrocarbons and, in some vehicles, lead into the atmosphere.

Perhaps the major problem with hydrogen as a transportation fuel is storage. The section on Hydrogen discusses H_2 storage in some detail however, so the following paragraphs describe only those methods which show particular promise for transportation applications.

Liquid hydrogen can be used as a power fuel but there are particular difficulties involved with storing it. First, it must be kept cold and, since it boils at −217°C, well insulated. Furthermore, since hydrogen has only a fraction of the energy value of gasoline by volume, a large quantity must be carried on board a vehicle making tank size unacceptable if long-range driving is expected. Both West Germany and the United States have built experimental cars fueled by liquid hydrogen and research is continuing to reduce the cost of such vehicles, to demonstrate their safety, and to extend their range.

The storage of hydrogen as a metal hydride has also been examined. Although metal hydrides are heavy, they can be used for storing hydrogen in automotive applications where weight is not a serious concern. For example, large vehicles such as buses can accommodate the added weight. In West Germany, Daimler-Benz has demonstrated the feasibility of operating hydrogen-powered buses and a fleet of 20 such vehicles is currently being built for use in Berlin. Similar buses have been tested in several cities in the United States, and Pittsburgh is considering the purchase of a fleet of hydrogen-powered buses. (The environmental advantages of burning hydrogen fuel are particularly attractive in urban areas where exhaust emissions pose a potentially serious health problem.)

Liquid hydrides are also of interest as they avoid the weight problem of metal hydrides. A liquid hydride is any liquid which contains hydrogen. Gasoline is an example of a liquid hydride but it has a high carbon to hydrogen ratio. This means that in addition to producing heat upon combustion, a large amount of carbon dioxide is generated when gasoline is burned. Liquid hydrides which do not contain carbon, and which have a high proportion of hydrogen relative to a carrier element (such as nitrogen), release primarily water upon combustion. Synthetic liquid hydrides resembling ammonia are attractive for this reason and are being actively investigated in the United States.

A liquid hydride can be carried on board a vehicle as a hydrogen source, and when H_2 is required, it is generated in a catalytic cracker (a device which can separate hydrogen from a liquid hydride). A company in California claims to have a test vehicle running on such a hydrogen carrier, but the vehicle has not been independently tested. At the present time, these compounds are thought of as a means of providing on-board H_2 for use in internal combustion engines, but they can be used in fuel cells as well.

CONCLUSION

Linking a fuel cell with a liquid hydride source of hydrogen, such as methanol, for ground transportation appears to be a particularly interesting area for investigation.

Liquid hydrogen (LH_2) holds promise for use as an aviation fuel. Hydrogen was used for its buoyant properties in airships in the 1920s and 1930s but it was never employed as a fuel. The history of accidents with these vehicles still raises serious questions about the safety of hydrogen, and the spectacular explosion of the German airship Hindenburg in May 1937 is still vivid in the minds of many. However, the hydrogen on the Hindenburg was not stored in the way a *fuel* would be stored, and only people who jumped from the ship or were burned with diesel fuel were seriously injured or killed. The burning hydrogen soared upwards because of its lightness and probably injured no one. In any event, proponents of hydrogen use argue that, although hydrogen is highly combustible, it can be handled safely and without incident, a fact which has been well demonstrated during the U.S. space program.

No definitive studies comparing the safety of jet fuel and liquid hydrogen have been completed, yet hydrogen seems to offer certain advantages. If a pressurized tank of hydrogen is ruptured and the gas ignited, the fire burns upwards because hydrogen is lighter than air. It does not spread sideways like a liquid-fuel fire. This characteristic means that if a plane's fuel tanks were ruptured, say on a forced landing, and the fuel was ignited, a hydrogen-powered plane would not sit in a pool of flame as would a modern jet.

Safety considerations aside, liquid hydrogen has a further advantage over conventional jet fuel in that it is very light on an energy-per-pound basis. LH_2 has an energy content of 52,000 Btu/lb., which is about two and a half times that of conventional jet fuel. Consequently the use of LH_2 could lead to considerable energy savings since a conventional aircraft consumes much of its energy taking off with and carrying its own heavy fuel. Since initial take-off weights would be lower with hydrogen-powered aircraft, less thrust would be required and they would be quieter than conventional jets. A final advantage of hydrogen use would be a reduction in atmospheric pollution, as water and nitrogen oxides are the only emission resulting from combustion.

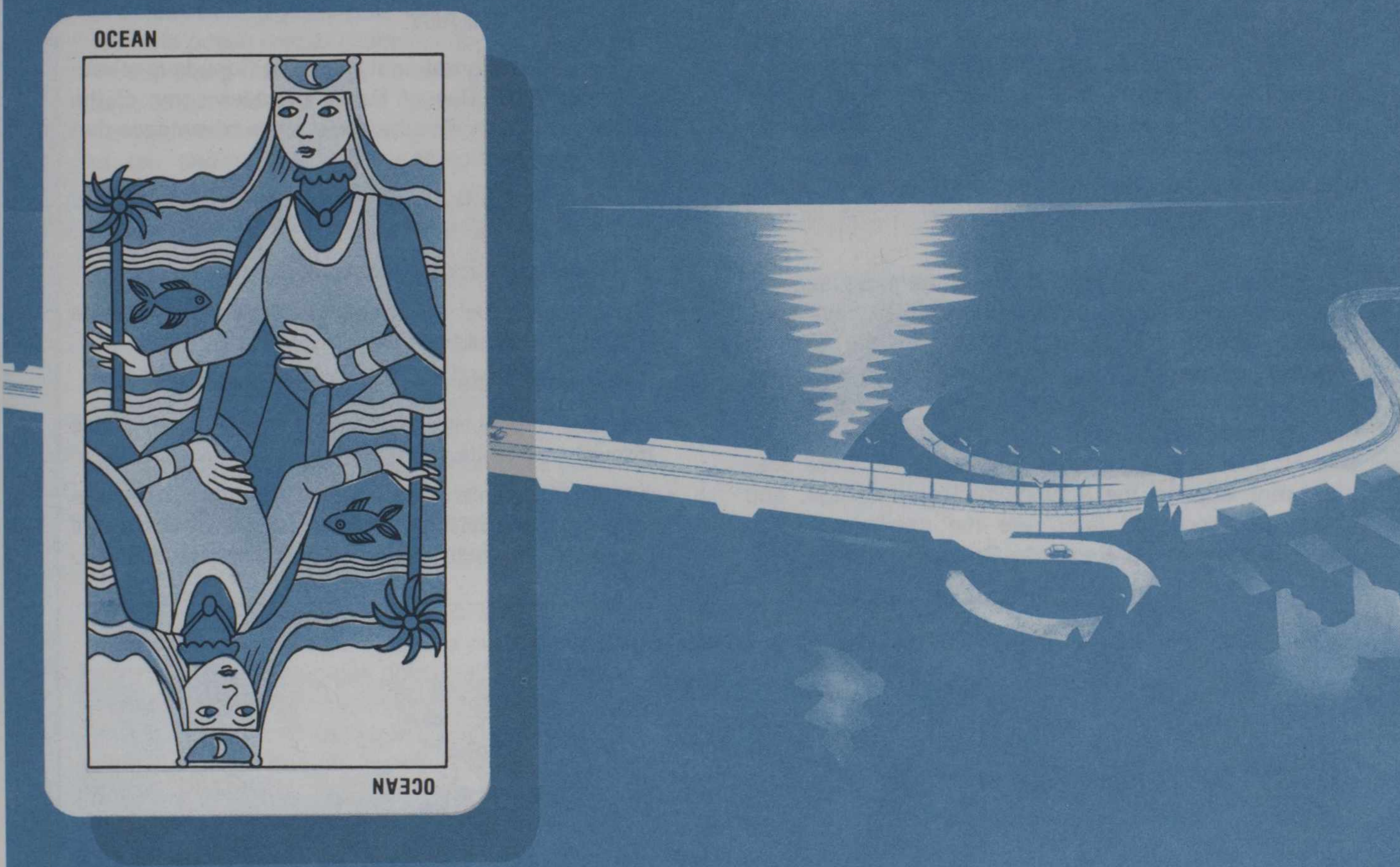
These advantages must be weighed against several disadvantages. While hydrogen has a higher energy content per pound, it has a lower energy content by volume than jet fuel. In fact, LH_2 aircraft would require three to four times the volume of fuel needed in a conventional jet. The design of a hydrogen-powered airplane would therefore have to allow space for very large volumes of fuel and new insulation materials and metals would have to be developed to contain the fuel.

After examining the advantages and disadvantages of hydrogen and assessing the future supply prospects for oil, the Lockheed Corporation is moving towards commercialization of a liquid-hydrogen-fueled aircraft. Lockheed is redesigning the L-1011 TriStar to accommodate LH_2 tanks within the fuselage, and is adapting gas turbine engines to burn hydrogen. The corporation has proposed that the United States, Britain, Germany and Saudi Arabia build and operate a fleet of liquid hydrogen-powered airfreighters as an experiment. Canada will participate in the demonstration phase of this program and one of the hydrogen fueling centres may be located at Mirabel airport. With an intensive research and development program, Lockheed hopes that this fleet will be operating by 1987. Questions about the cost and supply of hydrogen fuel remain, but Lockheed is convinced that liquid hydrogen is the aviation fuel of the future.

RECOMMENDATION

Canada should pursue the use of hydrogen as an alternative aviation fuel and this activity should form part of the overall RD&D efforts of Hydrogen Canada.

Ocean Energy



1. TIDAL ENERGY

A. THE NATURE OF TIDAL ENERGY

The gravitational attractions of the moon and the sun on the Earth are the forces that produce the tides. Because of its nearness to the Earth, the moon plays the dominant role while the sun's influence is reduced to that of a moderator. The pull of the moon causes two bulges to form on the seas, along the line of gravitational attraction, on opposite sides of the Earth. As the Earth rotates in the same direction as the moon's advance, these tidal bulges sweep once around the Earth every 24 hours and 50 minutes.

The additional 50 minutes over the 24-hour solar day results in the high water level occurring at progressively later times on succeeding days. Thus the tidal cycle moves in and out of phase with man's activities. The tidal range also varies on a day-to-day basis. Roughly twice a month, when the moon, sun and Earth are aligned and their gravitational effects are additive (at new moon and full moon), a maximum high water level is achieved which is called the spring tide. At the first and third quarters, the sun and moon form a right angle with the Earth and partially neutralize each other's gravitational influence. This produces a minimum high water level known as the neap tide. Again, at the vernal equinox (about 21 March) and the autumnal equinox (around 23 September) the tidal ranges are larger than usual and must be taken into account when designing a tidal-electric power plant.

More important though in determining the tidal range is the configuration of the coastline. For example, the amplification of the Fundy tide as it progresses towards Minas and Cumberland Basins is a result of the length and configuration of the Bay. The approximate five-fold amplification of the tidal range between the Gulf of Maine (2 to 3 metres) and the head of the Bay (16 metres) makes the Bay of Fundy one of the few sites on Earth where large-scale tidal power generation can be considered commercial.

An important feature of the tides is that regardless of how much they vary locally, they occur in an orderly fashion and are therefore predictable. This predictability is a major advantage in exploiting tidal energy because one can forecast with assurance the amount of energy that will be available next week, next month or next year.

While the Bay of Fundy is one of the most favoured tidal power sites in the world, others which have been studied include Penzhinskaya Guba in the Sea of Okhotsk in the U.S.S.R.; Cook Inlet in Alaska; the Severn Estuary in the United Kingdom; San Jose, Argentina; Inchon Bay, South Korea; and the Jervis and Sechelt Inlet near Vancouver (Figure 6-23). Three sites that went beyond the scrutiny and study stage, and which are discussed later, are the commercial tidal power station at La Rance in Brittany and the small experimental stations at Kislaya Guba in Russia and on Yueqing Bay in China.

B. ADVANTAGES AND DIFFICULTIES IN EXPLOITING TIDAL ENERGY

The exploitation of tidal energy in Canada is attractive because the Bay of Fundy provides some of the best sites on Earth. But there are other advantages that warrant consideration as well.

- A tidal development utilizes a readily available and inexhaustible energy source.
- The resource is accurately predictable.
- There are no fuel costs and maintenance costs of a tidal facility should be low.
- A tidal-electric plant is a clean, non-polluting facility.
- The cost of tidal energy should remain relatively stable throughout the life of the plant.
- A tidal power plant would place Canada in the forefront of a technology of interest to a number of countries. It could also provide an opportunity to

Figure 6-23: THE LOCATION OF POTENTIAL TIDAL POWER SITES

Source: After Clark, 1979, Figure 1.

Tidal Power Schemes

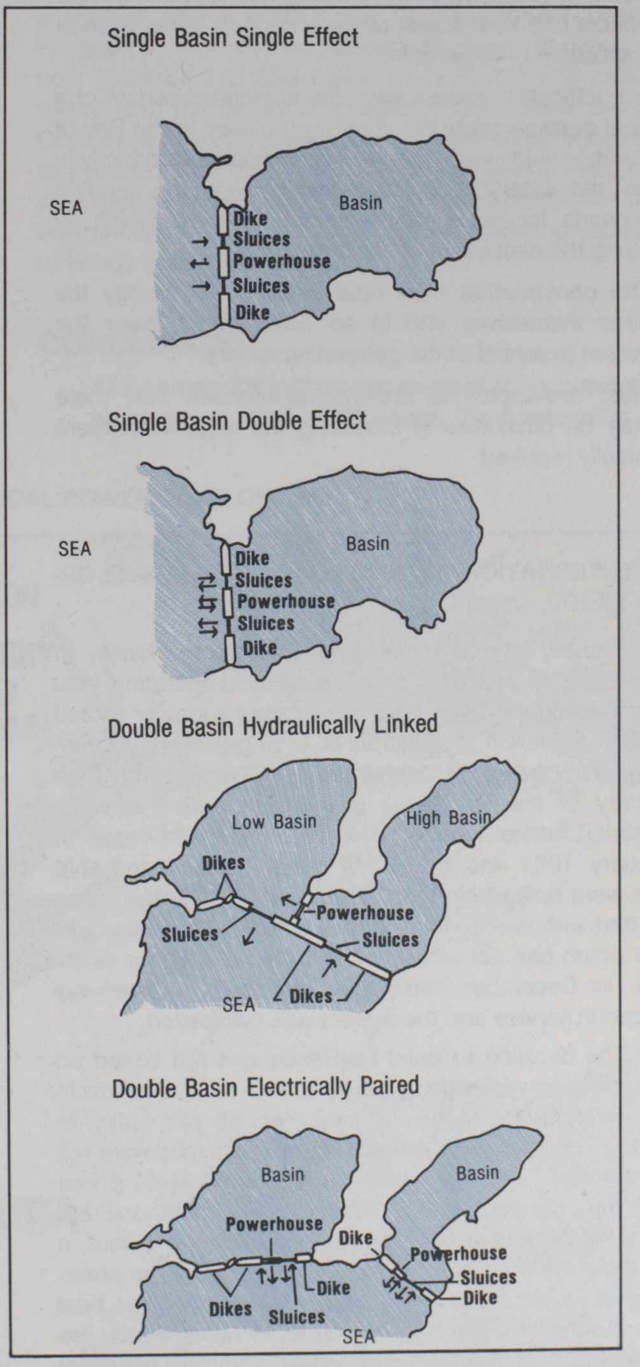
The lack of concurrence between the lunar-oriented tidal rhythm and man's solar-oriented life-style poses unique problems for planners bent on exploiting tidal energy on a large scale. Many development schemes have been put forward over the years but most have been either too complex or too unattractive economically, or both. The simplest and least expensive scheme is a single-effect tidal operation at the mouth of a single basin. Here the sluices in a barrier dam are opened on the flood tide to fill the basin. At high tide, the sluices are closed and the ebbing sea gives rise to a head of water between the basin and the sea. Flow is then permitted through the turbines which, in turn, generate electricity (Figure 6-24). The single-basin concept with a single-effect mode of operation does not produce continuous power. Its period of power generation is dictated by the lunar cycle and maximum energy is often delivered at times of low demand.

A variation on this theme is a turbine that functions both in the basin-to-sea direction and in reverse. This single-basin double-effect operation permits electric generation during both emptying and filling and is the scheme employed at the La Rance tidal development. It too, however, does not produce continuous power. Engineering works in these single-basin schemes are less complex than for double-basin schemes and less costly.

Discontinuous energy output from the single-basin scheme can be overcome with hydraulically-linked basins. A coastal configuration favourable to the creation of two storage basins is necessary for this kind of development. The water level is held high in one basin and low in the other, with generating units linking the two. The high basin is filled as the tide comes in through one set of gates and the low basin is emptied as the tide goes out through another set of gates. The scheme's attraction lies in its ability to generate continuous power although the output is less than that from an equivalent single-basin scheme. Since the linked concept requires an interconnecting waterway with a power plant and additional dikes and gate structures to control the level of each basin, capital costs are greatly increased

A paired-basin development also affords flexibility in electrical generation. The tie in this case is electrical with a generating plant located in each basin. One basin is operated at a low level with energy being generated on the flood tide, while the other functions as the high basin with generation on the ebb tide. Capital costs are commensurate with the hydraulically-linked scheme (Clark, 1979).

Figure 6-24: TYPES OF TIDAL DEVELOPMENTS



Source: Clark, 1979, Figure 2.

develop an industrial capacity not solely oriented towards tidal power but also towards low-head hydroelectric development.

The main disadvantage of tidal energy is its dependence on the lunar rather than the solar cycle, which changes the daily timing of power generation. Other difficulties arise from environmental and economic considerations.

- Too little is known at the present time about the likely effects of a tidal power development on the erosion or deposition of sediments.
- It is difficult to assess what the ecological impact of a tidal barrage might be. Altering the tides in the Bay of Fundy could, however, reduce biological productivity on the intertidal mudflats which are the feeding grounds for many of the migratory birds which fly along the east coast of North America.
- The construction of a tidal barrage will modify the tides themselves and in so doing could lower the output potential of the generating facility.
- Tidal developments are capital-intensive and there may be difficulties in amassing the large investment initially required.

C. INTERNATIONAL AND CANADIAN DEVELOPMENT

France, with its commercial tidal-electric facility at La Rance, is one of only three nations operating tidal power stations today. With an installed capacity of 240 MW, the French installation is a single-basin double-effect scheme and consists of a barrage across the estuary of the La Rance river which opens into the English Channel near St. Malo. Construction began in January 1961 and the powerhouse, barrage and ship lock were built within three cofferdams. The powerhouse is fitted with twenty-four 10 MW bulb-type turbogenerators which can act as pumps or turbines in either direction. In December 1967, the 24th bulb turbine was placed in service and the project was completed.

The decision to build La Rance was not based on economic considerations as the cost of oil was so low in the early 1960s (generally less than $2 per barrel in world markets) that alternative energy schemes were not competitive. However, with the increases in oil prices over the past decade, La Rance is now an economically competitive generator of electricity in France. In fact, a Commission was established in 1975 to study the possibility of constructing a much larger, multi-purpose tidal power scheme (from 6,000 to l5,000 MW) at nearby Iles Chausey. This development would combine electrical generation with harbour facilities, agriculture and tourism, but has not been precisely defined or costed.

One of the experimental stations is the Russian 400 kW tidal powerplant which was completed in 1968 at Kislaya Guba. This small station is located in the Gulf of Ura about 45 km north of Murmansk, near existing transmission lines. The site was selected because a minimum of civil works was required and it provided an opportunity to study material stresses and construction techniques in a hostile environment. The tidal amplitude at Kislaya Guba is about 4 metres, which is too small to permit justification of the project on economic grounds. It is reported, however, that the plant has performed so well that a second 400 kW bulb-type turbine-generator is to be installed in the near future.

China operates the 500 kW Jiangxia tidal station on Yueqing Bay in the East China Sea. Tidal-electric capacity is presently being doubled at Jiangxia and six 500 kW turbines are ultimately planned for the site.

As far as Canada is concerned, most tidal power studies consider development in the Bay of Fundy, although several sites have recently been investigated along the British Columbia coastline. Dr. W. Rupert Turnbull of Rothesay, New Brunswick, the inventor of the variable pitch propellor, was one of the first men to appreciate Fundy's potential. In 1919 he proposed a tidal project for the confluence of the tidal estuaries of the Petitcodiac and Memramcook Rivers in Shepody Bay, but it was not until the closing months of the Second World War that the first major study was undertaken. This project investigated a tidal development in Shepody Bay but along with the studies which followed in the 1950s, the conclusion was the same — tidal power was uneconomic.

In 1966, the Federal Government, New Brunswick and Nova Scotia initiated yet another investigation of tidal power in the Bay of Fundy. The Atlantic Tidal Power Programming Board (ATPPB) came to a familiar conclusion however: tidal power developments, while technically feasible, were not cost competitive with other energy sources. The Board also recommended that further investigation only be undertaken when interest rates dropped sufficiently to indicate that economic development was feasible; or a breakthrough in technology indicated the likelihood of designing an economic facility; or alternative energy sources became exhausted.

Following the ATPPB's report, increases occurred in the costs of conventional energy to the point where tidal power looked promising. Accordingly, in February 1972 the Federal Government, New Brunswick and Nova Scotia established the Bay of Fundy Tidal Power Review Board (TPRB) to go over the findings of the old Atlantic Tidal Power Programming Board. In September 1974 it announced that the economic prospects of tidal power had improved so much that a further detailed investigation was desirable.

Acting on this recommendation, the three Governments signed an Agreement in December 1975 whereby a Management Committee was formed to carry out a Study Program under the general direction of the Tidal Power Review Board. The Committee's objective was to develop

> ...a firm estimate of the cost of tidal energy on which to base a decision to proceed further with detailed investigations and engineering design.

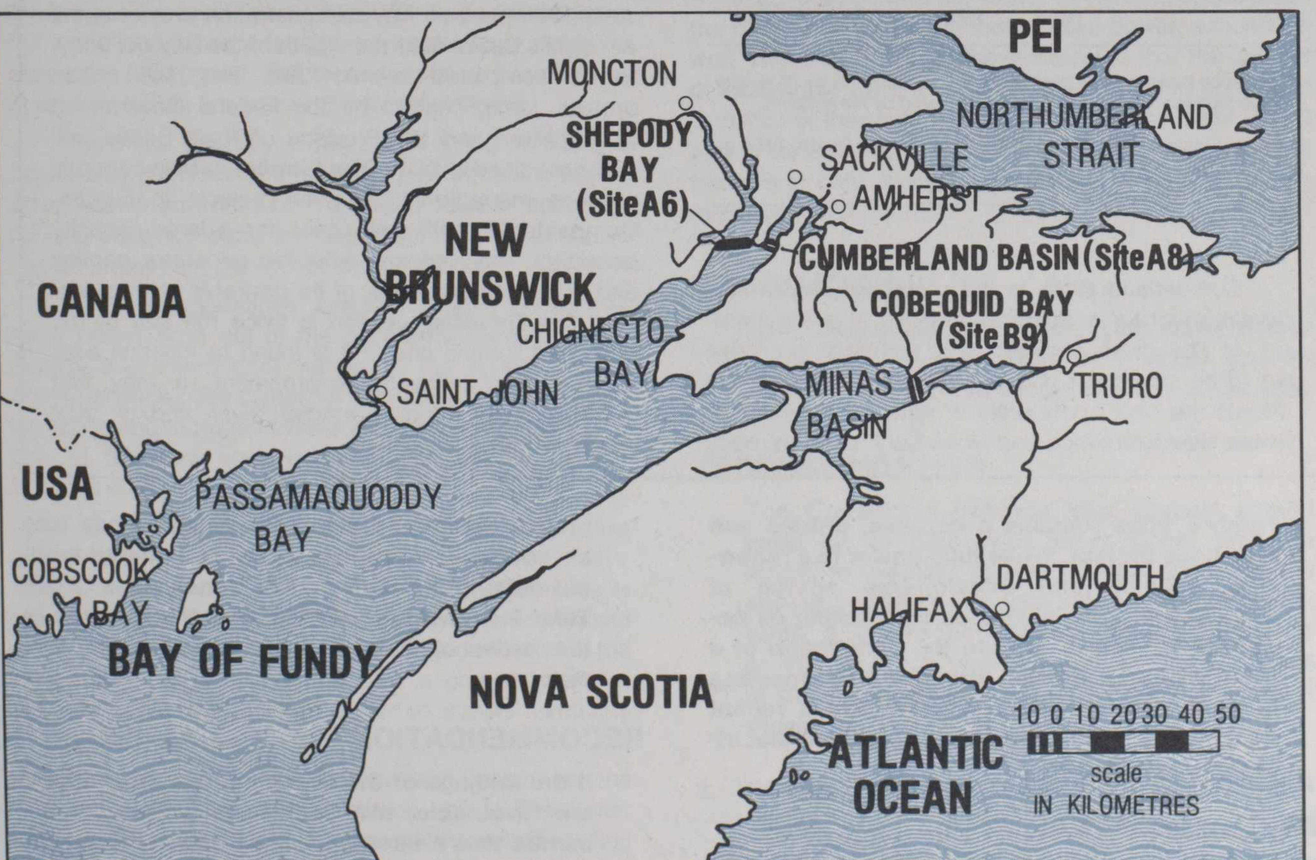
In November 1977, the Bay of Fundy Tidal Power Review Board published its findings in a report entitled *Reassessment of Fundy Tidal Power.* The report concluded that: (1) the construction of a tidal power plant in the Bay of Fundy was economically feasible and its output could be integrated into the projected supply system for the Maritime Provinces; (2) a tidal plant would eliminate the need for new fossil-fueled generating stations in the expansion plans of Maritime utilities; (3) the building of a plant is conditional upon direct and substantial financial participation by governments and a minimum investment in the range of $3 billion would be required; and (4) the results warrant proceeding with detailed engineering studies and environmental and socio-economic investigations. Three sites, indicated in Figure 6-25, were considered to provide the best prospects for development.

The first phase of the 1977 reassessment ended with the above conclusions and remains the definitive study on tidal power in the Bay of Fundy. Adding its cost of $3.4 million to that of earlier studies, one finds that some $8 million has been spent investigating Fundy's tides. The original intention was to follow this work with a second phase entitled the "Pre-Investment Design Program". This did not happen, however, because of cost (estimated at $33 million in 1978 and $50 million today) and the failure to establish the Maritime Energy Corporation (MEC), under whose auspices the work was to proceed. The three-year $50 million Design Program was intended to provide a detailed assessment of all the environmental, socio-economic and engineering aspects of Fundy tidal development.

CONCLUSION

After some $8 million spent on studies conducted over a period of 60 years, the harnessing of

Figure 6-25: PREFERRED SITES FOR BAY OF FUNDY TIDAL POWER DEVELOPMENT



Source: After Canada, Bay of Fundy Tidal Power Review Board, 1977, p. 15.

Fundy Tidal Development

The 1977 *Reassessment of Fundy Tidal Power* selected three sites in the Bay of Fundy for detailed consideration, from an initial group of 37. Details of the three sites are given below.

Table 6-13: COMPARATIVE DATA FOR THREE TIDAL POWER SITES IN THE BAY OF FUNDY

Site Location	Installed Capacity (megawatts)	Average Annual Output (gigawatt-hours)	Capital Costs in Millions of Dollars 1977	1981[a]
Shepody Bay (A6)-Mary's Point to Cape Maringouin	1550	4533	2197	2966
Cumberland Basin (A8)- Peck's Point to Boss Point	1085	3423	1234	1666
Cobequid Bay (B9)- Economy Point to Cape Tenny	3800	12653	3988	5384

[a] Inflation is assumed to have increased capital costs by 35% over the four-year period 1977-1981 (calculated by the authors).

Source: Canada, Bay of Fundy Tidal Power Review Board, 1977, p. 5.

Cumberland Basin is the preferred site for tidal development for a variety of reasons. It is the smallest of the three projects and technical problems would be minimized. It is a joint provincial site which affords the best opportunity to equalize benefits between New Brunswick and Nova Scotia. When ready for commissioning (1995 or later), the Maritimes would be able to absorb an estimated 90% of its power output. If, on the other hand, development took place at either Shepody Bay or Cobequid Bay, an export market would be required for the energy surplus to Atlantic Canada's needs. (In this regard, talks held in February 1981 between the Premier of Nova Scotia and the Chairman of the Power Authority of the State of New York indicate renewed interest in financing the larger Cobequid Bay development.) Finally, environmental concern over possible changes in tide levels along the New England seaboard would not be an issue in a Cumberland Basin development.

There have, however, been substantial changes in the assumptions underlying the 1977 study. The price of imported oil is approaching $40 a barrel; new energy forms (natural gas and nuclear) will soon enter the Maritime market and provide competition for tidal power; and electrical energy load growth has been less than anticipated because of high oil costs and a greater energy consciousness. This indicates the need for updating the 1977 work. It is thought that a new economic feasibility study would take some six months to complete at a cost of $300,000.

In a related development, work commenced in June 1980 on a 20 MW demonstration project in the Annapolis Basin, near the mouth of the Bay of Fundy, to be completed in mid-1983. This $46 million project, jointly funded by the Federal Government ($25 million) and the Province of Nova Scotia, will test a modified straight-flow (Straflo) turbine currently used in many low-head river projects in Europe. Compactness, sufficient space for a large-capacity generator, easy access, effective generator cooling and simplicity are some of its desirable characteristics. The Canadian version is twice the size of the European turbine and, if it is found to function adequately in a saltwater environment, it may find application in future Canadian river and/or tidal power systems.

Fundy's tides remains a massive, untried and ambitious project. While tidal power is a renewable, reliable and inflation-free source of energy, there are obstacles confronting its development. These include the completion of a pre-investment design program; the amassing of capital to finance a project; and a recent decline in the rate of growth of Maritime electrical energy demand.

RECOMMENDATION

To determine whether a tidal power development in the Bay of Fundy remains a viable proposition, the Committee recommends that an economic feasibility study be initiated without delay to verify the 1977 conclusions of the Tidal Power Review Board, and that funding in the order of $300,000 be allocated for this purpose.

RECOMMENDATION

If the findings of the economic feasibility study are favourable, the Committee further recommends that a three-year pre-investment design engineering, socio-economic and environmental study, as outlined in the 1977 Report, be

undertaken and that funding in the order of $50 million be allocated for this purpose.

RECOMMENDATION

If the findings of the definitive study are favourable, the Committee recommends that tidal power development be undertaken in the Bay of Fundy.

2. WAVE ENERGY

The prospect of using the energy of waves has probably interested man since he first witnessed the awesome power of breakers crashing against the shore. Certainly the effort to design machines to harness this renewable energy source has gone on for quite some time. Since 1876, 150 patents for wave power devices have been issued in the United States and some 350 patents are registered in the United Kingdom. Recently there has been a resurgence of interest in developing wave power devices as uncertainty about world petroleum supplies increases and as concern about the appropriateness of using nonrenewable energy resources develops.

Waves represent a very large and renewable source of energy. The resource is widely distributed throughout the world and it has a far greater total energy potential than does tidal power. But there are severe problems to overcome before wave energy is widely utilized.

The prime difficulty arises out of trying to marry a necessarily sophisticated technological device to a very often hostile environment. To assure reliable operation for long periods means, at the present time, a prohibitive capital investment per unit of energy output.

Other disadvantages associated with developing wave power arise out of the geographically widely-dispersed and intermittent nature of the source. These characteristics pose problems with the collection, transportation and storage of wave energy and make integration of this new energy source into existing energy systems difficult.

The United Kingdom is probably pursuing wave power research more vigorously than any other nation, having decided in 1976 to fund this energy alternative at an accelerated rate. The program now in place should allow it to choose the most promising device from the wide array being tested and give a grant to build a full-scale demonstration generator to supply electricity to the national grid.

Today Britain's two most promising designs are the "Salter Duck" and the "Cockerell Raft". The Salter Duck is an oscillating vane device which uses the rolling movement of the waves. It can, apparently, extract over 90% of available wave energy under experimental conditions. The Cockerell Raft floats on the surface and follows the contours of the waves. Electrical energy is generated by the movement of hydraulic motors or pumps which connect a series of these rafts.

Sweden is conducting a wave energy research program which should be completed in 1983. Other countries such as Norway, Finland, West Germany and France are also conducting wave power research.

In Japan full-scale generators of British manufacture powered by air-driven turbines have been installed in a ship called the *Kaimei.* This ship has chambers in the hull which are open to the sea and the movement of waves causes the water level in them to change, forcing air in and out. This moving air is passed through a series of rectifying valves to make its flow unidirectional, and it is then forced through a turbine to produce electricity by means of a generator. The *Kaimei* has been registered as a 1 MW power station and can supply electricity to the Japanese national grid. This research and demonstration program has been underway for two years under the auspices of the IEA with Britain, Japan, Ireland, the United States and Canada as active participants.

Canadian R & D has centred on studying an innovative design for a contouring raft device and testing a wave-absorbing plate but work has been done to assess the magnitude of the Canadian wave power resource as well. These latter studies have indicated that the amount of exploitable wave energy in Canada is small compared with that of the United Kingdom, Norway or South Africa and is spread out over a wide area. This suggests that there are only limited possibilities for exploiting the resource in this country.

CONCLUSION

The Committee recognizes that wave power could only be considered as a minor supplement to conventional power sources in Canada.

RECOMMENDATION

The Committee believes that Canada should keep up to date with international developments in the field of wave power research and should continue to participate in joint R&D ventures. It also recommends, however, that wave power research should have no priority status in Canadian energy research and development programs.

3. OCEAN THERMAL ENERGY CONVERSION (OTEC)

The Earth's oceans act as giant solar energy receptors which absorb much of the sun's radiation arriving at our planet's surface. This energy is stored in the form of heat. The surface waters warm up first but since warm water is lighter or less dense than cold water it tends to remain on top. This reduces the rate at which ocean waters mix and, as a consequence, the Earth's large saltwater bodies have become thermally stratified. Very deep waters are universally cold but surface waters, particularly in the tropics, can be quite warm by comparison.

It is this difference in temperature between surface and deep waters which is exploited in generating ocean thermal energy conversion (OTEC) power. With a temperature differential of about 18°C, an OTEC plant can convert the water's stored thermal energy into mechanical and, subsequently, electrical energy.

The exploitation of temperature gradients in the sea for energy production looks attractive to some tropical nations for a variety of reasons. First, oceanic thermal gradients offer a virtually limitless energy supply and, second, OTEC plants require no fuel. But there are other considerations as well. The energy output of OTEC installations would vary only marginally with seasonal water-temperature differences and the thermal energy resource itself is continuously exploitable. OTEC plants do not require any radically new technology, although existing technology would have to be refined and optimized before commercial installations are constructed.

OTEC facilities could generate electricity directly or, alternatively, they could produce a variety of energy-intensive products such as hydrogen, methanol, ammonia, aluminum, chlorine and magnesium. The circulation of large quantities of nutrient-rich, cold, deep water required for energy production could enhance biological production in the vicinity of the plant. And, finally, OTEC-derived electricity could help reduce future polarizations among nations over energy resources.

On the other hand, there are some difficulties associated with OTEC development which cannot be overlooked. The installations will be very large and very capital intensive. They could also have detrimental environmental effects although these have yet to be determined and much study has to be done in this area. The best sites for OTEC development are often located far from centres of power consumption; thus there may be difficulties and losses in the transmission of energy from the production site.

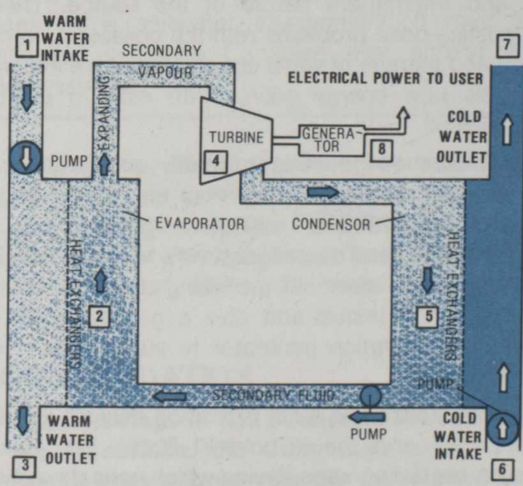
The main problem with developing closed-system OTEC power plants arises out of the necessity of exchanging heat from the seawater to a working fluid. With the relatively small temperature differences being exploited in this process, large surface areas for heat exchange are required and large flows of water are necessary in order to extract utilizable quantities of heat. The cost of the heat exchangers very much increases the capital cost of an OTEC installation (they can repre-

Ocean Thermal Energy Conversion Processes

There are two types of OTEC plants which have been considered for development. In the *open* OTEC process, warm surface water is evaporated and the resultant water vapour drives a turbine to generate power. The steam is then condensed by cold water which is pumped up from the depths and subsequently returned to the ocean. This is called an open system because seawater drives the plant and no working fluid is required. The main problems with this design are the size of the turbine required (some 14 metres in diameter), the removal of dissolved gases from the seawater and the corrosive properties of saltwater.

OTEC installations may perhaps more profitably operate using a *closed* system. In this process, warm water is used to heat a working fluid such as ammonia, propane or fluorocarbons, which evaporates, drives the turbine and is subsequently condensed by cold water (Figure 6-26). Warm water enters the OTEC plant at location 1, is pumped through the heat exchanger at location 2, and leaves the plant at location 3. The heat exchanger-evaporator (2) vapourizes the working fluid. This vapour is expanded in a turbine (4); then it leaves the turbine to enter the condenser (5). From there a pump returns the working fluid to the heat exchanger-evaporator (2). The cold water enters at location 6 and flows through the heat exchanger-condenser (5), leaving the plant at location 7. The turbine operates the electric generator (8), providing electric power to the user.

Figure 6-26: SCHEMATIC DIAGRAM OF A CLOSED-CYCLE OCEAN THERMAL POWER PLANT



Source: Knight *et al*, 1977, p. 3.

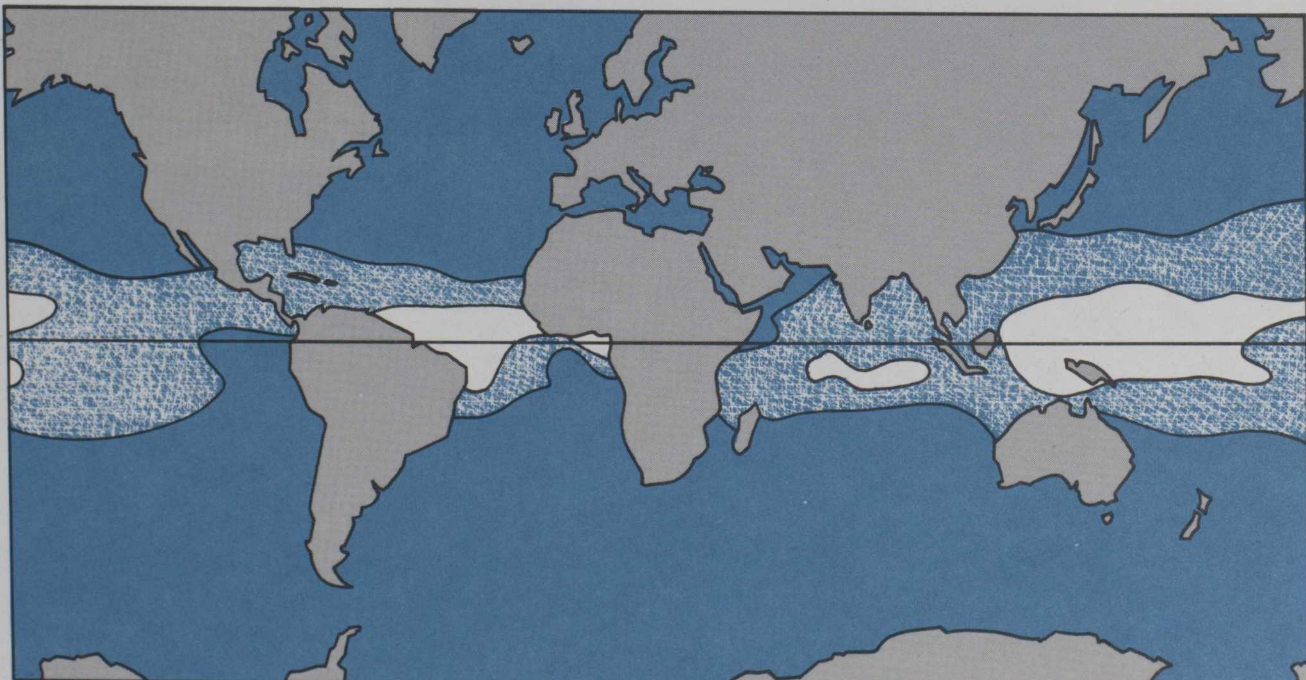
sent up to half the total plant investment) and the exchangers themselves present a continuous problem with corrosion and fouling with marine creatures on their seawater side.

There are also serious legal questions which must be addressed and resolved at the international level over who owns oceanic resources before extensive commercial development of OTEC power takes place.

Because of the great potential of the ocean thermal energy resource, a number of countries are interested in its development. Projects have been considered off the coasts of Curaçao, the Ivory Coast, Florida, Brazil, Zaire, Tahiti and Martinique and nations most actively involved in R & D include France, Japan and the United States Additional interest has been shown by a consortium of European industrial firms known as EUROCEAN and another industrial consortium is conducting a mini-OTEC experiment in cooperation with the State of Hawaii. The United States Government OTEC development program was funded at $38 million during fiscal 1979.

As mentioned earlier, OTEC facilities may only be seriously considered in regions where temperature differences between shallow and deep waters are 18°C or greater. This prerequisite essentially limits the exploitable resource to the tropics as temperature differences of at least this magnitude are required before plants of acceptable efficiency can be constructed (Figure 6-27). Efficiency is not important in terms of energy cost because the warm water required to power a plant is available at no cost. It is important, nevertheless, in determining the capital cost and size of a plant required to produce a given amount of power. With the efficiency being low (a typical OTEC plant may have an operating efficiency of 4% or less), very large amounts of warm and cold water must be circulated to extract energy. Thus the lower the efficiency the greater the size of the plant and the greater the required capital investment.

Figure 6-27: ZONES[a] OF THE EARTH'S OCEANS FAVOURABLE FOR THE EXTRACTION OF ENERGY FROM THERMAL GRADIENTS



Exploitable temperature difference between the surface and a depth of 1000m.

Exploitable temperature difference between the surface and a depth of 500m.

[a] These zones refer to regions where the temperature differential between surface and deep waters (500 or 1,000 m) is always greater than 18°C.

Source: After Brin, 1979, p. 85.

CONCLUSION

Since the scale and cost of an OTEC plant depend upon the temperature differential at a site, OTEC units will not be economic in Canadian waters.

RECOMMENDATION

The Committee believes that research and development of OTEC energy should not be funded by the Federal Government at this time.

Solar Energy

1. THE NATURE OF SOLAR ENERGY

The solar radiation which man seeks to harness originates 93 million miles away in the sun, a sphere of incandescent gases with an effective surface temperature of 6,000 K (over 10,000°F). The centre of the sun is estimated to reach a temperature of some 15 million degrees Kelvin (27 million degrees Fahrenheit).

The sun is a continuously operating fusion reactor converting mass into energy at a calculated rate of about 4.5 million tonnes per second. Scientists have deduced that the principal fusion reaction taking place is one in which two hydrogen nuclei (protons) combine to produce helium. The small loss of mass which accompanies this reaction appears as energy. Virtually all of this energy is generated within the sun's core and then radiated into space.

Radiant energy is emitted from the sun at the prodigious rate of some 4×10^{23} kilowatts (nearly 1.5×10^{27} Btu) per hour but the Earth intercepts only a tiny fraction of this radiation. On the basis of data received by spacecraft at the outer edge of the Earth's atmosphere, the solar radiation crossing a perpendicular surface of one square metre every second is 1,353 watts, or 428 Btu/foot^2/hour. This value is known as the *solar constant*.

Not all of this energy reaches the Earth's surface. About 30 % is directly reflected by the atmosphere back into space while an estimated 47 % is absorbed as heat by the atmosphere, bodies of water and the surface of the land, becoming part of our planet's low-temperature heat budget. Almost all of the remaining solar power drives the hydrologic cycle — the evaporation, precipitation and circulation of water. Roughly speaking, one-half to two-thirds of the radiation incident on the outer edge of the atmosphere ultimately reaches the surface of the Earth, either as direct or diffused radiation. In the Earth's temperate regions, mid-day solar radiation, on a clear day perpendicular to the sun's rays, typically reaches 260 Btu/foot^2/hour (823 watts/metre^2/second). By comparison, a barrel of crude oil contains approximately six million Btu, or the equivalent of 23,000 hours of sunshine on that one square foot.

Expressed in this way, available solar energy does not appear very impressive, yet the total amount of energy involved is immense. To illustrate this point, the amount of sunlight received in one year by 4,300 square miles of land, which is only 0.15% of the surface area of the contiguous United States, is roughly equal to that country's entire 1970 energy consumption.

Solar radiation is diffuse and intermittent both seasonally and diurnally. Substantial areas of collectors are therefore needed to make large-scale use of this resource and costly backup systems and/or storage facilities are required for some applications. Yet in spite of these disadvantages, solar energy has numerous characteristics which make it attractive as a future energy source. As already noted, the total amount of energy available is immense. Solar energy is also inexhaustible, ubiquitous, free and relatively non-polluting in its end use.

A wide variety of technologies have been and are being developed as man attempts to exploit the solar resource to meet his energy needs. For ease of discussion these applications can be divided into three categories: space and water heating, solar-thermal power generation, and direct conversion to electricity (photovoltaics).

2. SOLAR SPACE AND WATER HEATING SYSTEMS

A. PASSIVE SYSTEMS

The benefits of passive solar design are only now being appreciated in this country, but such design offers a great potential for reducing conventional energy consumption in Canadian homes and buildings.

A passive solar space heating system is one in which the structural and architectural elements (walls, floors, windows) of a building are used to collect, store and distribute part of the thermal energy needed to meet the structure's heating requirements. In a purely passive system there are no fans, pumps or other mechanical devices needed to distribute the thermal energy as it moves by natural means (conduction, convection and radiation). Passive solar heating systems can be divided into three main types: direct gain, indirect gain and isolated gain (Figure 6-28).

In addition to the passive solar design features aimed at maximizing solar collection (increased south-facing windows) and storage (additions of thermal mass) noted in Figure 6-28, there is a third integral part to passive solar design which involves energy conservation or the reduction of heat loss. To maximize the contribution of passive solar gain to a building's heat requirements the building must be energy-efficient. Passive solar and energy-efficient design are thus inseparable. A detailed account of potentials and problems associated with these two concepts is presented in the section on Conservation as an Energy Source.

Information and education are essential elements in bringing about increased demand for passive solar and energy-conserving houses and buildings. Many people are not aware that passive solar and energy-conserving designs are already cost-effective in some applications at today's energy prices. The economics of this combined approach to energy saving can only improve as the price of oil continues to rise. The program of public information on energy conservation which the Department of Energy, Mines and Resources has in place has been highly successful and has served as a model for similar programs in other countries. This effort should be expanded making sure that new publications keep up-to-date with developments in the field.

CONCLUSION

Passive solar space heating coupled with energy-efficient design and construction has a great deal of potential to reduce energy demand for space heating in Canada. Information on passive solar design is a natural companion to the conservation message which the Government has been carrying to the public.

RECOMMENDATION

The Federal Government should extend its public education program on conservation to include information on passive solar energy and energy-efficient building practices.

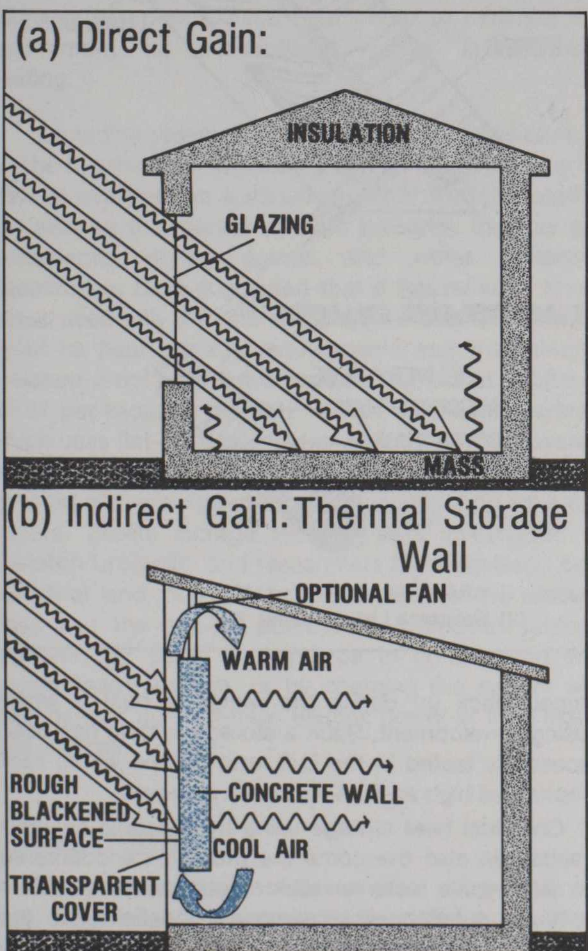
B. ACTIVE SYSTEMS

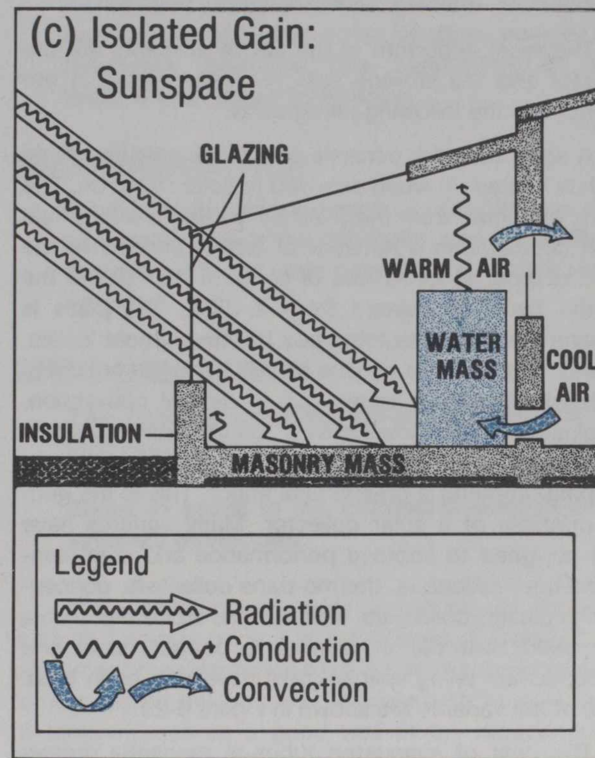
Active solar systems differ from passive systems in that heat is transferred through the system in a regulated way by pumps or fans. In addition, a heat storage device other than the building mass is used. An active solar heating system is therefore composed of the following components: a solar collector whose function is to gather the sun's energy; a circulating loop with pumps and pipes to carry the heat from the collector to the house; a heat storage reservoir of some kind to assure that the heat can be distributed evenly during the day; and a thermostatic control system to distribute the heat when and where required. Depending on the

Passive Solar Heating

Direct gain is the most commonly used form of passive solar system. It utilizes the sunlight entering a building directly through the windows and careful design can maximize the heat gained directly in this way. South-facing windows admit the most solar radiation (in the northern hemisphere), consequently passive solar buildings are designed with the largest window area facing south. An overhanging roof on this side admits sunlight in the winter when the sun is low in the sky, and blocks out unwanted solar radiation in summer when the sun is high. Since the solar radiation is both collected and stored within the living space, adequate thermal mass (heat storage capacity) must be provided in the interior of the building to minimize temperature fluctuations — heat absorbed during the day is available at night to warm the building. The required thermal mass

Figure 6-28: APPROACHES TO PASSIVE SOLAR HEATING





Source: After Anderson and Riordan, 1976, p. 14, 121, 234.

can take such forms as concrete floors or walls, masonry block walls, slate floors, stone fireplaces or double layers of drywall. Any of these features built into a house will act as a storage unit for the solar system and the distinguishing feature of all of these passive solar components is that they are an integral part of the building itself.

In systems employing indirect gain, a heat absorbing material is placed directly behind the windows in the path of the sunlight. Such a thermal storage wall can be made of concrete, stone, brick or containers of water, and vents at the top and bottom of the wall allow the convective circulation of warm air into the room. The wall absorbs heat during the day and radiates warmth at night.

The third method of using passive solar energy for space heating is through isolated gain. In this system a structure is built onto a house to capture solar energy and the captured heat circulates through the living space by convection. The most common example of such a structure is a solar greenhouse, which often uses water drums as the heat storage medium. This method of utilizing passive solar heating is most suitable for retrofit onto existing buildings.

system, other elements (such as heat exchanger, expansion chamber, draining mechanism) may be required.

The most important of the above elements are the collector and the storage system. These elements are described in the following paragraphs.

A solar collector consists of a black-coloured plate which is heated up when exposed to solar radiation. The heat is extracted from the plate by cooling it with a fluid which circulates in a network of tubing bonded to the plate. In order to avoid loss of some of the heat to the air, the plate is isolated from it. First, the plate is contained in a well-insulated box to prevent heat losses. Second, it is covered by one or two transparent covers which will stop heat losses due to natural convection. The glass or plastic cover allows "visible" solar radiation to enter but prevents long-wave radiation (heat) from escaping, creating a greenhouse effect. This is the general principle of a solar collector. Many variants have been designed to improve performance and cost: evacuated-tube collectors, thermo-pane collectors, concentrators, plastic collectors, and so on. Absorber plates have been built out of aluminum, copper, steel and plastic; covers using special glass have also been tried. Three of the variants are shown in Figure 6-29.

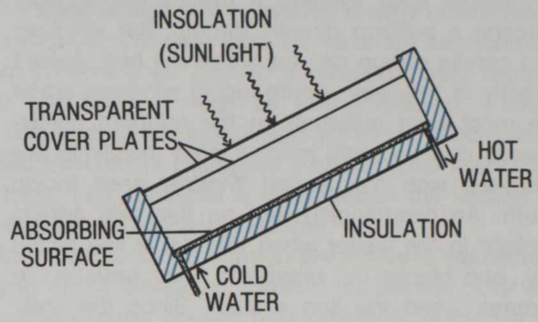
The cost of evacuated tubes is presently greater than that of the more commonly used flat-plate collectors but the excellent insulation afforded by the vacuum preserves their operating efficiency in cold weather and partially offsets their added cost. These collectors seem well suited to Canadian climatic conditions but some problems have been encountered. They lose so little heat that snow can accumulate on them, greatly reducing their efficiency. Concentrating collectors are used in applications where higher temperatures are required.

The other important component of an active solar system is the heat storage element. One of the disadvantages in using active solar heating in northern climates or in cloudy areas is the lack of sufficient sunlight to allow the system to handle the full heating load. Thus, where daily insolation in winter may not be sufficient to meet heating needs or where rain and fog can persist for days on end, a storage system becomes necessary.

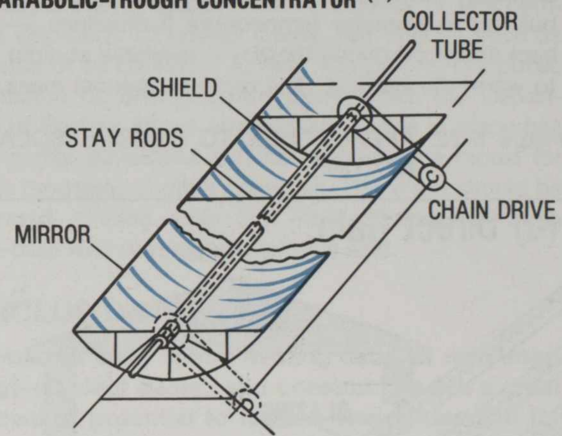
Conventional heat storage systems using insulated containers of water, rocks or other materials are very bulky and gradually lose their heat to their surroundings. In order to reduce the heat losses normally encountered in small heat reservoirs, it has been suggested that huge volumes of heated water be stored underground in a confined aquifer isolated from the surface by a thick, naturally-occurring layer of impermeable clay. The idea is to withdraw many millions of gallons of water from the aquifer during the summer, pass it through solar water heaters and reinject the heated water into the aquifer through a second well. The hot water would then be

Figure 6-29: THE THREE PRINCIPAL TYPES OF SOLAR COLLECTORS

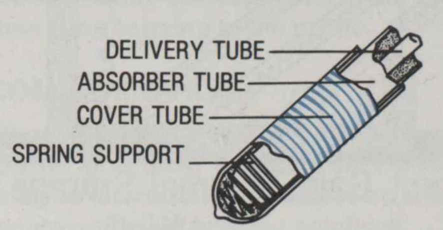
FLAT-PLATE SOLAR COLLECTOR (1)



PARABOLIC-TROUGH CONCENTRATOR (1)



EVACUATED-TUBE COLLECTOR (2)



Source: (1) After Williams, 1977, p. 10, 16.
(2) Solartech Ltd., undated, p. 2.

pumped back up during the winter to heat a whole housing development. Such a storage system has been successfully tested in the U.S. and Europe where heat recapture as high as 75 % has been achieved.

Chemical heat storage using hygroscopic minerals or salts can also overcome the problems encountered with small-scale water or rock storage systems. When dry, these substances store energy indefinitely in the form of a chemical potential and, when moistened, they give up heat in an exothermic or heat-releasing reaction.

Moreover, hygroscopic materials can be used indefinitely without deterioration. When solar radiation is inadequate to meet heating requirements, thermal energy can be released from the chemical storage system. When sunlight is freely available, the chemical storage system can be dehydrated or "recharged".

Systems using hygroscopic compounds for heat storage are under development in Sweden and Canada, and a Swedish experimental system has been in operation since November 1979 meeting all the heating needs of a five-room house with no backup systems whatsoever. The hygroscopic salt used is sodium sulphide (NaS_2). Eight separate storage tanks of the material are situated in the basement and solar heat is derived from 40 square metres of solar panels on the roof. The sodium salt has a very high energy density compared with conventional heat storage media such as water or rocks. Eight tons of the dry salt can store and deliver 8,000 kWh of heat — enough to meet the space and water heating needs of a small, well-insulated house even allowing for the storage of up to half the year's collected energy for winter use. An attractive and novel feature of the Swedish "Tepidus" system is its combination with a ground-source heat pump to minimize the requirement for conventional energy in domestic heating.

Canadian research in chemical storage has centred on the hygroscopic mineral zeolite, a naturally occurring mineral available as a mined product. Artificial zeolites are also on the market and are presently used as gas adsorbents, drying agents and water softeners. Researchers have suggested that a typical solar house would need only 1 to 4.6 cubic metres of zeolite to meet all of its heat storage requirements and that airtight, moisture-proof bins of this material might cost as little as $0.37 per kilogram by 1982. Unlike the Swedish system which uses flat-plate collectors, a zeolite storage system requires a higher operating temperature and must be coupled with evacuated-tube or concentrating solar collectors. Zeolite storage systems were investigated at Carleton University and researchers there envisage both industrial and domestic applications for the system. They see the greater potential in domestic settings, however, by using heat pumps in combination with zeolite-based storage, or by charging the system with heat derived from off-peak electric power or from industrial sources.

CONCLUSION

The Committee believes that chemical and large-scale thermal heat storage systems should have a high priority in solar research and development in this country. Such systems seem to offer a means of overcoming one of the major impediments to the widespread application of active solar heating, namely the mismatch between the availability of and requirement for solar energy.

RECOMMENDATION

Research should be aimed at reducing the cost and establishing the reliability and durability of thermal storage components in active solar systems.

RECOMMENDATION

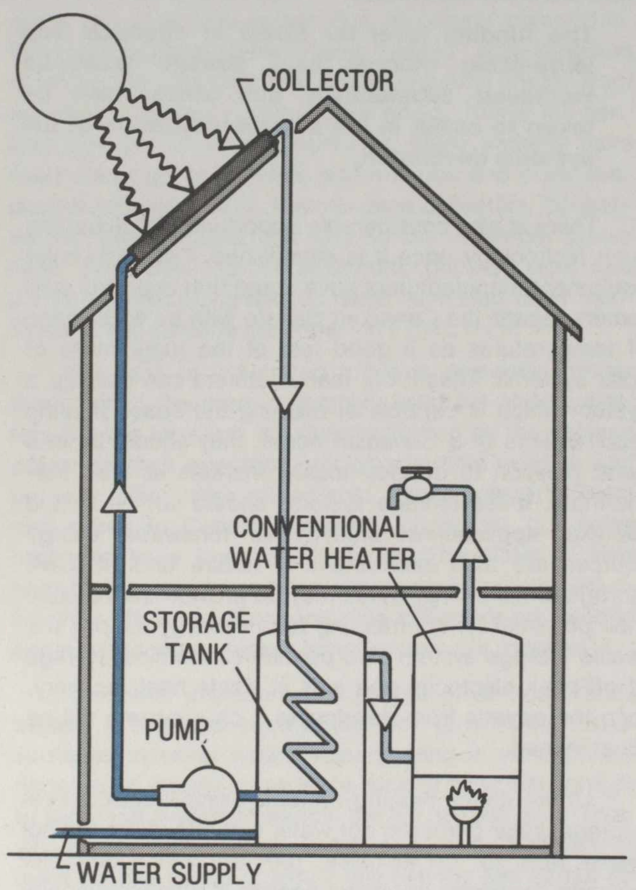
The funding level for RD&D in chemical and large-scale thermal heat storage must be increased substantially and steps must be taken to assist in the commercialization of the systems developed.

There is also considerable opportunity for exporting such technology once it is established. Canadian solar equipment manufacturers have noted that overseas customers regard the Canadian climate with its wide range of temperatures as a good test of the ruggedness of solar systems. Thus if our manufacturers can develop a system which is capable of meeting the space heating requirements of a Canadian home, they should be in a good position to develop export markets as well. Furthermore, these storage systems should not be limited to solar applications. Many other renewable energy sources are also intermittent in nature and effective storage of the energy which they do provide will increase their potential for contributing to our energy supply. If a zeolite storage system also permits economical storage of off-peak electricity and aids in waste heat recovery, then the payoffs from developing such a system will be great indeed.

Unlike space heating systems using chemical heat storage, solar domestic hot water systems utilize the hot water tank (or an auxiliary, pre-heat water tank) for storage. Domestic hot water heating is a solar technology (along with swimming pool heaters) which is already competitive in certain parts of Canada, particularly in the Maritime Provinces where electricity costs are the highest in the country. Figure 6-30 shows a solar domestic water heating system.

Economics represents a major barrier to the widespread use of active space-heating systems. The relatively low cost of conventional fuels and the high front-end costs of active solar systems are holding back the development of a solar market in Canada. Furthermore, the need for building standards to promote passive solar design is paralleled by the need for durability and reliability standards for active systems. However, a careful balance is required in which standards must be developed to instill consumer confidence in solar equipment but not to the extent that those standards stifle improvements in design. The National Research Council is already working with the solar industry on the establishment of standards for solar systems and the Committee believes that this effort should proceed as quickly as possible.

Figure 6-30: A DOMESTIC SOLAR WATER HEATING SYSTEM



A number of witnesses suggested that the solar market in Canada will not develop until financial incentives are offered to consumers, to offset the economic barriers already noted. To date, incentives have been aimed primarily at establishing solar equipment manufacturers so that reliable, tested equipment will be available when the market develops. The best known of these programs are PASEM and PUSH.

PASEM (Program of Assistance to Solar Equipment Manufacturers) was set up to encourage the early establishment of a viable Canadian solar industry through a series of cost-sharing agreements. A national competition was held among solar equipment manufacturers, and ten companies were chosen to participate in shared-cost contracts with the Federal Government to produce solar heating systems and components and to establish production and marketing capabilities. A total investment of $3.9 million has been made, of which the Federal Government's share has been $3.6 million.

The other aspect of fostering the growth of a solar industry is market development and, therefore, the Federal Government set up the PUSH program (Purchase and Use of Solar Heating). In this program the Government itself became the initial market for solar heating equipment and is slated to buy $125 million worth of hardware by 1984. The program experienced difficulties in the federal bureaucracy which led to delays in orders being placed.

Despite the delays, however, projects worth over $10 million had been proposed, designed or were under construction in 1980 and more have been approved for 198l. There are installations in every province, on Post Offices, federal administrative buildings, conference centres, schools, airport buildings, correctional centres and recreational complexes. Also under the auspices of PUSH, the Department of Public Works (which administers both PASEM and PUSH) has chosen nine buildings to be fitted with complete solar systems by firms which were awarded contracts under PASEM. PUSH funds have been approved for up to $100,000 per project.

In another effort to demonstrate the use of solar energy, the installation of solar systems for hot water heating has been approved for 75 federal buildings. All of these systems are to be complete, ready-to-install packages, which are more attractive to the general public than custom-built systems (which are viewed as "experimental" rather than "operational"), and it is hoped that such demonstrations will develop packages suitable and acceptable for widespread domestic use.

These programs appear to be having their desired effect, but the major criticism which has been levelled at the plan is that the Federal Government has been virtually the only customer. With no concurrent market development in the private sector, the companies which have expanded under these initiatives face the prospect of bankruptcy when the program ends in 1984. Clearly incentives to the consumer would help establish a private sector demand, but a certain amount of caution should be used in this regard. In the United States, early incentives led some consumers to buy equipment which was not well-designed or tested. This experience with equipment which came onto the market too quickly through the pull of increased demand has not been good for the solar industry's reputation.

RECOMMENDATION

Consumer incentives for active solar systems should be put in place only when standards have been developed and warranties can be offered.

A second criticism of PUSH and PASEM is that most of the installations have been large. This, of course, arises from the nature of the facilities under federal jurisdiction. It does not seem prudent, however, to expect the solar industry to begin its development with only large, complex commercial systems, as their failure to operate as designed may well be expected given the present stage of development of the industry. Those involved in industrial development should not find this hard to comprehend, but the public perception of such difficulties may work against the introduction of domestic solar systems. A demonstration program featuring domestic solar space heating systems thus should be an essential part of any solar strategy. The National Research Council has such a program already in which a variety of space heating systems are being tested, but the results of testing deserve to be better publicized than in the past. Additional demonstrations should be undertaken by the Federal Government as solar systems evolve and the results of these tests need to be widely publicized. The 1980 National Energy Program announced such a demonstration for solar domestic hot water heating with 1,000 units to be installed in homes across Canada. Of course, some thought will have to be given to the timing of such programs to ensure that both trained individuals and equipment are available when required.

RECOMMENDATION

The Committee welcomes the recent announcement of a large-scale demonstration program for solar domestic hot water heating systems and recommends a similar program for active solar space heating systems. This program should incorporate a range of storage systems including zeolite and sodium sulphide.

Experience gained in the solar water heating demonstration program will obviously be useful in implementing this recommendation.

3. SOLAR-THERMAL POWER SYSTEMS

Solar-thermal power systems first convert solar energy into heat and subsequently change the thermal energy into mechanical energy by means of a turbine. The output from the turbine then generates electricity.

Two technologies currently exist for collecting, concentrating and converting solar energy. They are known as the central receiver system and the distributed collector system. The central receiver system consists of a large field of sun-tracking mirrors (heliostats) which intercept and redirect incoming solar radiation to a single large receiver mounted on top of a tower. This configuration is sometimes referred to as a "power tower". The redirected radiation heats a circulating working fluid in the receiver. A number of working fluids are being examined including high-pressure water, superheated steam, oils, molten salts and liquid metals. The choice of working fluid depends in part on the system's operating temperature. The United States, for example, intends to develop receivers which will operate at about 925°C (1,700°F) by the early 1980s and at 1,100°C (2,000°F) by 1985.

The distributed collector system does not focus the sunlight on a central receiver but instead converts the sunlight to heat at the individual collector module. Each collector module consists of a cylindrical mirror surface which redirects the solar radiation onto the receiver/absorber unit at the focus of the mirror. In this design, the working fluid circulates through the collector where it is first heated, then pumped through a pipe network to a boiler or heat exchanger. From this point on, the central receiver and the distributed collector systems are identical (Figure 6-31).

As in conventional power generation technologies, cooling towers or condensers are used to remove and reject waste heat. A thermal storage unit also forms part of the system to make use of sunlight which is in excess of immediate needs. Various storage media including rocks, oil and salts are being considered. No research and development is being done on solar-thermal power systems in Canada.

CONCLUSION

The Committee believes that Canada should not pursue an RD&D program in solar-thermal power systems since they offer less promise than other solar technologies in this country for both the short and long term.

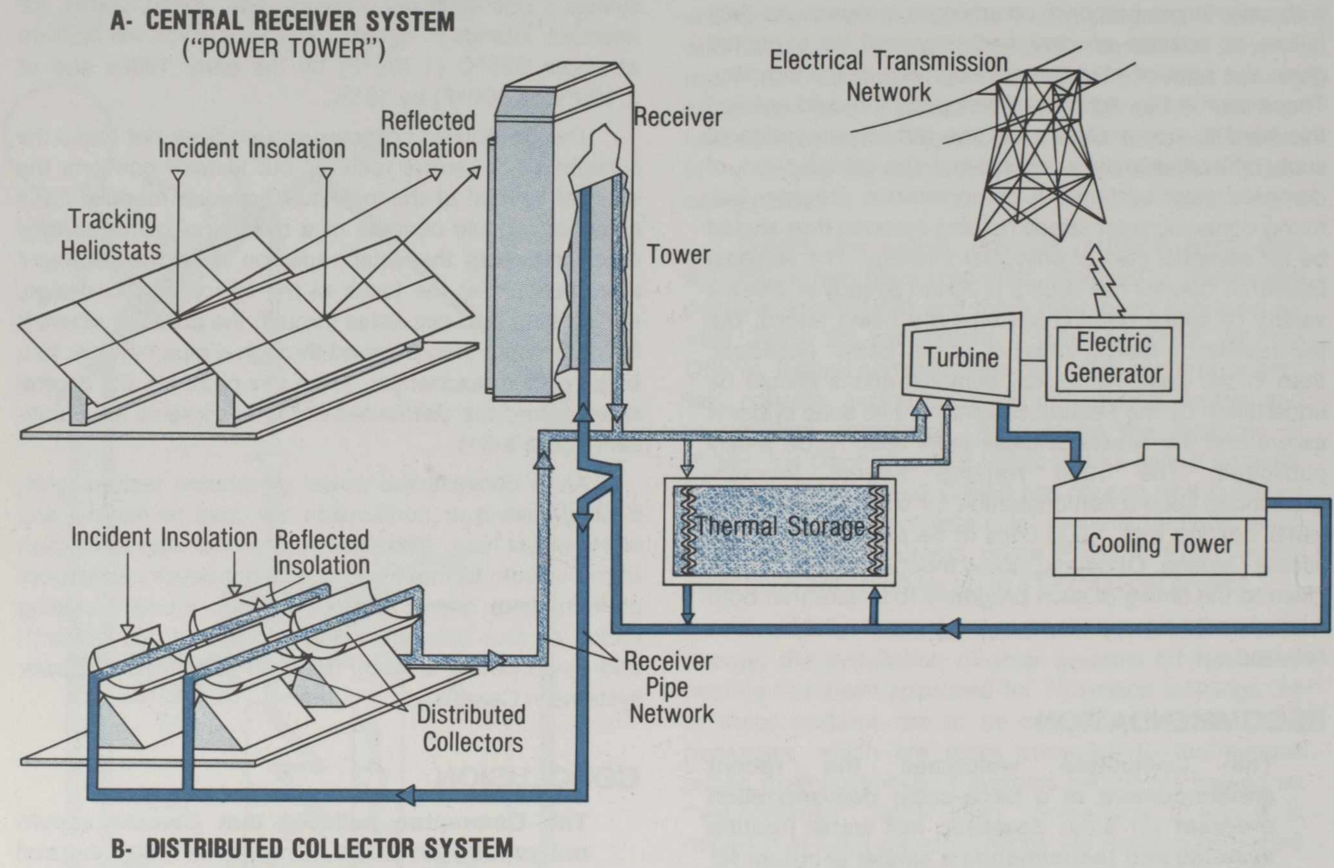
4. PHOTOVOLTAICS

A solar, or photovoltaic, cell produces electricity directly when exposed to the sun's rays. It has no moving parts, consumes no fuel, produces no pollution during operation and can be made out of one of the most abundant elements on Earth — silicon.

The technology for manufacturing solar cells is already well developed. It was established in the early 1960s in the U.S. space program for satellites requiring a source of electrical power which could operate reliably for long periods of time. Nevertheless, while the space program provided the impetus for development of solar cell technology, it also inadvertently created a major barrier to the widespread use of such cells. In the space program the only feature required of this technology was efficiency. Research thus concentrated on delivering the most watts per cell, regardless of the expense involved. High costs have since been a major impediment to this technology penetrating other markets.

but they are also much less costly. It may well prove cheaper to use more of these less expensive solar cells to produce a given amount of electricity than fewer expensive but highly efficient ones. Work is also underway on extending this thin-film concept to less expensive materials such as cadmium, cuprous sulphate, and indium and tin oxide. Other research is being directed at developing more expensive solar cells (such as gallium

Figure 6-31: SOLAR-THERMAL POWER SYSTEM CONFIGURATIONS



Source: After United States, Department of Energy, 1978, p. 5.

arsenide) which have the ability to operate at very high temperatures. Such a cell could be placed at the focal point of a group of concentrating mirrors, like that atop a solar power tower (silicon cells would fuse in this high-temperature environment).

The expense evolves from the need to use extremely pure and perfectly formed silicon crystals. The conventional way to make photovoltaic cells is to pull a single, pure crystal of silicon from a melt, slice it into thin wafers with a diamond saw and "dope" it with impurities in a high-temperature furnace. This process is very energy intensive and expensive; thus much research is concentrating on reducing the cost of photovoltaic cells.

Canada is investigating the use of thin films of inexpensive grades of silicon (such as amorphous silicon) formed at low temperatures. These cells are only about one-half as efficient as pure silicon crystal cells

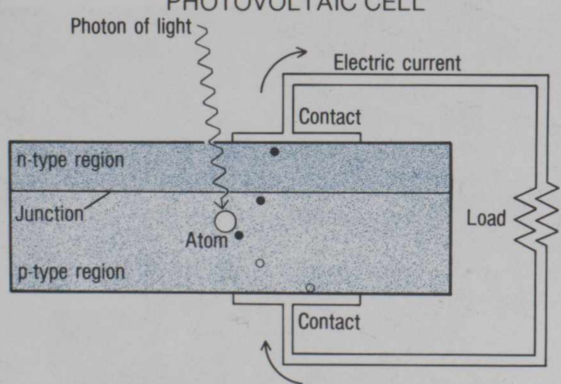
Photovoltaic cells still remain too expensive to compete with conventionally-generated electricity in areas with an electrical grid. In places far from central generating facilities, however, photovoltaic systems can compete with other energy sources. Important areas for early application of photovoltaic systems include marine

The Design and Operation of a Photovoltaic Cell

When sunlight falls on a silicon crystal, it knocks an electron out of its fixed position in the crystal structure. Negatively charged electrons thus freed to move produce a current, but under normal circumstances they quickly fall back into the positively charged "holes" they have vacated.

In order to get useful work from a solar cell, an electrical barrier must be set up which stops the free electrons from simply dropping into the nearest hole. The barrier separates the electrons and holes (negative and positive charges) and drives them in different directions. It is created by adding minute quantities of impurities to the silicon, making it a semiconductor. If phosphorus, for example, is added, an excess of electrons over holes is created and one has an "n-type" semiconductor in which some electrons remain free to move. But, to have an electrical current, a positive charge is also required; thus an element like boron is added to another silicon crystal, creating additional holes or a positively charged "p-type" semiconductor. In a solar cell an n-type and a p-type semiconductor are joined together and their outer faces connected by an electrical wire, as illustrated in below.

Figure 6-32: SCHEMATIC DRAWING OF A PHOTOVOLTAIC CELL



Key: • electrons
o holes

Source: After "The Sun on a Semiconductor", 1978, p. 23.

When a photovoltaic cell is exposed to sunlight, the electrons knocked loose do not fall into holes but instead follow the line of least resistance out of the n-type layer and through the external circuit to re-enter the p-type layer. This flow of electrons constitutes an electrical current and the flow continues as long as sunlight falls on the cell.

and air navigational aids (fixed-site hazard/warning lights, buoys) and environmental monitors and sensors. Thereafter, domestic markets will be developed for telecommunications applications, outdoor lighting and the replacement of small diesel/gas generators in remote areas. The development of a sufficiently large market to make mass production feasible will hopefully reduce the cost of solar cells.

In an evolving electricity/hydrogen economy, electricity generated directly from sunlight may become increasingly important in replacing electricity from other sources. As R&D continues over the next few years the potential for photovoltaic electricity production in Canada will become better established. Certainly for environmental reasons it is a preferred method for the generation of electricity.

If Canadian industry can develop these systems, a substantial Third World export market exists as photovoltaics can be used for running water pumps, for communications facilities and for supplying electricity to small villages. With a view to developing an industry capable of producing low-cost photovoltaic devices, the Federal Government is presently funding RD&D at $600,000 under the NRC's solar program, and at $250,000 for university research through the National Scientific and Engineering Research Council. A further $200,000 is assigned to applicable laboratory work at NRC and $100,000 is earmarked for joint federal/provincial programs. The NRC has proposed a five-year RD&D program, with funding increasing yearly from the present level of just over $1 million, to over $4 million by 1984-85.

CONCLUSION

It is essential that the most promising photovoltaic systems developed during the RD&D program be commercialized as early as possible. Only then will Canada be able to capture part of the export market and develop a viable domestic industry.

RECOMMENDATION

In light of both the domestic and export potential for photovoltaic systems, the Committee recommends that Canada's RD&D efforts in photovoltaics be accelerated beyond the levels currently planned.

5. SOLAR ENERGY: AN APPROPRIATE TECHNOLOGY

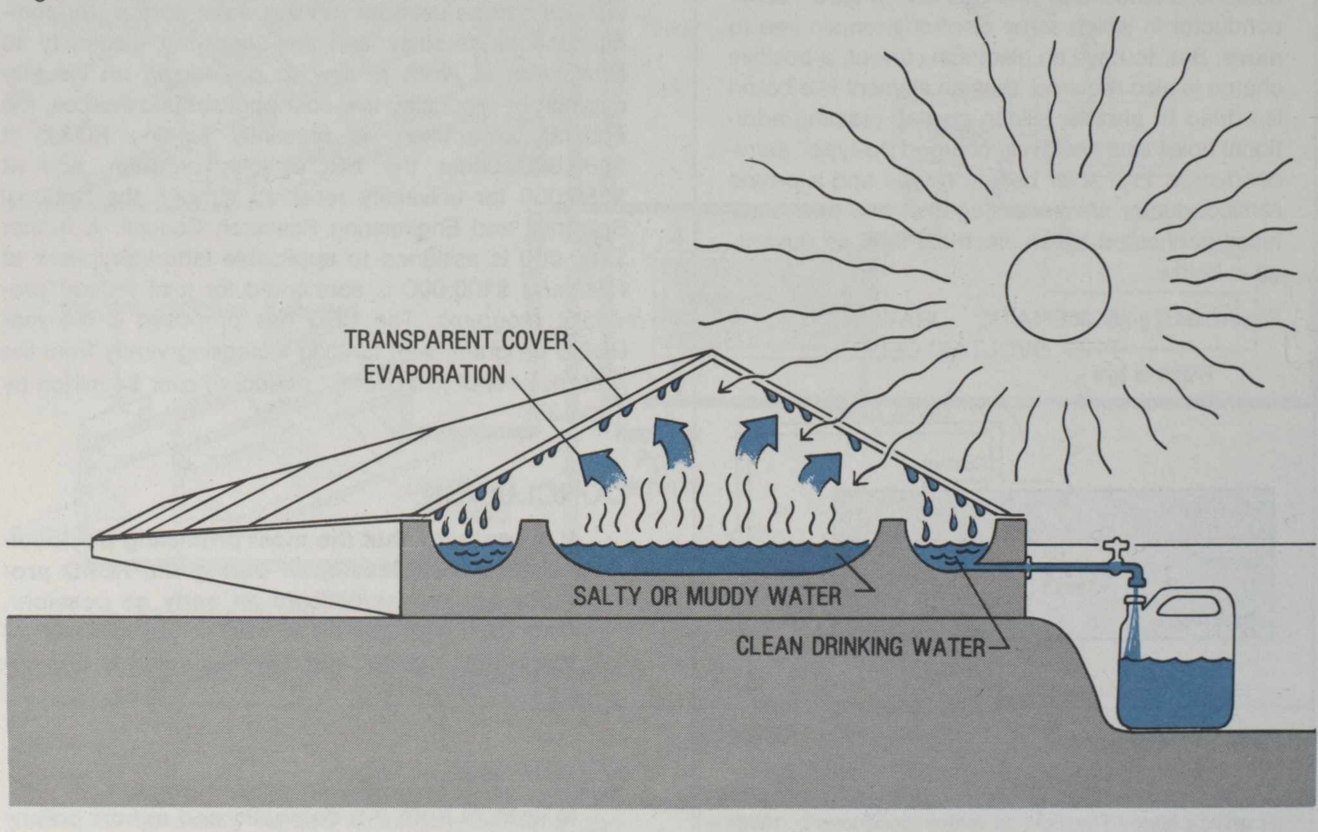
The term "appropriate technology" has come into use in recent years in discussions of technology transfer to Third World countries. Technical devices which are small-scale, comparatively simple to build and maintain, and which can be built and operated by local people using local materials are described as being "appropriate" for use in the Third World.

The Brace Research Institute, an affiliate of McGill University in Montreal, is a world leader in the development and introduction of a number of solar and other alternative energy devices which meet the above criteria. This Committee had the pleasure of visiting the Institute during its Canadian travel.

The Brace Institute has spent many years developing solar stills, solar domestic hot-water systems, solar dryers and solar cookers. Many of their designs are in use throughout the world. Designs are kept as simple as feasible and, to the greatest extent possible, the availability of local materials is taken into account when systems are developed. Solar stills provide a good example of such technology. A solar still (Figure 6-33) consists of a shallow flat-bottomed container with a curved, V-shaped or inclined transparent cover. The sunlight passes through the cover and heats the salt water in the container. The water evaporates, leaving the salt behind. When the water vapour hits the cover it condenses, runs down the inside of the transparent cover and is collected at the edges of the container. In many regions of the world such a system can be used to provide potable water where the local supply is contaminated by high salt concentrations, or by particulate matter. The unit is simple to construct and has no moving parts, so that there is a minimal requirement for maintenance.

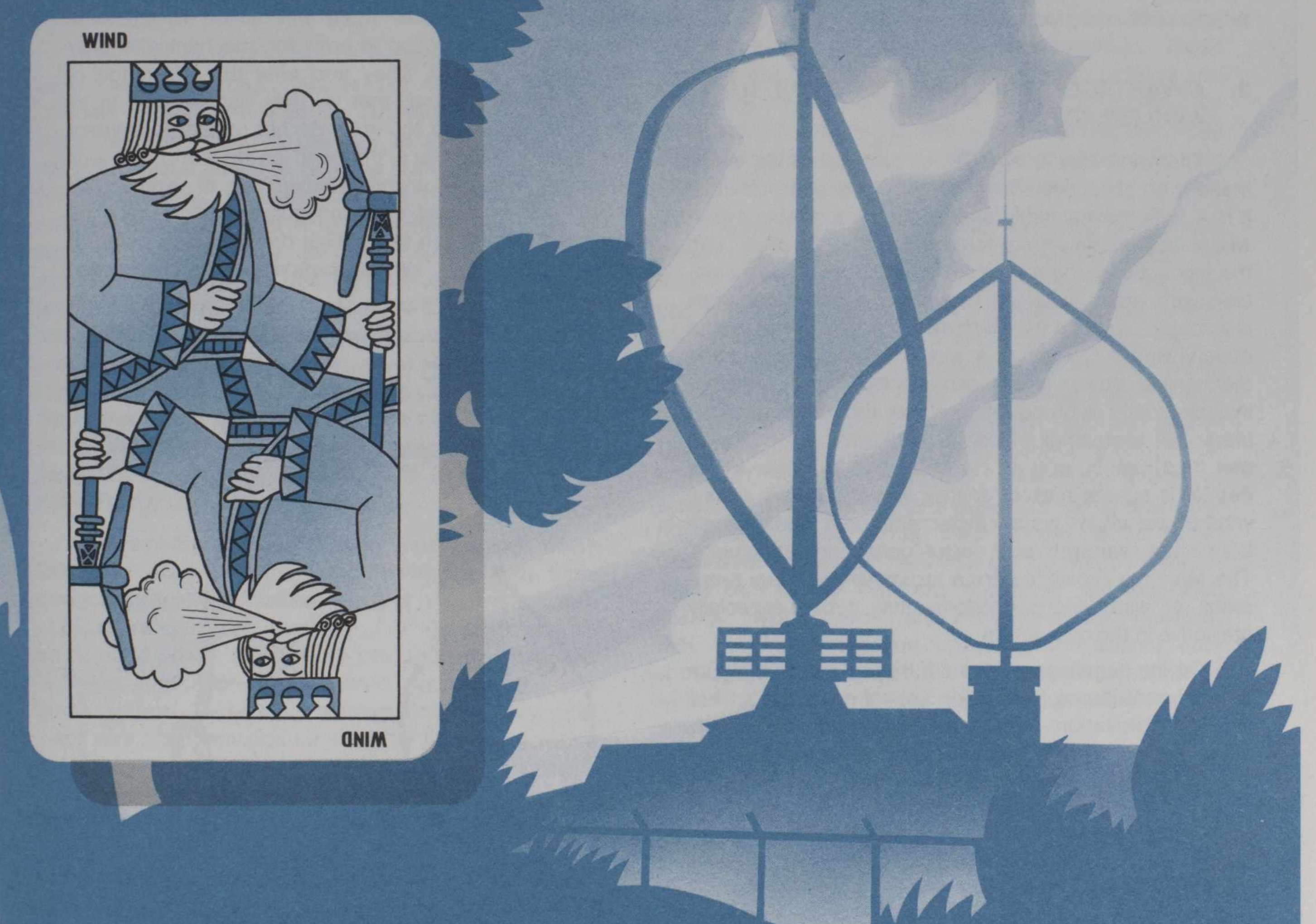
Solar cookers and dryers are available which incorporate the same ideas of simplicity of design and construction with functional utility. In many Third World countries, these simple devices allow rural people to cook their food and dry their crops without purchasing any fuel. To these people this represents a significant saving. In many parts of Africa, for example, wood which is the traditional cooking fuel is becoming increasingly hard to come by. Deforestation is an extremely serious problem so any technology which can replace fuel wood can make a significant contribution to the well-being of people who now rely on this energy supply. Clearly solar energy has a major role to play in such situations and the Committee would like to see the work of the Brace Research Institute and other similar endeavours encouraged to the greatest possible extent.

Figure 6-33: A SIMPLE SOLAR STILL



Source: After Brace Research Institute, 1979.

Wind Energy



1. THE NATURE OF WIND ENERGY

Wind is the energy of motion (kinetic energy) of the Earth's atmosphere. The source of the energy driving atmospheric circulation is the sun, so winds are actually a manifestation of solar energy.

Some of the insolation (incoming solar radiation) received by the Earth's surface is absorbed and then re-emitted to the atmosphere by radiation, conduction and convection. Unequal heating, absorption and re-emission from the surface of the Earth cause differences in the density of the air, setting up variations in atmospheric pressure. These pressure differences originate and maintain the general circulation of the Earth's atmosphere. Although only a small amount of the solar energy incident on the Earth's surface is converted into the kinetic energy of wind, this energy source is vast in comparison to man's needs for mechanical energy.

Extracting Energy from the Wind

The amount of power which a windmill can extract from a volume of moving air is dependent principally upon the area swept by the windmill blades and the velocity of the wind. These factors are not, however, of equal magnitude; the power which can be extracted from the wind increases with the *square* of the blade diameter, but it increases with the *cube* of the wind speed. This latter factor is what makes the application of wind energy technology so site sensitive. For example, a windmill which delivers 1 kW in a 10 km/h wind will deliver 8 kW in a 20 km/h wind. Detailed information concerning wind characteristics is thus essential for proper siting of windmills.

Both wind speed and direction vary considerably with height above the surface. In the lowest few metres, ground cover and topography are dominant in determining these two characteristics but above this level, variations in the wind are the result of horizontal changes in temperature and pressure.

2. ADVANTAGES AND DIFFICULTIES IN USING WIND ENERGY

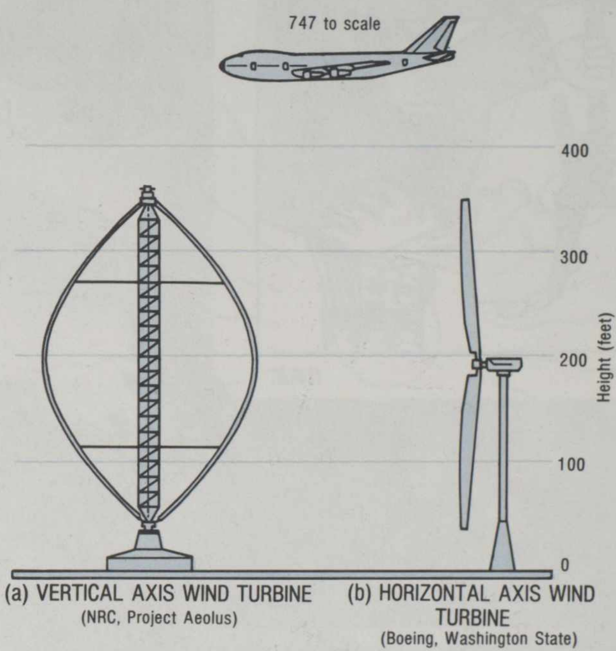
The wind has a number of characteristics which make it an attractive energy source. Like solar radiation it is a free, inexhaustible energy source available everywhere. In Canada we are fortunate in that the areas with the highest average annual wind speed happen to coincide with areas in which conventional energy sources are scarce, such as the Maritimes, Northern Ontario and coastal British Columbia. A windmill delivers high-grade mechanical power which can efficiently be converted into electricity (with no intermediate thermal conversion stage), so even small windmills (5 kilowatts for example) can feed directly into an electrical grid. In areas where capital is scarce and/or energy demand grows slowly, wind power allows supply increments on a smaller scale than is the case with most conventional generating units. The Maritime Provinces are a region where these properties of wind energy systems may prove especially attractive in the near future.

On the negative side the diffuse and variable nature of wind contributes to the high capital costs associated with its exploitation — large, expensive conversion systems are required to capture a significant amount of energy. For example, the 3.8 MW wind turbine to be built by NRC and Hydro Quebec will stand taller than the Peace Tower. The variable nature of wind also means that wind systems cannot provide an uninterrupted energy supply. There are means of overcoming this difficulty by using wind energy in systems where it is not the sole source of electricity or by providing storage facilities, but both add significantly to the cost. Wind turbines can interfere with electromagnetic signals (radar, television and microwave communications), and can generate noise and visual (aesthetic) pollution. These characteristics may pose problems in the future, particularly if one is considering widespread use of this energy source.

3. INTERNATIONAL AND CANADIAN DEVELOPMENT

Research and development of wind energy technology in Canada is directed by the National Research Council. The Canadian program concentrates exclusively on the vertical axis wind turbine (VAWT), while most other countries have invested in the development of horizontal axis wind turbines (HAWT). Figure 6-34 schematically represents these two types of wind turbine. The VAWT is preferred in this country because it is more efficient, extracting more power at a given wind speed than a HAWT. VAWTs have a simpler configuration and operate at a higher speed than other wind turbines, which makes them well suited to electrical generation (as opposed to providing mechanical energy for pumping water). They also offer the advantage of being omnidirectional; that is, they can operate in all wind directions and therefore do not require equipment to move them to face the wind as do horizontal axis turbines. A further practical advantage of vertical axis wind turbines is that their configuration allows most of the machinery which the turbine drives to be located at ground level. This simplifies repair and maintenance procedures.

Figure 6-34: WIND TURBINE CONFIGURATIONS



Source: After Chappell, 1980, 2A:20.

Due to its early entry into the field of VAWTs Canada has a world lead in this technology. Other countries which in the past have concentrated on HAWTs are beginning to realize the advantages of the vertical axis configuration and the United States in particular is putting substantial amounts of money into the development of vertical axis systems.

CONCLUSION

Unless Canada moves quickly into the commercialization and marketing of its vertical axis system, the early advantage which this country holds will be lost.

The current research efforts of the NRC can be usefully discussed under three headings: resource assessment, small to medium size windmills, and large windmills.

The first area of research involves assessing the wind energy resource in Canada. The Atmospheric Environment Service (AES) of the Department of Environment has done much of the work in this area to date, using archival material to derive a standard set of data for the purpose of identifying areas which deserve detailed evaluation. The NRC has established a set of technical specifications for wind speed monitoring equipment to promote the development of standard testing procedures. In addition, the NRC is working with provincial utilities on detailed evaluations of a number of promising sites across Canada which were identified in the AES study. Canada is also taking part in an international evaluation of computer models for wind energy siting under the auspices of the International Energy Agency's Program of Research and Development on Wind Energy Conversion Systems.

The small and medium sized wind turbines which NRC has examined are being developed with three distinct applications in mind. The first is special purpose applications in which turbines of 1 kW (DC) provide on-demand power at a remote site. Storage is required in these applications as the wind system is the sole power source. These units are expensive as they must meet very rigid demands for reliability and the provision of storage capacity adds to the total cost. Such systems are designed primarily to power remote communications networks and navigational aids, where high costs can be justified. Six installations of this type are now being made across Canada. Five of them — in Alberta, Saskatchewan, Ontario, New Brunswick and Newfoundland — will supply energy for telecommunications networks. The sixth installation will provide cathodic protection for an oil pipeline in Alberta.

The second area of application is in small- and medium- sized wind energy systems which can be used for electrical generation in remote communities. Many settlements in Canada depend entirely on diesel generation for their electricity. The NRC has been working on a wind/diesel hybrid system with the Ontario government and a 10 kW(AC) VAWT has been coupled with a diesel generator at an experimental test site on Toronto Island. Two years of operation have demonstrated that significant savings in diesel fuel can be achieved on a site with an average wind speed in excess of 13 mph (21 km/h) and at a diesel fuel cost greater than $1.00/gallon. Many northern communities satisfy both of these conditions and the NRC, the Ontario Ministry of Energy and Ontario Hydro are arranging to finance the installation of a 50 kW VAWT wind/diesel hybrid system in Sudbury, Ontario.

Medium-sized turbines (around 50 kW in output) are also being tested while linked into electrical grids. Four 50 kW units with no storage are already installed and coupled to major grids, one each in British Columbia, Saskatchewan, Manitoba and Newfoundland. These systems are the forerunners of larger wind turbines and are being monitored to determine what problems may arise from feeding the variable wind-generated electricity into an electrical grid which has traditionally relied on steady energy inputs from large facilities.

Concerning large windmills, the NRC and Hydro Quebec in a joint project have constructed a 230 kW VAWT on the Magdalen Islands. The machine was first erected in 1977 and early tests showed that this version of the VAWT performed as expected. Unfortunately, a procedural error in the operation of the machine led to its destruction in July 1978. An identical machine was erected on the same site in January 1980 and subsequent testing has shown this wind turbine to perform as expected, reaching full power operation ahead of schedule. The original plans called for the operation of the facility to be turned over completely to Hydro Quebec at the end of 1980 with the installation generating a part of the electricity supply for the Magdalen Islands. Hydro Quebec and the NRC agreed, however, that the instrumentation collecting operational data should remain in place so that experiments can continue while the wind turbine is contributing power to the Islands' grid.

Following the success of the Magdalen Islands experiments, scientists at the NRC proposed the construction of a megawatt-size VAWT, seeing this as the next logical step in the wind energy program. Running a vertical axis wind machine of this size would give Canada unique operating experience and consolidate its position as a world leader in vertical axis wind turbine research and development. "Project Aeolus" involves the design and construction of a VAWT which can generate up to 3.8 megawatts of electricity (enough electricity to supply the non-heating requirements of 600-700 homes) and which is expected to cost $23 million to complete. It is believed that such a system could operate at sites with average wind speeds of approximately 30 mph (48 km/h) and deliver energy which is cost competitive with conventional electricity. Hydro Quebec has agreed to participate in this program on a cost-shared basis with the Federal Government and the wind turbine will be erected at a suitable site in eastern Quebec with operation expected in 1983.

The market for wind turbines in Canada may not prove to be large, given other options available to us for the production of electricity. However, in certain regions of the country such large-scale wind conversion systems could be very important in replacing fossil fuels currently used for electrical generation. In addition to the domestic market, a large export market seems likely to develop in both industrialized and Third World countries.

CONCLUSION

The Committee agrees that Canada should pursue the development and commercialization of megawatt-scale vertical axis wind turbines and welcomes the recent announcement that "Project Aeolus" has been approved for funding.

In its visit to the Yukon and the Northwest Territories, the Committee was struck by the vulnerability of northern communities depending solely upon diesel generation for their electricity. We thus recognize the uncertainty which many Canadians feel about the supply and price of petroleum products in isolated regions of the country.

CONCLUSION

The Federal Government should quickly institute measures to assist remote communities in diversifying their energy supplies. In this connection, wind energy and small-scale hydro are two options meriting close consideration. Such a program would complement the energy conservation efforts of northern communities and the off-oil philosophy as outlined in the National Energy Program. In the case of wind energy, an assistance program would aid in establishing a wind turbine manufacturing capability in Canada by providing an immediate market.

RECOMMENDATION

Funding and technical assistance for installing wind/diesel hybrid systems should be provided to remote communities, with appropriate wind characteristics, now relying on diesel fuel for electrical generation. This assistance would not only help such communities reduce their need for petroleum but would also create an immediate market for wind turbines and hasten the commercialization of this technology.

7 RECOMMENDATIONS

Recommendations

The following recommendations are listed in the order in which they appear in the text, not in order of importance.

The page on which each recommendation appears in the Report is listed so that the reader can easily determine the context in which it is made.

RD&D (1) **In its own best interest and in the interest of furthering the objectives of the IEA, Canada should accelerate the rate of increase in its alternative energy RD&D expenditures.**
(p. 68)

Ministry of State (2) **The Committee recommends that a Ministry of State for Alternative Energy and Conservation be created under the Ministry of Energy, Mines and Resources. We further recommend that this new Ministry be divided into four sections responsible for Conservation, Solar Energy, Methanol, and Other Alternatives.**
(p. 79)

Canertech (3) **The Committee recommends that the new alternative energy corporation, Canertech, report to the proposed Minister of State for Alternative Energy and Conservation at the time that it becomes an independent Crown corporation.**
(p. 79)

Energy Economics (4) **The Committee recommends that the Department of Energy, Mines and Resources initiate a comprehensive study of energy and the economy to clarify this important relationship in the Canadian context and to provide guidance in formulating energy policy and more general economic policy.**
(p. 83)

Conservation (5) **The Committee recommends that a detailed study into all aspects of energy conservation, in all sectors of the economy, be undertaken immediately.**
(p. 118)

Conservation — Passive Solar (6) **All levels of government should cooperate in ensuring that architects, builders and contractors learn and practice energy-efficient design and construction. In particular, these people should be made aware of the energy-saving benefits which result from the passive use of solar energy.**
(p. 119)

(7) **The Committee urges that Federally-financed housing incorporate energy-conserving and passive solar design in order to demonstrate its benefits.**
(p. 120)

Conservation (8) **Energy performance standards for buildings should be incorporated in the National Building Code so that conservation and innovative design and construction are promoted.**
(p. 121)

Conservation

(9) Standard tests for the energy performance of buildings should be established by the Federal Government so that energy-efficiency ratings can be assigned. (p. 121)

(10) The Committee recommends that the Federal Government establish a standard procedure for testing the airtightness of buildings.The Committee further recommends that, once established, the test be applied to Federal buildings and to all new homes financed through the Canada Mortgage and Housing Corporation. (p. 121)

(11) Lighting regimes in businesses and homes should be designed to ensure that electric energy is not wasted. (p. 121)

(12) Underground construction should be encouraged in appropriate circumstances as an energy-conserving building technology. (p. 122)

Ethanol

(13) The Committee recommends that the Federal Government, through Canertech, encourage the research, development and commercialization of cellulose-to-ethanol technology. (p. 127)

(14) Ethanol should be used as a gasoline extender only and not as a substitute transportation fuel in pure form, except perhaps on farms. (p. 127)

(15) The Committee recommends that the Government ensure, in its amendments to the Excise Act, that production of ethanol in excess of individual requirements may be sold to retail suppliers of alcohol fuel or gasohol. (p. 128)

(16) The Committee does not endorse pure ethanol from starch or sugar feedstocks as a major alternative liquid transportation fuel for Canada. It does, however, recommend that fuel ethanol be permitted for personal use or for the production of gasohol. (p. 128)

Methanol

(17) The Committee recommends that the construction of a hybrid natural gas/biomass methanol plant be encouraged to demonstrate this technology of methanol production as soon as possible. (p. 129)

(18) Since hybrid natural gas/biomass methanol plants are a transitional step in establishing a fuel methanol industry, the Committee further recommends that such plants be converted when feasible to operation using biomass alone or biomass spiked with electrolytic hydrogen. (p. 129)

(19) In the short term, Canada should allow fuel methanol to be sold at prices lower than gasoline in order to make it attractive as an alternative transportation fuel. (p. 130)

Biogas

(20) The Committee recommends that the technology of anaerobic digestion should be actively pursued in Canada and that additional biogas reactors should be installed to demonstrate their effectiveness in the Canadian environment. (p. 131)

Biomass Densification	**(21)**	**As the technology for biomass densification is available now and is being used in some locations, the Committee recommends that development of the wood densification industry should be encouraged in Canada. This means that increased emphasis in R&D should be placed on improving combustion technologies for densified biomass fuels and on developing end uses and markets for the densified biomass product.** **(p. 134)**
Wood	**(22)**	**The Committee recommends that a study of how the increasing combustion of wood in urban areas will affect air quality should begin immediately. Such a study should be completed before expanded use of firewood is recommended for urban centres.** **(p. 135)**
	(23)	**Fire safety regulations should be reviewed and strengthened so that the installation and use of wood stoves and fireplaces does not lead to a tragic increase in the incidence of fires in homes using fuel wood.** **(p. 135)**
Wood— Methanol	**(24)**	**The Committee believes that the technology of biomass gasification should be funded on a priority basis in biomass R&D. It has the potential of allowing greater use of wood (and other biomass feedstocks) to fire systems which traditionally have used fossil fuels. It is perhaps the last part of the technology of methanol synthesis from biomass which must be improved upon to assure commercialization of this alcohol fuel option.** **(p. 135)**
Peat	**(25)**	**Canada's extensive peat deposits represent a significant alternative energy opportunity, but our resource base has been only partially outlined. An accurate assessment of its quantity, quality and location should be completed.** **(p. 138)**
	(26)	**The Committee recommends that peat R&D encompass the development of an efficient technology for the gasification of peat. This would allow Canada to broaden its resource base for the production of the alternative liquid transportation fuel methanol.** **(p. 138)**
Fluidized Bed Combustion	**(27)**	**The Federal Government should undertake a thorough analysis of the opportunities and benefits of fluidized bed combustion in the Canadian context, and of the funding levels necessary to exploit the technology to maximum advantage. Topics which should be addressed in the analysis include the choice between various FBC technologies from economic and environmental standpoints, the use of fuels other than coal, and the nature of regional opportunities.** **(p. 142)**
Coal-Oil Mixtures	**(28)**	**Canadian RD&D in coal-oil mixture technology should be accelerated where feasible. A heavy emphasis should be placed on the rapid deployment of this technology in the Maritime Provinces.** **(p. 142)**

Coal Liquefaction	(29)	**Coal liquefaction should not be adopted as a long-term energy option for Canada. In the shorter term, however, a limited number of coal liquefaction projects aimed primarily at export markets could be accepted — with stringent environmental safeguards — to earn foreign exchange, to generate skilled employment and technological expertise, and to provide a supplementary source of synthetic fuel for domestic use in an emergency.** (p. 146)
District Heating	(30)	**The Committee recommends that district heating should be considered as an energy-conserving technology for new subdivisions, communities and industrial parks.** (p. 150)
Co-generation	(31)	**The Committee encourages Canadian utilities to look more favourably upon co-generation and to devise means for promoting the broader use of this technology, possibly through joint ownership of such systems with industrial partners.** (p. 154)
Small-Scale Hydro	(32)	**The Committee recommends that financial assistance be extended to isolated communities which rely upon diesel-generated electricity to enable them to install small hydro units where an appropriate site exists. The Committee further recommends that this technology be vigorously promoted for its export potential.** (p. 156)
Fuel Cells—Hydrogen	(33)	**The Committee recommends that research on fuel cells be funded as part of a commitment to developing a hydrogen economy for Canada. In particular, the development of fuel cells for the transportation sector should be given high priority as their use promises to substitute for transportation fuels, to reduce vehicle exhaust emissions and to develop a market for hydrogen.** (p. 159)
Fusion	(34)	**The Committee recommends that the program of expenditures proposed by the NRC Advisory Committee on Fusion-Related Research be adopted by the Federal Government. For the five-year period from fiscal year 1980-81 to 1984-85, this represents an expenditure of approximately $54 million (in constant 1979 dollars). An independent review should be carried out in the third year of the program and after five years to determine its effectiveness.** (p. 169)
Geothermal Energy	(35)	**The Committee recommends that Federal expenditures on geothermal energy be sufficiently large to accomplish at least the following: to define the size of the geothermal resource in Canada; to promote development of this energy form, especially for space heating; and to determine the feasibility of extracting thermal energy from hot, dry rocks.** (p. 177)
Heat Pumps	(36)	**The Committee recommends that heat pump use in suitable community recreation complexes be encouraged and that all three levels of government investigate the potential for financial assistance in this regard.** (p. 181)
	(37)	**Governmental and industrial R&D in Canada should continue to refine heat pump technology. Emphasis should be placed upon penetrating commercial, residential and industrial markets and upon seeking the most effective marrying of heat pumps with other energy technologies.** (p. 182)

Hydrogen	(38)	**The Committee recommends that an energy system based upon hydrogen and electricity as the principal energy currencies be adopted by the Government of Canada as a long-term policy objective.** **(p. 188)**
	(39)	**The Committee believes that hydrogen will be an important element of Canada's future energy system and recommends that we begin now to develop the technology and infrastructure for hydrogen production, distribution and use.** **(p. 188)**
	(40)	**The Committee agrees that the early demonstration of a hydrogen-based urban transportation system is required in Canada and recommends that research into this use of hydrogen be supported with the aim of rapid commercialization.** **(p. 188)**
	(41)	**The Committee recommends that the Federal Government be prepared to spend up to $1 billion over the next five years to foster the broad development of a hydrogen-based energy system and to establish Canada as a world leader in hydrogen technology.** **(p. 189)**
	(42)	**The Committee recommends that a Commission, to be known as Hydrogen Canada, be established to act as the lead agency for hydrogen RD&D and commercialization in Canada. This Commission should report to the proposed Minister of State for Alternative Energy and Conservation.** **(p. 189)**
	(43)	**The Committee recommends that the proposed Minister of State for Alternative Energy and Conservation begin a review of the progress and accomplishments of Hydrogen Canada after eighteen months, with the review to be completed within six months. A further review should be conducted after the fourth year of the program, with subsequent reviews to follow at five-year intervals.** **(p. 190)**
	(44)	**The Committee recommends that the results of the periodic reviews of Hydrogen Canada's progress be tabled in Parliament within three months of their completion and, in the event that Parliament is not sitting at the time, the Minister be permitted to make them public.** **(p. 190)**
Propane	(45)	**Propane use should be encouraged in the short and medium terms for vehicle fleets refueled at central locations.** **(p. 192)**
Compressed Natural Gas	(46)	**The Committee recommends that compressed natural gas be encouraged for use as a fuel in large fleets of vehicles which travel limited distances and are fueled at central filling stations.** **(p. 193)**
Synthetic Gasoline	(47)	**Because synthetic gasoline does not reduce hydrocarbon usage and because its production is nonconserving in nature, the Committee recommends that the production of synthetic gasoline from fossil fuel resources should not be viewed as an alternative energy solution of major importance for the transportation sector.** **(p. 194)**

Methanol	(48)	**To develop a truly alternative vehicle fuel option for consumers, the Committee recommends that the Government of Canada urge automobile manufacturers to produce methanol and dual-fuel engines in Canada. Through this action and the development of a methanol-fuel-producing industry, Canada could become a world leader in methanol production and utilization.** (p. 195)
Ethanol	(49)	**The Committee recommends that ethanol produced in this country should be used for extending supplies of gasoline through the production of gasohol. We do not recommend the use of ethanol-powered cars as a major alternative transportation option.** (p. 196)
Air-Aluminium Battery	(50)	**The Committee recommends that the Federal Government closely monitor the development of the aluminum-air battery system and that it support commercialization of this power system in Canada.** (p. 196)
Electric Vehicle	(51)	**The Committee recommends that Canada become much more actively involved in electric vehicle research, development and demonstration. This effort should be a systems approach which concentrates not only on propulsion but also on the design and construction of all the components required to produce a completely Canadian electric vehicle.** (p. 198)
	(52)	**The Committee believes that RD&D in this country should concentrate on all-electric vehicles rather than on heat engine/electric hybrids. If hybrid propulsion RD&D is pursued at all, it should be directed towards developing a fuel cell/electric hybrid. This would allow Canada to do research in two areas of nonconventional propulsion simultaneously, so that at some future date each technology could be profitably exploited on its own.** (p. 198)
Hydrogen	(53)	**Canada should pursue the use of hydrogen as an alternative aviation fuel and this activity should form part of the overall RD&D efforts of Hydrogen Canada.** (p. 200)
Tidal Power	(54)	**To determine whether a tidal power development in the Bay of Fundy remains a viable proposition, the Committee recommends that an economic feasibility study be initiated without delay to verify the 1977 conclusions of the Tidal Power Review Board, and that funding in the order of $300,000 be allocated for this purpose.** (p. 206)
	(55)	**If the findings of the economic feasibility study are favourable, the Committee further recommends that a three-year pre-investment design engineering, socio-economic and environmental study, as outlined in the 1977 Report, be undertaken and that funding in the order of $50 million be allocated for this purpose.** (p. 206)
	(56)	**If the findings of the definitive study are favourable, the Committee recommends that tidal power development be undertaken in the Bay of Fundy.** (p. 207)

Ocean Energy	(57)	**The Committee believes that Canada should keep up to date with international developments in the field of wave power research and should continue to participate in joint R&D ventures. It also recommends, however, that wave power research should have no priority status in Canadian energy research and development programs.** (p. 207)
	(58)	**The Committee believes that research and development of OTEC energy should not be funded by the Federal Government at this time.** (p. 210)
Passive Solar—Conservation	(59)	**The Federal Government should extend its public education program on conservation to include information on passive solar energy and energy-efficient building practices.** (p. 212)
Active Solar	(60)	**Research should be aimed at reducing the cost and establishing the reliability and durability of thermal storage components in active solar systems.** (p. 215)
	(61)	**The funding level for RD&D in chemical and large-scale thermal heat storage must be increased substantially and steps must be taken to assist in the commercialization of the systems developed.** (p. 215)
	(62)	**Consumer incentives for active solar systems should be put in place only when standards have been developed and warranties can be offered.** (p. 217)
	(63)	**The Committee welcomes the recent announcement of a large-scale demonstration program for solar domestic hot water heating systems and recommends a similar program for active solar space heating systems. This program should incorporate a range of storage systems including zeolite and sodium sulphide.** (p. 217)
Photovoltaics	(64)	**In light of both the domestic and export potential for photovoltaic systems, the Committee recommends that Canada's RD&D efforts in photovoltaics be accelerated beyond the levels currently planned.** (p. 219)
Wind Energy	(65)	**Funding and technical assistance for installing wind/diesel hybrid systems should be provided to remote communities, with appropriate wind characteristics, now relying on diesel fuel for electrical generation. This assistance would not only help such communities reduce their need for petroleum but would also create an immediate market for wind turbines and hasten the commercialization of this technology.** (p. 224)

Selected Bibliography

Acres Shawinigan Ltd., *District Heating Study*, Report to the Ontario Ministry of Energy, Toronto, February 1976.

Acres Shawinigan Ltd., *District Heating for Small Communities*, Research Report No. 9, Office of Energy Conservation, Department of Energy Mines and Resources, Ottawa, January 1977a.

Acres Shawinigan Ltd., *Gas Turbines and District Heating*, Research Report No. 10, Office of Energy Conservation, Department of Energy, Mines and Resources, Ottawa, February 1977b.

Akarca, Ali T. and Thomas Veach Long II, "On the Relationship Between Energy and GNP: A Re-examination", *Journal of Energy and Development*, Vol. V, No. 2, Spring 1980, p. 326-331.

Alberta, Energy Resources Conservation Board, *Conservation in Alberta 1978*, Calgary, April 1979.

Alberta Gas Trunk Line, *Annual Report, 1979.*

Altshuller, A.P. and G.A. McBean (Chairmen), *The LRTAP Problem In North America: A Preliminary Overview*, Report prepared by the United States-Canada Research Consultation Group on the Long-Range Transport of Air Pollutants, October 1979.

Anderson, B. and M. Riordan, *The Solar Home Book*, Cheshire Books, Harrisville, New Hampshire, 1976.

An Overview of the Magnetic Fusion Energy Development and Technology Program, Grumman Aerospace Corporation and Office of Magnetic Fusion Energy, U.S. Department of Energy, March 1978.

Auldridge, Larry, "World Oil Flow Slumps, Reserves Up", *Oil & Gas Journal*, Vol. 78, No. 52, 29 December 1980, p. 75-82.

Australia, Senate Standing Committee on National Resources, *The Replacement of Petroleum Based Fuels by Alternative Sources of Energy*, Australian Government Publishing Service, Canberra, 1980.

Aylesworth, J.A. and H.J. Weyland, "Coal and Coke", *Canadian Minerals Yearbook 1978* (preprint), Department of Energy, Mines and Resources, Ottawa, 1980.

Bachynski, M.P. and R.A. Bolton, *Tokamak de Varennes - Industrial Impact*, Institut de recherche d'Hydro-Québec, Institut national de la recherche scientifique, Université de Montréal, Canatom and MPB Technologies, October 1980.

Bank of Nova Scotia, "Canadian Business Conditions - A Chart Survey", *Scotiabank Monthly Review*, Toronto, December 1980.

Beale, Barry, *Energy and Industry*, James Lorimer and Co., Toronto, 1980.

Berkowitz, M.K., "Incentive Schemes for Encouraging Solar Heating Applications in Canada", in Peter N. Nemetz (ed.), *Energy Policy: The Global Challenge*, Institute for Research on Public Policy, Butterworth Co., Toronto, 1979.

Berndt, Ernst R., "Canadian Energy Demand and Economic Growth", in Campbell Watkins *et al* (eds.), *Oil in the Seventies*, The Fraser Institute, Vancouver, 1977.

Berndt, Ernst R. and Catherine Morrison, "Energy, Capital and Productivity", in Joy Dunkerley (ed.), *International Energy Strategies*, Proceedings of the 1979 IAEE/RFF Conference, Oelgeschlager, Gunn & Hain, Publishers, Cambridge, Mass., 1980, p. 79-99.

Bielenstein, H.V., L.P. Chrismas, B.A. Latour and T.E. Tibbetts, *Coal Resources and Reserves of Canada*, Report ER 79-9, Department of Energy, Mines and Resources, Ottawa, December 1979.

Bockris, J.O'M., *Energy Options: Real Economics and the Solar-Hydrogen System*, John Wiley " Sons, Toronto, 1980.

Bolton, R.A. and B.C. Gregory, *Tokamak de Varennes National Facility, Executive Summary and Final Report*, Institut de recherche d'Hydro-Québec, Institut national de la recherche scientifique, Université de Montréal, Canatom and MPB Technologies, October 1980.

Booz, Allen and Hamilton, Applied Research Division, *Introduction to the Analysis of Commercialization Conditions*, ERDA-76-99, United States Energy Research and Development Administration, 1976.

Brace Research Institute, *Annual Report*, Report Number M-39, Macdonald College of McGill University, 1978-1979, 1979.

Brin, A., *Océan et Énergie*, Editions Technip, Paris, 1979.

British Columbia, British Columbia Hydro and Power Authority, *Tidal Power in British Columbia*, June 1979.

Brooks, David B., *Economic Impact of Low Energy Growth in Canada: An Initial Analysis*, Discussion Paper No. 26, Economic Council of Canada, Ottawa, December 1978.

Brooks, David B., *Zero Energy Growth for Canada*, McClelland and Stewart, Toronto, 1981.

Brown, T.D., *Coal Gasification and Liquefaction*, CANMET Report ERP/ERL 80-10 (OP), Department of Energy, Mines and Resources, Ottawa, February 1980.

Budiansky, Stephen, "Bioenergy: The Lesson of Wood Burning?", *Environmental Science & Technology*, Vol. 14, No. 7, July 1980, p. 769-771.

Cain, B., H.M. Saiyed and R.S. Preston, *Canadian Crude Petroleum Self Sufficiency in Alternative Domestic and International Pricing Environments*, Technical Background Documentation to the Special Committee on Alternative Energy and Oil Substitution (unpublished), Economic Council of Canada, Ottawa, November 1980.

Cain, B. and H.M. Saiyed, *An Exploration of Crude Petroleum Self-Sufficiency in Alternative Canadian Demand Environments*, Technical Background Documentation to the Special Committee on Alternative Energy and Oil Substitution (unpublished), Economic Council of Canada, Ottawa, January 1981.

Cameron, T.A. and S.L. Schwartz, "Sectoral Energy Demand in Canadian Manufacturing Industries", *Energy Economics*, Vol. 1, No. 2, April 1979, p. 112-179.

Canada, Bay of Fundy Tidal Power Review Board, *Reassessment of Fundy Tidal Power*, November 1977.

Canada, Department of Agriculture, *Farm-Scale Production and Use of Fuel Alcohol—Opportunities and Problems*, Ottawa, September 1980.

Canada, Department of Energy, Mines and Resources, *An Energy Policy for Canada: Phase 1*, Ottawa, 1973.

Canada, Department of Energy, Mines and Resources, *An Energy Strategy for Canada: Policies for Self-Reliance*, Ottawa, 1976.

Canada, Department of Energy, Mines and Resources, *Energy in Canada: An Overview*, Report Prepared for the 1978 Meeting of the International Executive Council of the World Energy Conference, Ottawa, 1978.

Canada, Department of Energy, Mines and Resources, *Background to a New Energy Strategy*, Ottawa, November 1979a.

Canada, Department of Energy, Mines and Resources, *Canadian Oil and Gas Supply/Demand Overview*, Energy Strategy Branch, Economic and Policy Analysis, Ottawa, November 1979b.

Canada, Department of Energy, Mines and Resources, *Electric Power in Canada 1979*, Electrical Branch, Energy Policy Sector, Ottawa, 1980a.

Canada, Department of Energy, Mines and Resources, *Energy Information Handbook*, Energy Information Division, Energy Policy Sector, Ottawa, 1980b.

Canada, Department of Energy, Mines and Resources, *List of Undeveloped Hydroelectric Power Sites in Canada*, Electrical Branch, Ottawa, July 1980c.

Canada, Department of Energy, Mines and Resources, *Renewable Energy in Remote Locations: Energy Demand and Resource Base*, Report ER80-10E, Ottawa, 1980d.

Canada, Department of Energy, Mines and Resources, *The National Energy Program 1980*, Ottawa, 28 October 1980e.

Canada, Department of Energy, Mines and Resources, untitled submission to the Special Committee on Alternative Energy and Oil Substitution, 25 June 1980f.

Canada, Department of Energy, Mines and Resources, *Uranium in Canada, 1979 Assessment of Supply and Requirements*, Report EP 80-3, Ottawa, September 1980g.

Canada, Department of the Environment, *Images of Canadian Futures: The Role of Conservation and Renewable Energy*, Ottawa, 1976.

Canada, Department of Finance, *The Effects of Higher Prices on Long-Run Growth*, November 1978.

Canada, National Energy Board, *Canadian Oil Supply and Requirements*, Ottawa, September 1978.

Canada, National Energy Board, *Submission by the National Energy Board to the Parliamentary Task Force on Alternative Energy and Oil Substitution*, Ottawa, December 1980.

Canada, National Research Council, *The Urgent Investment: A Long Range Plan for the National Research Council of Canada*, Ottawa, October 1980.

Canada, Statistics Canada, *Quarterly Report on Energy Supply-Demand in Canada*, Catalogue 57-003 (Quarterly), 1978-IV, Ottawa, February 1980.

Canada, Statistics Canada, *Refined Petroleum Products*, Catalogue 45-004 (Monthly), December 1980, Ottawa, March 1981.

Canadian Enerdata, *Canadian Energy Trends* (sample issue), Toronto, December 1980.

Canadian Petroleum Association, *Statistical Handbook*, Calgary, 1980.

Cane, R.L.D., *Residential Space Heating with the Heat Pump*, Report No. 125, Division of Building Research, National Research Council of Canada, Ottawa, January 1978.

Cane, R.L.D., *The Cost of Owning and Operating a Residential Heat Pump System in Canada*, Paper No. 905, Division of Building Research, National Research Council, Ottawa, April 1980.

Chapman, Stephen, "Energy: The Myth of Independence", *Atlantic*, Vol. 247, January 198l, p. 11ff.

Chappell, M., *Canadian Wind Energy Research and Development*, Presentation to the Special Committee on Alternative Energy and Oil Substitution, 2 July 1980.

Ciriacy-Wantrup, S.V., *Resource Conservation: Economics and Policies*, 3rd ed., Agricultural Experimental Station, Division of Agricultural Sciences, University of California, 1968.

Clark, R.H., *Prospects for Tidal Power*, Paper prepared for the Conference on Long Term Energy Resources sponsored by the United Nations Institute for Training and Research (UNITAR) at Montreal, 26 November-7 December 1979.

Conservation Commission of the World Energy Conference, *World Energy: Looking Ahead to 2020*, IPC Science and Technology Press, London, 1978.

"Conserving Energy can Damage Your Health", *The Economist*, Vol. 275, No. 7134, 24 May 1980, p. 109-110.

"Conversion Factors Used in Oil Industry", *Petroleum Economist*, Vol. XLVII, No. 3, March 1980, p. 140.

Cooper, Bryan (ed.), *OPEC Oil Report*, 2nd ed., Petroleum Economist, London, November 1979.

Crane, David, *A Dictionary of Canadian Economics*, Hurtig Publishers, Edmonton, 1980.

Cranstone, D.A., J.A. McIntosh and A. Azis, *Canadian Reserves of Copper, Nickel, Lead, Zinc, Molybdenum, Silver and Gold*, Mineral Bulletin MR 178, Department of Energy, Mines and Resources, Ottawa, 1978.

Crowe, Bernard J., *Fuel Cells: A Survey,* Computer Sciences Corporation, prepared under contract to the National Aeronautics and Space Administration, U.S. Government Printing Office, Washington, 1973.

DAF Indal Limited, *Development, Installation and Testing of a Wind Turbine Diesel Hybrid*, prepared for the Ontario Ministry of Energy and the National Research Council, Mississauga, 1980.

Davis, M. and A. Colling, "District Heating and the Energy Policy of the European Community", in W.R.H. Orchard (Chairman), *Whole City Heating*, Construction Industry Conference Centre Ltd. Conference, 21-22 November 1979, London, p. 57.

Decker, Robert and Barbara Decker, "The Eruptions of Mount St. Helens", *Scientific American*, Vol. 244, No. 3, March 1981, p. 68-80.

DeGolyer and MacNaughton, *Twentieth Century Petroleum Statistics 1980*, Dallas, November 1980.

"District Heating in Canada", *Modern Power and Engineering*, Vol. 73, No. 11, November 1979, p. 35-46.

"District Heating in Canada", *Modern Power and Engineering*, Vol. 74, No. 11, November/December 1980, p. 39-41.

Douglas, Bob, "The Line that Government Wants", *Canadian Petroleum*, Vol. 22, No. 3, March 1981, p. 40-43.

Dunkerley, Joy, "Energy-Output Relationships: Implications for Energy Conservation", in Joy Dunkerley (ed.), *International Energy Strategies*, Proceedings of the 1979 IAEE/RFF Conference, Oelgeschlager, Gunn & Hain, Publishers, Cambridge, Mass., 1980, p. 71-77.

duPlessis, M.P., "Coal Conversion Research", *CIM Bulletin*, Vol. 74, No. 826, February 1981, p. 81-88.

Economic Council of Canada, *A Climate of Uncertainty*, Seventeenth Annual Review, Ottawa, 1980.

Ellison, Anthony P., *The Effects of Rising Energy Costs on Canadian Industries*, Canadian Energy Research Institute, Calgary, April 1979.

Farkas, G.S., *District Heating - North American Versus European Style*, Shawinigan Engineering Company Ltd., Montreal, April 1975.

Farkas, G.S., *District Heating*, Submission to the Special Committee on Alternative Energy and Oil Substitution, July 1980.

Fassbender, Linda L. and Clarence H. Bloomster, "Economics of Geothermal Fluid Transport", *Geothermal Energy Magazine*, Vol. 7, No. 8, August 1979, p. 28-29.

Fickett, Arnold P., "Fuel-Cell Power Plants", *Scientific American*, Vol. 239, December 1978, p. 70-76.

Friedenberg, W.B., *Energy in Canada: Review and Outlook to 1995*, Canadian Energy Research Institute, Calgary, July 1979.

Friedenberg, W.B. and A.J. Nixon, *Prospects for Reduced Oil Consumption in Canada*, Working Paper 80-4, Canadian Energy Research Institute, Calgary, May 1980.

Friedrich, F.D., *Coal Energy for Canada*, CANMET Report ERP/ERL 78-39 (OP), Department of Energy, Mines and Resources, Ottawa, April 1978.

Friedrich, F.D., *Fluidized Bed Combustion - An Emerging Technology*, CANMET Report 79-39, Department of Energy, Mines and Resources, Ottawa, 1980a.

Friedrich, F.D., *R,D&D in Fluidized Bed Combustion: The Coal Program for FY 1980-81 and Beyond*, CANMET Report ERP/ERL 80-39 (OP), Department of Energy, Mines and Resources, Ottawa, April 1980b.

Gary, Margaret, Robert McAfee Jr. and Carol L. Wolf (eds.), *Glossary of Geology*, American Geological Institute, Washington, 1972.

Gerolde, Steven (ed.), *A Handbook of Universal Conversion Factors*, 2nd printing, The Petroleum Publishing Co., Tulsa, 1977.

Gibson, Edward G., *The Quiet Sun*, Scientific and Technical Information Office, National Aeronautics and Space Administration, U.S. Government Printing Office, Washington, 1973.

Gordon, Donald and Alan Longhurst, "The Environmental Aspects of a Tidal Power Project in the Upper Reaches of the Bay of Fundy", *Marine Pollution Bulletin*, Vol. 10, February 1979, p. 38-45.

Gough, Bruce, *Passive Solar Heating in Canada: A Discussion Paper*, Report ER 79-6, Department of Energy, Mines and Resources, Ottawa, 1980.

Gregory, D.P., "The Hydrogen Economy", *Scientific American*, Vol. 228, No. 1, January 1973, p. 13-21.

Gregory, D.P. and J.B. Pangborn, "Hydrogen Energy" in J.M. Hollander and M.K. Simmons (eds.), *Annual Review of Energy*, Vol. I, Annual Reviews Inc., California, 1976, p. 279-310.

Hand, A.J., "Blow Out Stale Air but Save the Heat", *Popular Science*, Vol. 217, No. 4, October 1980, p. 77ff.

Hanson, J.A. and J.D. Escher, "Toward the Renewables: A Natural Gas/ Solar Energy Transition Strategy", *Proceedings of 14th Intersociety Energy Conversion Engineering Conference*, Vol. I, Boston, 5-10 August 1979, p. 796-799.

Heap, R.D., *Heat Pumps*, Halsted, New York, 1979.

Hedlin, Menzies and Associates Ltd., *A Study of the Economic Implications of Optimal Building Insulation of District Central Heating Systems*, Research Report No. 7, Office of Energy Conservation, Department of Energy, Mines and Resources, Ottawa, April 1976.

Henderson, Hazel, "Dissecting the Declining Productivity Flap", *Technological Forecasting and Social Change*, Doubleday, 1980.

Holdren, John P., "Fusion Energy in Context: Its Fitness for the Long Term", *Science*, Vol. 200, 14 April 1978, p. 168-180.

Holdren, John P., "Energy, Economy, Environment: Interactions and Choices", *Energy in America: Fifteen Views*, Proceedings of a conference sponsored by the Center for Study of the American Experience, University of Southern California, May 1979, p. 57-71.

Holdren, John P., Invited comments on energy from fusion made to the Special Committee on Alternative Energy and Oil Substitution (unpublished), 10 December 1980a.

Holdren, John P., "Renewables in the U.S. Energy Future: How Much, How Fast?" Report No. ERG-WP-80-13, Energy and Resources Group, University of California/Berkeley, prepared for the National Conference on Renewable Energy Technologies, Honolulu, Hawaii, 7-13 December 1980b.

Hollands, K.G.T. and J.F. Orgill, "Potential for Solar Heating in Canada", *University of Waterloo Research Institute*, February 1977.

"How Does a Solar Cell Work?", *Science Dimension*, Vol. I, No. 1, 1979, p. 12.

Hubbert, M. King, *U.S. Energy Resources, A Review as of 1972*, Background Paper prepared for the Committee on Interior and Insular Affairs, United States Senate, 93rd Congress, 2nd Session, Serial No. 93-40 (92-75), U.S. Government Printing Office, Washington, 1974.

Hudson, Edward A., "Economic Effects of Increased Penetration of Solar Energy", *The Energy Journal*, Vol. 1, No. 3, 1980, p. 97-111.

Hunt, John M., *Petroleum Geochemistry and Geology*, W.H. Freeman and Company, San Francisco, 1979.

International Atomic Energy Agency, *Urban District Heating Using Nuclear Heat*, Proceedings of an Advisory Group Meeting held in Vienna, 15-19 March 1976, 1977.

International Atomic Energy Agency, *Executive Summary, International Tokamak Reactor: Zero Phase*, Vienna, 1980.

International Energy Agency, *Annual Report on Energy Research, Development and Demonstration Activities of the IEA 1979-1980*, Organization for Economic Co-operation and Development, Paris, 1980a.

International Energy Agency, *Energy Research, Development and Demonstration in the IEA Countries, 1979 Review of National Programs*, Organization for Economic Co-operation and Development, Paris, 1980b.

James F. MacLaren Ltd., *A Study of the Potential Industrial Use of District Heating*, Report No. 8, Office of Energy Conservation, Department of Energy, Mines and Resources, Ottawa, December 1976.

James, J.W., "Some Observations on District Heating in Europe", Report No. 75065, Design and Development Division, Ontario Hydro, Toronto, December 1975.

Jansson, B., S. Bjurström and S-A. Hultin, "Energy Conservation through Use of the Underground", Technical Papers, Vol. 1B, 11th World Energy Conference, 8-12 September 1980, Munich, p. 489-509.

Jessop, Alan, *Geothermal Energy from Sedimentary Basins*, Geothermal Series No. 8, Geothermal Service of Canada, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, 1976.

Jessop, Alan, "The Role of Non-Conventional Energy Resources: Geothermal", in *The Canadian Energy Situation in 1990 and Beyond*, Proceedings of the Canadian National Energy Forum, Canadian National Committee of the World Energy Conference, Halifax, 4-5 April 1977.

Joskow, Paul L. and Robert S. Pindyck, "Those Subsidized Energy Schemes", *Wall Street Journal*, Monday, 2 July 1979.

Kelley, J.H. and R. Hagler, "Storage, Transmission and Distribution of Hydrogen", *Hydrogen Energy System - Proceedings of 2nd World Hydrogen Energy Conference*, Vol. 1, Zurich, Switzerland, 21-24 August 1978, p. 26.

Kellogg, W.W., "Is Mankind Warming the Earth?", *Bulletin of the Atomic Scientists*, Vol. 32, No. 2, February 1978, p. 10-19.

Kelly, J.F., *Coal Liquefaction - A Technical Perspective*, CANMET Report ERP/ERL 80-67 (R), Department of Energy, Mines and Resources, Ottawa, February 1980.

Kelly, J.F., "Coal Liquefaction in Canada - the CANMET Program", *CIM Bulletin*, Vol. 74, No. 826, February 1981, p. 72-80.

Kempling, J.C., "Upgrading Heavy Crude", Imperial Oil Research and Development Symposium, Sarnia, Ontario, 17 September 1980.

Kernan, G. and J. Brady, "Economic Evaluation of Heat Pumps", *Energy Research*, Vol. I, 1977, p. 115-125.

Kestin, Joseph (ed.-in-chief), *Sourcebook on the Production of Electricity from Geothermal Energy*, prepared under contract to the U.S. Department of Energy, Division of Geothermal Energy, U.S. Government Printing Office, Washington, March 1980.

Killian, H.J., G.L. Dugger and J. Grey (eds.), *Solar Energy for Earth*, American Institute of Aeronautics and Astronautics, New York, 21 April 1975.

Knight, H.G., J.D. Daniel and R.E. Stein (eds.), *Ocean Thermal Energy Conversion: Legal, Political & Institutional Aspects*, Lexington Books, Mass., 1977.

Kovarik, T., C. Pipher and J. Hurst, *Wind Energy*, Domus Books, Northbrook, Illinois, 1979.

Kral, Paul, "Energy and Economic Development: A Close Look at Inter-Country Comparisons", *Natural Resources Forum*, No. 4, 1980, p. 239-257.

Kusuda, T. (ed.), "Underground Heat and Chilled Water Distribution Systems", *Proceedings of a Symposium on Underground Heat and Chilled Water Distribution Systems*, 26-27 November 1973, U.S. Department of Commerce, Washington, D.C., May 1975.

"Laser Fusion", *Energy and Technology Review*, Lawrence Livermore Laboratory, University of California/Livermore, August 1977.

Laser Fusion, Book Two, Lawrence Livermore National Laboratory, University of California/Livermore, May 1980.

Law, Charles, "Hydrogen Supply May Not Meet Demand", *Canadian Petroleum*, Vol. 22, No. 3, March 1981, p. 61-63.

Lecomber, Richard, *The Economics of Natural Resources*, John Wiley & Sons, New York, 1979.

Lee, G.K., F.D. Friedrich, H. Whaley and I.C.G. Ogle, "An Overview of Coal Activities at the Canadian Combustion Research Laboratory" (Synopsis), *CIM Bulletin*, Vol. 73, No. 822, October 1980, p. 62-64.

Lee, W., J. Mazuik, V.W. Weekman, Jr. and S. Yurchak, "Catalytic Conversion of Alcohols to Gasoline by the Mobil Process", in *Energy from Biomass and Wastes IV*, Symposium held under the auspices of the Institute of Gas Technology, Lake Buena Vista, Florida, 21-25 January 1980, p. 721-745.

Leeds, Michael W. and Jill Evensizer, *A Market Survey of Geothermal Wellhead Power Generation Systems — Final Report, March 1979*, Jet Propulsion Laboratory, California Institute of Technology, prepared under contract to the U.S. Department of Energy, U.S. Government Printing Office, Washington, April 1979.

Leigh, J., A. Cohen, W. Jacobsen and R. Trehan, *Site Specific Analysis of Geothermal Development, Volume 1 — Summary Report*, MITRE Corporation, prepared under contract to the U.S. Department of Energy, U.S. Government Printing Office, Washington, February 1979.

LeRoy, R.L., "Hydrogen in Canada's Energy Future", *Metallurgical Society of the Canadian Institute of Mining and Metallurgy: Annual Volume*, 1978, p. 1-10.

Leslie, J.R., "Heat Pumps", *The Nuclear Option for Canada; The Renewable Energy Resources*, Report ER-77-2, Department of Energy, Mines and Resources, Ottawa, 1977, p. 75-80.

Lindström, O., T. Nilsson, M. Bursell, C. Hörnell, G. Karlsson, C. Sylwan and B. Ahgren, "Utility Fuel Cells for Biomass Fuels", *Proceedings of the 14th Intersociety Energy Conversion Engineering Conference*, Boston, 5-10 August 1979, p. 1178-1184.

Love, Peter and Ralph Overend, *Tree Power: An Assessment of Forest Biomass in Canada*, Renewable Energy Resources Branch, Department of Energy, Mines and Resources, Ottawa, 1978.

Lovins, Amory B., *World Energy Strategies: Facts, Issues, and Options*, Harper & Row, New York, 1980 (reprinted).

Lucas, N.J.D. (ed.), *Local Energy Centres*, Applied Science Publishers Ltd., London, 1978.

Lunin, G., A.E. Silva and J.M. Denis, "The CANMET Hydrocracking Process: Upgrading of Cold Lake Heavy Oil", *Chemistry in Canada*, Vol. 33, No. 3, March 1981, p. 17-21.

Lynch, F.E. and E. Snaps, "The Role of Metal Hydrides in Hydrogen Storage and Utilization", *Hydrogen Energy Systems - Proceedings of 2nd World Hydrogen Energy Conference*, Vol. 3, Zurich, Switzerland, 21-24 August 1978.

Mackenzie-Kennedy, C., *District Heating — Thermal Generation and Distribution*, Pergamon Press, Willowdale, 1979.

Maniscalco, J., J. Blink, R. Buntzen, J. Hovingh, W. Meier, M. Monsler and P. Walker, *Civilian Applications of Laser Fusion*, Lawrence Livermore Laboratory, University of California/Livermore, 14 August 1978.

Mathers, David E., "Methanol, the Other Alcohol; Its Production and Use", in *Proceedings—CANPAC '80*, the First Canadian National Power Alcohol Conference 1980, Winnipeg, 19-20 June 1980, p. XXII-1—XXII-11.

McPherson, Beth, *Hot Water from the Sun - A Consumer Guide to Solar Water Heating*, United States Department of Housing and Urban Development and the Department of Energy, Washington (undated).

Middleton Associates, *Report to the House of Commons Special Committee on Alternative Energy and Oil Substitution* (unpublished), Toronto, November 1980.

MLM Ground-Water Engineering, *Applicability of Ground-Water Source Heat Pumps in Western Canada*, prepared for the National Research Council, Division of Building Research, Ottawa, July 1979.

Montreal Engineering Company, *Coal-Oil Combustion Study*, Final Report CEA 77-56, Canadian Electrical Association, 1979.

Munn, R.E., D. Mackay and M. Havas, *Atmospheric and Related Impacts of Coal Utilization*, paper prepared for UNEP/Beijer Institute Workshop on Environmental Implications and Strategies for Expanded Coal Utilization, Moscow, 6-10 October 1980.

Nemetz, Peter (ed.), *Energy Policy: The Global Challenge*, Institute for Research on Public Policy, Toronto, 1979.

"NS Power Orders Straflo Turbine for Annapolis Tidal Power Project", *Modern Power and Engineering*, Vol. 74, No. 8, August 1980, p. 28-29.

Orchard, W.R.H. (Chairman), *Whole City Heating*, Construction Industry Conference Centre Ltd., London, 21-22 November 1979.

Otte, Carel, "Developing Our Geothermal Energy", *Engineering and Science*, California Institute of Technology, March-April 1979.

Parkin, J.H., "Wallace Rupert Turnbull, 1870-1954, Canadian Pioneer of Scientific Aviation", *Canadian Aeronautical Journal*, Vol. 2, No. 2, February 1956, p. 1-48.

Particle-Beam Fusion Research Facilities at Sandia National Laboratories, Sandia National Laboratories, Albuquerque, New Mexico, July 1980.

Patterson, J.N., *The Future Role of Hydrogen Fuel in an Electrical Society*, UTIAS Report #241, University of Toronto Institute of Aerospace Studies, Toronto, 1979.

"Peat Facts", preface to *Preliminary Release of the Newfoundland and Labrador Peat Resources Seminar*, Memorial University, St. John's, 21-22 September 1977.

Pedde, Lawrence D., Warren E. Foote, LeRoy F. Scott, Danny L. King and Dave L. McGalliard, *Metric Manual*, Bureau of Reclamation, U.S. Department of the Interior, U.S. Government Printing Office, Washington, 1978.

Pindyck, Robert S., "Higher Energy Prices and Economic Growth", in Joy Dunkerley (ed.), *International Energy Strategies*, Proceedings of the 1979 IAEE/RFF Conference, Oelgeschlager, Gunn & Hain, Publishers, Cambridge, Mass., 1980, p. 113-117.

Post, R.F. and J.L. Emmett, *Fusion Power Research in Canada - Some Comments*, submission to the Special Committee on Alternative Energy and Oil Substitution, 10 December 1980.

Powrie, T.L., *Energy Policy and the Balance of Payments: An Outline of the Issues*, Study No. 6, Canadian Energy Research Institute, Calgary, July 1979.

Press, Frank and Raymond Siever, *Earth*, 1st and 2nd eds., W.H. Freeman and Company, San Francisco, 1974 and 1978.

Princeton Plasma Physics Laboratory, *Annual Report*, Report No. PPPL-Q-36, Princeton University, Princeton, New Jersey, January 1980.

"Producing Fuel With Sunbeams", *Newsweek*, 14 January 1980, p. 56-57.

Ramain, P., "District Heating and Economic Analysis - the French Case", *Energy Economics*, Vol. 2, No. 3, July 1980, p. 154-160.

Ranney, M.W., *Oil Shale and Tar Sands Technology - Recent Developments*, Noyes Data Corporation, Park Ridge, N.J., 1979.

Reardon, P.J., *Presentation to the Special Committee on Alternative Energy and Oil Substitution*, Princeton University Plasma Physics Laboratory, Princeton, New Jersey, 2 October 1980.

Reed, Tom and Becky Bryant, *Densified Biomass: A new Form of Solid Fuel*, Solar Energy Research Institute, Golden, Colorado, July 1978.

Reilly, J.J. and G.D. Sandrock, "Hydrogen Storage in Metal Hydrides", *Scientific American*, Vol. 242, No. 2, February 1980, p. 118-129.

"Review and Forecast 1981", *Oilweek*, Vol. 32, No. 1, 9 February 1981.

Riva, Joseph P. Jr. and James E. Mielke, *Energy from Geothermal Resources*, 2nd ed., Congressional Research Service, Library of Congress, prepared for the Committee on Science and Technology, U.S. House of Representatives, 95th Congress, 2nd Session, Washington, June 1978.

Rosenberg, Nathan, "Historical Relations Between Energy and Economic Growth", in Joy Dunkerley (ed.), *International Energy Strategies*, Proceedings of the 1979 IAEE/RFF Conference, Oelgeschlager, Gunn & Hain, Publishers, Cambridge, Mass., 1980, p. 55-70.

Sandori, P., "Heat Pumps in Residential Buildings", *Canadian Architect*, Vol. 23, September 1978, p. 51-53.

Sassin, Wolfgang, "Energy", *Scientific American*, Vol. 243, No. 3, September 1980, p. 118ff.

Scotia Liquicoal Limited, *Brief Presented by Scotia Liquicoal Limited to the Senate* (Sic) *Special Committee on Alternate Energy and Oil Substitution*, Halifax, Nova Scotia, 15 September 1980.

Scott, Anthony, *Natural Resources, The Economics of Conservation*, McClelland and Stewart, Toronto, 1973.

Selected Articles on Magnetic Fusion Energy from Energy & Technology Review, Lawrence Livermore Laboratory, University of California/Livermore, 1979.

Sewell, W.R.D., *A Report on the International Symposium on Non-Technical Obstacles to the Use of Solar Energy, 20-22 May 1980*, prepared for the Conservation and Renewable Energy Branch, Department of Energy, Mines and Resources, 10 June 1980.

Shick, W.L. and Jones, R.A., "The Illinois Lo-Cal House", *Council Notes*, Vol. 1, No. 4, Small Homes Building Research Council, University of Illinois/Urbana-Champaign, March 1976.

Sivard, Ruth Leger, *World Energy Survey*, World Priorities, Inc., Leesburg, Virginia, 1979.

Slagorsky, Z. Charles, *Energy Use in Canada in Comparison with Other Countries*, Study No. 8, Canadian Energy Research Institute, Calgary, October 1979.

Slesser, Malcolm, *Energy in the Economy*, St. Martin's Press, New York, 1978.

Smith, Auld and Associates Ltd., *Some Administrative and Jurisdictional Aspects of District Heating*, Research Report No. 11, Office of Energy Conservation, Department of Energy, Mines and Resources, Ottawa, December 1976.

Solartech Limited, *Evacuated Tube Collectors*, Mississauga, Ontario (undated).

Solar Technology Today, Electric Power Research Institute, Palo Alto, California, March 1980.

Sorenson, Jean, "Which Way to Vancouver Island", *Canadian Petroleum*, Vol. 22, No. 3, March 1981, p. 34ff.

Souther, J.G., "Geothermal Potential of Western Canada", in *Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources*, Volume 1, San Francisco, 20-29 May 1975.

Steward, F.R., "Energy Consumption in Canada since Confederation", *Energy Policy*, Vol. 6, No. 3, September 1978, p. 239-245.

Stobaugh, Robert and Daniel Yergin (eds.), *Energy Future: Report of the Energy Project of the Harvard Business School*, Random House, New York, 1979.

Stock, Francine, "Geothermal prospects", *Petroleum Economist*, February 1981, p. 66-68.

Stricker, S., *The Role of Heat Pumps in a Changing Energy Supply and Cost Save*, Ontario Hydro Research Division, Toronto, presentation to the Special Committee on Alternative Energy and Oil Substitution, 29 July 1980.

Swiss, M., "Coal Liquefaction - A Look at Recent Work", *Mining Magazine*, February 1980, p. 159-165.

Taylor, G.W., *Liquid Fuels from Canadian Coals*, CANMET Report 79-13, Department of Energy, Mines and Resources, Ottawa, June 1979.

"The Aluminum-Air Battery for Electric Vehicles: An Update", *Energy and Technology Review*, November 1980, p. 1-10.

The Mirror Fusion Test Facility, Lawrence Livermore Laboratory, University of California/Livermore, December 1978.

"The New Glow in Solar Electricity", *Dun's Review*, Vol. 116, No. 5, November 1980, p. 90ff.

"The Nova Laser Fusion Facility", *Energy and Technology Review*, Lawrence Livermore National Laboratory, December 1980, p. 1-14.

The Princeton University Plasma Physics Laboratory: An Overview, Plasma Physics Laboratory, Princeton University, Princeton, New Jersey, October 1979.

The Rance's Tidal Power Station, Electricité de France (undated).

"The Sun on a Semiconductor", *ERPI Journal*, Electric Power Research Institute, Palo Alto, California, March, 1978, p. 20-25.

Thurow, Lester C., *The Zero-sum Society*, Basic Books Inc., New York, 1980.

"Tide turns for Chinese power", *New Scientist*, Vol. 89, No. 1236, 15 January 1981, p. 148.

TransCanada PipeLines, *Annual Report, 1978*.

United Nations, Department of International Economic and Social Affairs, *World Energy Supplies*, Statistical Papers, Series J, No. 22.

United Nations, Environment Programme, *The Environmental Impacts of Production and Use of Energy*, Energy Report Series ERS-7-80, Nairobi, August 1980.

United States, Bureau of Mines and Geological Survey, *Principles of a Resource/Reserve Classification for Minerals*, Geological Survey Circular 831, Arlington, Virginia, 1980.

United States, Central Intelligence Agency, *International Energy Statistical Review*, 24 February 1981.

United States, Council on Environmental Quality and Department of State, *The Global 2000 Report to the President: Entering the Twenty-First Century*, Vols. 1 & 2, U.S. Government Printing Office, Washington, 1980.

United States, Department of Energy, *Environmental Development Plan, Solar Thermal Power Systems 1977*, Report No. DOE/EDP-0004, Washington, March 1978.

United States, Department of Energy, *Fossil Energy Program, Summary Document*, Document No. DOE/FE-0006, Washington, May 1980a.

United States, Department of Energy, *Magnetic Fusion Energy, Program Summary Document FY 1981*, Document No. DOE/ER-0059, Office of Fusion Energy, Washington, June 1980b.

United States, Department of Energy, *Passive Solar Progress*, Report No. DOE/CS/30046-01, Washington, October 1980c.

United States, Department of Energy, *Report on the Department of Energy Magnetic Fusion Program*, Fusion Review Panel, Energy Research Advisory Board, August 1980d.

United States, Department of Energy, *The Proceedings of the Sixth International Conference on Fluidized Bed Combustion*, Report CONF-800428, 3 vol., Atlanta, Georgia, 9-11 April 1980e.

United States, Environmental Protection Agency, *Environmental, Operational and Economic Aspects of Thirteen Selected Energy Technologies*, Report No. EPA-600/7-80-173, Washington, September 1980.

United States, National Research Council, *Hydrogen as a Fuel*, Hydrogen Panel, Committee on Advanced Energy Storage Systems, National Academy of Sciences, Washington, 1979.

United States, Office of Technology Assessment, *Energy from Biological Processes*, Vol. 1, U.S. Government Printing Office, Washington, July 1980a.

United States, Office of Technology Assessment, *Energy from Biological Processes*, Vol. 2, U.S. Government Printing Office, Washington, September 1980b.

United States, Senate Committee on Energy and Natural Resources, *The Geopolitics of Oil*, Staff Report, Publication 96-119, U.S. Government Printing Office, Washington, December 1980.

Van Nostrand's Scientific Encyclopedia, 4th ed., D. Van Nostrand Company, Toronto, 1968.

van Velzen, D. and H. Langenkamp, "Thermochemical Hydrogen Production by the Mark-13 Process: A Status Report", *Proceedings of 14th Intersociety Energy Conversion Engineering Conference*, Boston, 3-10 August 1979, p. 783-789.

Vielvoye, Roger and Larry Auldridge, "Global Oil Production Dips 4% during 1980", *Oil & Gas Journal*, Vol. 79, No. 10, 9 March 1981, p. 43-47.

Waddington, Daryll C., *The Canadian Balance of Payments to the Year 2000*, Royal Bank, November 1979.

Webb, Michael and Martin J. Ricketts, *The Economics of Energy*, MacMillan Press Ltd., London, 1980.

Weintraub, Pamela, "Splitting Water", *Discover*, Vol. 2, No. 2, February 1981, p. 36-38.

Westcoast Transmission Company, *Annual Report, 1979*.

Whaley, H., *The Canadian Coal-Oil Mixture Program*, CANMET Report ERP/ERL 80-11(J), Department of Energy, Mines and Resources, Ottawa, April 1980.

Wilkinson, B.W. and B.L. Scarfe, "The Recycling Problem", in *Energy Policies for the 1980s*, Vol. 1, Ontario Economic Council, Toronto, 1980.

Williams, J.D., *Solar Energy Technology and Applications*, Ann Arbor, Michigan, 1977.

Williams, R.M., "Uranium", in *Canadian Minerals Yearbook 1978* (preprint), Department of Energy, Mines and Resources, Ottawa, 1980.

Willson, Bruce F., *The Energy Squeeze: Canadian Policies for Survival*, James Lorimer & Company, Toronto, 1980.

Wilson, Carroll L. (Project Director), *Coal - Bridge to the Future*, Report of the World Coal Study, Ballinger Publishing, Cambridge, Mass., 1980a.

Wilson, Carroll L. (Project Director), *Future Coal Prospects: Country and Regional Prospects*, Report of the World Coal Study, Ballinger, Cambridge, Mass., 1980b.

Wyllie, Peter J., *The Dynamic Earth: Textbook in Geosciences*, John Wiley & Sons, Toronto, 1971.

Yaverbaum, L., *Fluidized Bed Combustion of Coal and Waste Materials*, Energy Technology Review No. 15, Noyes Data Corp., Park Ridge, N.J., 1977.

Zwartendyk, J., *What is Mineral Endowment and How Should We Measure It?*, Mineral Bulletin MR 126, Department of Energy, Mines and Resources, Ottawa, 1972.

Appendices

APPENDIX A

Units and Conversion Factors

THE INTERNATIONAL SYSTEM OF UNITS

A new system of units is being adopted worldwide. This system of measure, the most accurate ever devised, is called the International System of Units and officially abbreviated as SI (for *Système International)* in all languages. Established by the 11th General Conference of Weights and Measures in 1960, SI is intended as the basis for a global standardization of measurement.

In January of 1970, the Canadian Government introduced its *White Paper on Metric Conversion,* followed by the passage in April 1971 of its Weights and Measures Act. Canada's Metric Commission was established in June of 1971 and a target date of 1 January 1979 was set for the exclusive use of SI. Although this goal was not fully achieved, Canada nonetheless stood well along the road to SI conversion as the 1980s began.

Table A-1: SI BASE AND SUPPLEMENTARY UNITS

Quantity	Name	Symbol
BASE UNITS		
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin[a]	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
SUPPLEMENTARY UNITS		
Plane angle	radian	rad
Solid angle	steradian	sr

[a] Although the SI unit of thermodynamic temperature is the kelvin, the Celsius scale will continue to be most commonly used for temperature measurements. Application of the Kelvin scale is generally restricted to scientific work.

Source: Pedde *et al,* 1978, p. 2.

SI, while based upon the decimal system with its multiples of 10, is not synonymous with the metric system since it excludes many metric units that have become obsolete and includes a few units, such as the second, which are not metric. SI units are divided into three classes: (1) base units, (2) supplementary units and (3) derived units. The base and supplementary units were adopted by the International Organization of Weights and Measures at its 10th (1954) and 11th (1960) General Conferences. Derived units are formed by algebraic relations between base units, supplementary units and other derived units. Table A-1 gives the SI base and supplementary units; Table A-2 lists commonly used derived units.

Table A-2: COMMONLY USED SI DERIVED UNITS

Quantity	Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Density	kilogram per cubic metre	kg/m^3
Energy	joule	J
Power	watt	W
Pressure	pascal	Pa
Speed, velocity	metre per second	m/s
Acceleration	metre per second squared	m/s^2
Thermal flux density	watt per square metre	W/m^2
Frequency	hertz	Hz

The SI package allows for continued use of certain non-SI units. Again we consider only the most frequently occurring examples. The hectare (ha) generally replaces the acre as the measure of land and water areas, with the square metre being the preferred SI unit for other measures of area. Although the second is the SI base unit for time, other units such as the hour (h), day (d) and year (a) will continue to be used. Degrees Celsius (°C) will continue as the common measure of temperature, with Kelvin temperature being generally relegated to the scientific domain. Unfortunately, three names now exist to describe the same amount of mass, 1000 kilograms — metric ton (t), tonne (t) and megagram (Mg or one million grams). While the megagram is the correct SI expression, it is not widely recognized and "tonne" seems more likely to prevail in the Canadian literature. For this reason, we have preferred not to express mass in megagrams in this Report.

SI PREFIXES

Many of the SI units with which we work are small measures. The pascal, for example, is a very small pressure, about equivalent to a dollar bill lying flat on a surface. In comparison, atmospheric pressure at sea level normally falls in the range of 95,000 to 105,000 pascals. To avoid the cumbersome expression of large and small quantities, the SI package includes a system of decimal multiples expressed as word prefixes and added to the unit names. Thus atmospheric pressure becomes 95 to 105 *kilo*pascals, the generating capacity at Churchill Falls in Labrador is expressed as 5,225 *mega*watts and Canada's export of electricity to the United States in 1980 is given as 30,180 *giga*watthours of energy. Table A-3 presents the full list of SI unit prefixes and gives examples of their use.

Table A-3: SI UNIT PREFIXES

Multiplication Factor		Prefix and Symbol		Example and Symbol	
1 000 000 000 000 000 000	$= 10^{18}$	exa	E	exajoules	EJ
1 000 000 000 000 000	$= 10^{15}$	peta	P	petajoules	PJ
1 000 000 000 000	$= 10^{12}$	tera	T	terawatts	TW
1 000 000 000	$= 10^{9}$	giga	G	gigawatthours	GWh
1 000 000	$= 10^{6}$	mega	M	megalitres	Ml
1 000	$= 10^{3}$	kilo	k	kilopascals	kPa
100	$= 10^{2}$	hecto	h (a)		
10	$= 10^{1}$	deca	da (a)		
0.1	$= 10^{-1}$	deci	d (a)		
0.01	$= 10^{-2}$	centi	c (a)		
0.001	$= 10^{-3}$	milli	m	millimetres	mm
0.000 001	$= 10^{-6}$	micro	μ	micrograms	μg
0.000 000 001	$= 10^{-9}$	nano	n	nanoseconds	ns
0.000 000 000 001	$= 10^{-12}$	pico	p	picohertz	pHz
0.000 000 000 000 001	$= 10^{-15}$	femto	f	femtofarads	fF
0.000 000 000 000 000 001	$= 10^{-18}$	atto	a	attocoulombs	aC

(a) Except for the nontechnical reference to "centimetre", use of these four prefixes is avoided in most circumstances.

Source: After Pedde *et al*, 1978, p. 10.

CONVERSION FACTORS

The following conversion factors are either exact or correct to four significant figures.

Distance

1 foot = 0.3048 metre
1 metre = 3.281 feet
1 statute mile = 1.609 kilometres
= 0.8690 international nautical mile
1 international nautical mile = 1.151 statute miles
= 1.852 kilometres
1 kilometre = 0.6214 statute mile
= 0.5399 international nautical mile

Area

1 square foot = 0.09290 square metre
1 square metre = 10.76 square feet
1 square mile = 640 acres
= 2.590 square kilometres
= 259.0 hectares
1 square kilometre = 0.3861 square mile
= 100 hectares
= 247.1 acres
1 acre = 0.4047 hectare
1 hectare = 2.471 acres

Volume

1 cubic foot = 0.02832 cubic metre
1 cubic metre = 35.31 cubic feet

= 6.290 American barrels
= 1000 litres
1 American barrel = 42 American gallons
= 34.97 Imperial gallons
= 0.1590 cubic metre
= 159.0 litres
1 American gallon = 3.785 litres
1 Imperial gallon = 4.546 litres

Mass

1 long ton = 2240 pounds
= 1.12 short tons
= 1.016 tonnes
1 short ton = 2000 pounds
= 0.8929 long ton
= 0.9072 tonne
1 tonne = 2205 pounds
= 1.102 short tons
= 0.9842 long ton
= 1000 kilograms
= 1 megagram
1 pound = 0.4536 kilogram
1 kilogram = 2.205 pounds

Energy

1 British thermal unit = 1054 joules
1 kilowatthour = 3412 British thermal units
= 3,600,000 joules
1 quad = 1 quadrillion British thermal units
= 10^{15} British thermal units
= 1054 petajoules
= 1054 x 10^{15} joules

Power

1 kilowatt = 3,600,000 joules/hour
= 1.341 Imperial horsepower
1 Imperial horsepower = 745.7 watts
1 British thermal unit/hour = 0.2931 watt

TEMPERATURE

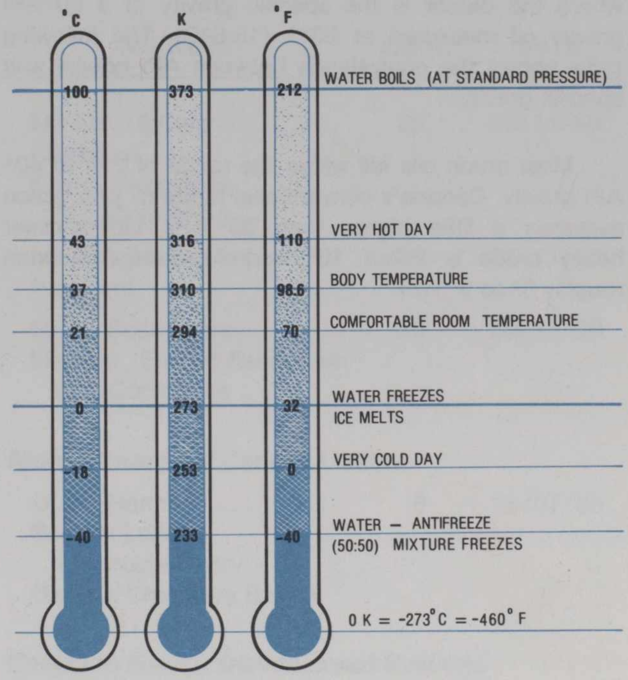
Temperature is that property of systems which determines if they are in thermodynamic equilibrium, two systems being in equilibrium when their temperatures (measured on the same scale) are equal. Temperature can be specified in various arbitrary and empirical ways based upon changes in volume, length, electrical resistance and so forth. Not surprisingly, an interesting variety of temperature scales has been devised of which three are of concern here — the Fahrenheit, Celsius (centigrade) and Kelvin scales. The correspondence among these three scales is illustrated in Figure A-1, the mathematical relationships being:

$$F = \frac{9C}{5} + 32$$

$$C = \frac{5}{9}(F-32)$$

$$K = C + 273.16$$

Figure A-1: A COMPARISON OF THE FAHRENHEIT, CELSIUS AND KELVIN TEMPERATURE SCALES



Source: After Pedde *et al,* 1978, p. 4.

Although the Kelvin scale is the one adopted in the SI scheme, its use is nonetheless limited to scientific matters and most temperatures are measured in degrees Celsius. Zero on the Kelvin scale (-273.16°C) is termed the *absolute zero of temperature,* with the third law of thermodynamics telling us that no system can be taken to a temperature of absolute zero (that is, to a state characterized by the complete absence of heat).

PETROLEUM SPECIFIC GRAVITY

The specific gravity of any liquid is the dimensionless ratio of the density of that liquid to the density of water, measured at a standard temperature of 4°C. If the specific gravity of a liquid is less than one, that liquid will float on water; if more than one, it will sink. Crude oils have a specific gravity normally falling in the range of 0.80 to 0.97, which corresponds to 8.0 to 6.6 barrels per tonne. Taking an approximate world average for the specific gravity of all crude oils produced, one tonne of crude is about equal to 7.3 barrels.

In the petroleum industry, however, the specific gravity of oil is normally expressed in degrees of API (American Petroleum Institute) gravity. In this measuring scheme, oil with a low specific gravity has a high API gravity and, other factors being equal, the higher the API gravity the more valuable the oil. The formula for calculating API gravity is

$$°\text{API} = \frac{141.5}{\text{specific gravity } 60°} - 131.5$$

where the divisor is the specific gravity of a 60°API gravity oil measured at 60°F (15.6°C). The following table shows the equivalence between API gravity and specific gravity.

Most crude oils fall within the range of 25° to 40° API gravity. Canada's conventional crude oil production averages a little higher than 35° API. Lloydminster heavy crude is about 16° and Athabasca bitumen roughly 8° to 9° API.

Table A-4: THE EQUIVALENCE BETWEEN API GRAVITY AND SPECIFIC GRAVITY

°API Gravity	Specific Gravity	Barrels/Tonne
0	1.076	5.86
10	1.000	6.30
15	0.9659	6.53
20	0.9340	6.75
26	0.8984	7.02
30	0.8762	7.19
36	0.8448	7.46
40	0.8251	7.64
46	0.7972	7.91
50	0.7796	8.09
60	0.7389	8.53

Source: Hunt, 1979, p. 544.

APPENDIX B

Witnesses and Intervenors at Public Hearings

List of witnesses and intervenors who appeared before the Special Committee, showing the Issue in which their evidence appears.

WITNESSES AT PUBLIC HEARINGS

WITNESS	ISSUE	DATE
Agriculture Canada		
Mr. R.D. Hayes Energy Engineer Engineering and Statistical Research Institute	25	12/11/80
Dr. E.J. LeRoux Assistant Deputy Minister Research Branch Chairman of Interbranch Energy Committee	25	12/11/80
Dr. B. Perkins Director Regional Development and Analysis Directorate Regional Development and International Affairs Branch	25	12/11/80
Mr. P.W. Voisey Director Engineering and Statistical Research Institute	25	12/11/80
Association of Consulting Engineers of Canada		
Mr. D. Farlinger Chairman Energy Affairs Standing Committee	29	20/11/80
Mr. J.L. Greer Past Chairman Energy Affairs Standing Committee	29	20/11/80

WITNESS	ISSUE	DATE
Mr. I.W. McCaig Chairman Energy Resources Sub-Committee	29	20/11/80
Mr. K.A. McLennan President	29	20/11/80
Mr. O. Scudamore Member, Energy Resources Sub-Committee	29	20/11/80
Atomic Energy of Canada Limited		
Dr. M. Hammerli Section Leader, Electrochemistry General Chemistry Branch	6	16/07/80
Canadian Energy Development Systems International		
Mr. D.A. Henry President	28	19/11/80
Canadian Federation of Agriculture		
Dr. L. Emery Member, Energy Committee	27	18/11/80
Mr. G. Flaten First Vice-President	27	18/11/80
Mr. D. Kirk Executive Secretary	27	18/11/80
Mr. D. Knoerr Executive Member	27	18/11/80
Canadian National Committee, World Energy Conference		
Dr. E.P. Cockshutt Member of Executive Committee	24	05/11/80
Dr. J.S. Foster Chairman	24	05/11/80

WITNESS	ISSUE	DATE
Canadian Renewable Energy News		
Mr. J. Passmore Features and International Editor	9	30/07/80
Canadian Solar Industries Association		
Mr. R. Davies Chairman	28	19/11/80
Mr. A. Gatrill Executive Director	28	19/11/80
Mr. J. Ramsden Treasurer	28	19/11/80
Chemical Institute of Canada		
Dr. W. Schneider Member of the Institute	23	04/11/80
Coal Association of Canada		
Mr. G.T. Page President	27	18/11/80
Co-generation Associates Limited		
Mr. A. Juchymenko President	10	31/07/80
Coreco Incorporated		
Mr. Daniel Crevier President	11	04/09/80
Duomo Import Limited		
Mr. S. Verrie President	12	05/09/80
Mr. M.S. Werger Secretary	12	05/09/80
Economic Council of Canada		
Mrs. Bobbi Cain Research Economist	9 26	30/07/80 13/11/80
Dr. P. Cornell Senior Policy Advisor	9	30/07/80
Mr. D. Paproski Director Seventeenth Review	9	30/07/80
Dr. R. Preston Director, Candide Research Group	9 26	30/07/80 13/11/80
Dr. D.W. Slater Chairman	26	13/11/80
Energy, Mines and Resources Canada		
Mr. B. Cook Technical Advisor Office of Energy Research and Development	31	02/12/80
Dr. P.J. Dyne Director Office of Energy Research and Development	6 31	16/07/80 02/12/80
Dr. A. Jessop Head, Geothermal Studies Group	26	13/11/80
The Honourable Marc Lalonde Minister	30	25/11/80
Dr. K. Whitham Assistant Deputy Minister Conservation and Non-Petroleum Branch	1	25/06/80
Energy Probe		
Dr. D. Brooks Coordinator, Ottawa Office	22	30/10/80
Environment Canada		
Mr. R.H. Clark Senior Engineering Advisor Inland Waters Directorate	5	15/07/80
Mr. J. Labuda Chief Fuels and Air Pollution Directorate Environmental Protection Service	26	13/11/80
Dr. D. McKay Climatological Applications Branch Atmospheric Environment Service	26	13/11/80
Mr. R.J. Neale Manager, ENFOR Program Canadian Forestry Service	26	13/11/80
Mr. D.L. Robinson Senior Scientific Advisor Environmental Conservation Service	26	13/11/80
Dr. E.F. Roots Science Advisor	26	13/11/80
Mr. J.B. Seaborn Deputy Minister	26	13/11/80
F.T. Fisher's Sons Limited		
Mr. S.T. Fisher	11	04/09/80

WITNESS	ISSUE	DATE
Friends of the Earth		
Mrs. H. Lajambe Researcher	10	31/07/80
Mr. J. Robinson Researcher	10	31/07/80
Mr. R. Torrie Researcher	10	31/07/80
Gaz Métropolitain Inc.		
Mr. J. Baladi Vice-President Exploitation and Expansion Group	11	04/09/80
Mr. Pierre Noel Economist	11	04/09/80
Mr. R. Noel Vice-President, Marketing	11	04/09/80
Mr. Jean-François Villion Director, General Planning	11	04/09/80
Huron Ridge Limited		
Mr. N.J. MacGregor	34	09/12/80
ICG Scotia Gas Limited		
Mr. M.G. Meacher Vice-President and General Manager	19	24/09/80
Mr. H. Smith Legal Counsel	19	24/09/80
Imperial Oil Limited		
Mr. W.A. Bain Manager, Energy Studies Corporate Planning Services	9	30/07/80
Mr. D.J. Cameron Manager, Renewable Energy Corporate Planning Services	9	30/07/80
Institute of Man and Resources		
Mr. B. Brandon Project Coordinator Wood Energy	20	25/09/80
Mr. A. Wells Executive Director	20	25/09/80
Mr. W. Zimmerman Research Director	20	25/09/80

WITNESS	ISSUE	DATE
Inter-City Gas Corporation		
Mr. P. Ashton Consultant	29	20/11/80
Mr. H.C. Coppen Vice-President	29	20/11/80
Mr. N.J. Didur Group Vice-President	29	20/11/80
Jacques A. Khouri and Associates		
Mr. J.A. Khouri President	14	09/09/80
Lawrence Livermore National Laboratories, California, U.S.A.		
Dr. J. Emmett Associate Director Laser Fusion Program	35	02/12/80
Dr. R. Post Deputy Associate Director Magnetic Fusion Energy Physics	35	02/12/80
Marinetech Laboratories Ltd.		
Mr. G. Jones President	14	09/09/80
Mohawk Oil Company Limited		
Mr. A.E. Meyer Consultant	15	10/09/80
Morrison Beatty Limited		
Mr. W.D. Morrison Principal of Morrison Beatty Ltd.	13	06/09/80
McKenzie-McCulloch Associates		
Mr. I. McKenzie Principal	13	06/09/80
National Energy Board		
Mr. E.S. Bell Director Electric Power Branch	34	09/12/80
Mr. C.G. Edge Chairman	34	09/12/80
Mr. A.N. Karas Assistant Director Planning Group Electric Power Branch	5	15/07/80
Mr. P.G. Scotchmer Director Oil Policy Branch	34	09/12/80

WITNESS	ISSUE	DATE
Mr. K.W. Vollman Director Energy Resources Branch	34	09/12/80
National Research Council of Canada		
Mr. R.M. Aldwinckle Program Convenor Solar Energy Project	4	09/07/80
Dr. R.C. Biggs Senior Technical Advisor Solar Energy Project	4	09/07/80
Mr. M.S. Chappell Task Coordinator Renewable Energy	2	02/07/80
Dr. E.P. Cockshutt Manager Energy Research and Development Program	33	04/12/80
Mr. W.A. Cumming Senior Vice-President	33	04/12/80
Dr. L. Kerwin President	33	04/12/80
Dr. G.M. Lindberg Director National Aeronautical Establishment	2	02/07/80
Dr. G.R. Mogridge Research Officer Hydraulic and Tidal Power	7	22/07/80
Dr. J.J. Murray Research Officer	6	16/07/80
Dr. R.P. Overend Program Convenor Biomass Energy	3 33	08/07/80 04/12/80
Mr. J. Ploeg Program Convenor Hydraulic and Tidal Power	7	22/07/80
Dr. B.D. Pratte Research Officer Hydraulic and Tidal Power	7	22/07/80
Dr. P.A. Redhead Director Division of Physics	2 33	02/07/80 04/12/80
Dr. J.H. Simpson Solar Energy Project	4	09/07/80
Dr. J.B. Taylor Program Convenor Conservation and Storage	6	16/07/80

WITNESS	ISSUE	DATE
Mr. R.J. Templin Laboratory Head Low Speed Aerodynamics	2	02/07/80
New Brunswick Development Institute		
Mr. R.E. Tweeddale Chairman, Energy Committee	21	26/09/80
New Brunswick Federation of Agriculture		
Mr. T. Demma Secretary-Manager	21	26/09/80
Newfoundland Light and Power Company		
Mr. G.J. Adams Treasurer	18	23/09/80
Mr. D.C. Hunt, Q.C. Director	18	23/09/80
Mr. A.F. Ryan Assistant to the General Manager	18	23/09/80
NOVA, an Alberta Corporation		
Mr. J.E. Feick Vice-President	15	10/09/80
Ontario Hydro		
Mr. S. Stricker Research Division Electrical Department	8	29/07/80
Prince Edward Island Energy Corporation		
Mr. C.K. Brown Executive Director	20	25/09/80
Public Works Canada		
Dr. F. Snape Director Solar Projects	24	05/11/80
Royal Architectural Institute of Canada		
Miss M. Demers Architect	32	03/12/80
Mr. R. Elliott Executive Director	32	03/12/80
Mr. J.O. Miller Vice-President	32	03/12/80
Saskatoon Environmental Society		
Mr. H. Boerma	16	11/09/80

WITNESS	ISSUE	DATE
Scotia Liquicoal Limited		
Mr. J.R. Clore Jr. Production Manager	19	24/09/80
Mr. R.M. Medjuck, Q.C. Chairman	19	24/09/80
Mr. L.E. Poetschke President	19	24/09/80
Solace Energy Centre		
Mr. V. Enns Vice-President	14	09/09/80
Solar Applications and Research		
Mr. R.W. Bryenton Professional Engineer	14	09/09/80
Mr. C.P. Mattock Representative	14	09/09/80
Solar Energy Society of Canada Inc.		
Professor R. Chant Treasurer	17	12/09/80
Dr. G. Yuill Vice-Chairman	17	12/09/80
Town of Oromocto, New Brunswick		
Mr. N. Mills Superintendant Public Works	21	26/09/80
Mr. W.C. Ripley Mayor	21	26/09/80
Transport Canada		
Mr. N.R. Gore Director Strategic Studies Branch	36	11/12/80
Mr. J.J. Gravel Director General Research and Development	36	11/12/80
Mr. G.B. Maund Strategic Studies	36	11/12/80
Union Gas		
Mr. R.S. Adie Manager Contract Sales	12	05/09/80
Mr. S.T. Bellringer Vice-President Regulatory Affairs	12	05/09/80

WITNESS	ISSUE	DATE
Individual Witnesses		
Mr. André Balu Montreal, Quebec	11	04/09/80
Mr. D.C. Campbell Montreal, Quebec	13	06/09/80
Hon. Jack Davis M.L.A. North Vancouver-Seymour British Columbia	14	09/09/80
Mr. R. Dumont Saskatoon, Saskatchewan	16	11/09/80
Dr. K. Hare Provost of Trinity College University of Toronto	34	09/12/80
Professor J. Helliwell Department of Economics University of British Columbia	14	09/09/80
Dr. R.F. Legget Consultant Ottawa, Ontario	23	04/11/80
Professor M. Margolick Department of Economics University of British Columbia	14	09/09/80
Mrs. Kay Matuseh Vancouver, B.C.	14	09/09/80
Professor C.H. Miller Department of Mechanical Engineering Technical University of Nova Scotia	19	24/09/80
Dr. Arthur Porter Belfountain, Ontario	13	06/09/80
Professor D. Scott Chairman Department of Mechanical Engineering University of Toronto	29	20/11/80
Professor F. Smith Department of Chemistry Memorial University of Newfoundland	18	23/09/80
Professor G.B. Ward Fredericton, New Brunswick	25	12/11/80
Mr. B.E. Werenskiold Mississauga, Ontario	13	06/09/80

INTERVENORS AT PUBLIC HEARINGS

INTERVENOR	ISSUE	DATE
Circul-Aire (Eastern) Incorporated, Montreal, Quebec		
Mr. S.E. Huza, Executive Vice-President	11	04/09/80
Dr. B.C. Pant, Vice-President, Research and Development	11	04/09/80
Ecology Action Centre, Halifax, Nova Scotia		
Ms. Susan Holtz	19	24/09/80
Energy Systems Limited, Toronto, Ontario		
Mr. D. Hart, President	12	05/09/80
Onakawana Development Limited, Ontario		
Mr. P. Turner	13	06/09/80
Mr. A. Olaf Wolff, Vice-President and General Manager	13	06/09/80
South Okanagan Civil Liberties Society, Penticton, British Columbia		
Mr. Walt Taylor, Vice-President	14	09/09/80
The Biomass Energy Institute Inc., Winnipeg, Manitoba		
Mr. E.E. Robertson, Executive Director	17	12/09/80
The Crossroads Resource Group, Winnipeg, Manitoba		
Mr. L. McCall	17	12/09/80
Mr. H. Selles	17	12/09/80
Trinity Solar Project, Toronto, Ontario		
Reverend Patrick Doran, Consultant, National Affairs	12	05/09/80
Reverend Peter Hamel	12	05/09/80
Individual Intervenors		
Mr. T. DeMone, Prince Edward Island	20	25/09/80
Mr. T. Easter, Prince Edward Island	20	25/09/80
Mr. K. Emberley, Winnipeg, Manitoba	17	12/09/80
Mr. A. Larochelle, Toronto, Ontario	13	06/09/80
Mr. H.F. MacDonald, Prince Edward Island	20	25/09/80
Mr. Dimitri Procos, Technical University of Nova Scotia, Halifax, Nova Scotia	19	24/09/80
Mr. Bruce Young, Penticton, B.C.	14	09/09/80

APPENDIX C

Witnesses at Informal Committee Hearings

List of witnesses who appeared before the Special Committee at informal hearings (not electronically recorded).

WITNESS	DATE
Allen-Drerup-White Limited, Toronto, Ontario	
Mr. G. Allen Principal	06/09/80
Ms. E. White Principal	06/09/80
Board of School Trustees, District No. 26, Fredericton, New Brunswick	
Mr. T. Joordens Director of Maintenance	14/11/80
Mr. R. Kilburn Chairman Property Committee	14/11/80
Mr. G. Young Member Property Committee	14/11/80
City of Fredericton, Fredericton, New Brunswick	
Mr. R. Danzinger Director of Planning	14/11/80
Conservation Council of New Brunswick, Fredericton, New Brunswick	
Mr. D. Silk President	14/11/80
Enerplan, Toronto, Ontario	
Mr. G. Ross President	06/09/80
Inertia Group Limited, Toronto, Ontario	
Mr. J. Lstiburek President	06/09/80
New Brunswick Electric Power Commission, Fredericton, New Brunswick	
Mr. K.B. Little Acting Assistant Treasurer	14/11/80
Mr. G.L. Titus Manager Strategic Development	14/11/80
Mr. P.J. Whalen Director Research and Development	14/11/80
Renewable Energy in Canada, Toronto, Ontario	
Mr. R. Argue President	06/09/80
The Hay River and Area Economic Development Corporation, Hay River, N.W.T.	
Mrs. F. Hasey Executive Manager	18/09/80
Yukon Conservation Society, Whitehorse, Yukon	
Ms. N. MacPherson President	19/09/80
Individual Witness	
Mr. M. Hambridge Whitehorse, Yukon	19/09/80

APPENDIX D

Other Written Submissions Received

List of individuals and organizations who submitted briefs and letters to the Special Committee, but who did not appear as witnesses.

Baird, Mr. Hamilton, Moncton, New Brunswick
Barichello, Mr. C., Windsor, Ontario
Batho, Mr. David G., Ottawa, Ontario
Brown, Cherry L., The Conserver Society, Dunster, British Columbia
Bryan, Mr. R.C., Council of Forest Industries of British Columbia, Vancouver, British Columbia

Campbell, Mr. D.C., Canadian Electrical Association, Montreal, Quebec
Caron, Mr. Jean R., Honeywell Limited, Scarborough, Ontario
Chrysler, Mr. Geoffrey, Caliente Sun Systems, Ottawa, Ontario
Cote, Mr. R., Atomic Energy of Canada Limited, Ottawa, Ontario
Coulter, Mr. Philip E., Scarborough, Ontario

D'Amore, Mr. L.J., L.J. D'Amore and Associates Ltd., Montreal, Quebec
Dangerfield, Mr. James, The Hydrogen Organization, Independence, Missouri, U.S.A.
Daniel, Mr. C. William, Shell Canada Limited, Toronto, Ontario
Davies, Mrs. Kay, Canadian Institute of Planners, Ottawa, Ontario
Dechow, Mr. Dick R., St. Catherines, Ontario
Delisle, Mr. André, Bolé Inc., Quebec, Quebec
DeLong, Mr. E.A., Kanata, Ontario
Desautels, Mr. René C., Lubrimax Inc., Pointe Claire, Quebec
Dionne, Mr. Pierre-Yves, Ste-Foy, Quebec

Edell, Mr. Dennis, Hampton Technologies Corp. Ltd., Charlottetown, Prince Edward Island
Egglestone, Mr. A.E., Alberta Gas Chemicals Limited, Edmonton, Alberta
Ellenberger, Mr. Roger, ACCESS, Porters Lake, Nova Scotia

Fetter, Mr. Stephen, Sault-Ste-Marie, Ontario
Fischer, Mr. Karl, Chilliwack, British Columbia
Foster, Mr. David, Energy Pathways - Policy Research Group, Killaloe, Ontario

Glasstetter, Mr. Rudy, Toronto, Ontario
Gordon's Feversham Feeds, Feversham, Ontario
Grammenos, Mr. Fanis, ECODOMUS Development Limited, Ottawa, Ontario
Gurney, Mr. Peter R., Intercontinental Engineering Ltd., Vancouver, British Columbia
Gutsfeld, Mr. A., Hamilton, Ontario

Hale, Mr. Neville E., Fathom Oceanology Limited, Port Credit, Ontario
Hart, Mr. Norman S., Sydenham, Ontario
Hathaway, Mr. Norman B., Dietrich-Hathaway Energy Systems, Toronto, Ontario

Jalkotzy, Mr. Christoff, Solartic Energy Conscious Housing Inc., Ottawa, Ontario
Jones, Mr. Trevor, Vancouver, British Columbia
Jones, Mrs. Anne H., The Regional Municipality of Hamilton-Wentworth, Hamilton, Ontario
Jones, Mr. R., Realyne Machine and Design, Orangeville, Ontario
Jones, Mr. R.D., The Conserver Society, Dunster, British Columbia

Kashtan, Mr. William, Communist Party of Canada, Toronto, Ontario
Keyes, Mr. Thomas E., Regina, Saskatchewan

Lavoie, Mr. Joseph, Montreal, Quebec
Leadman, Mr. Douglas, Perth, Ontario
Lépine, Mr. Yves, Ste-Anne-de-Bellevue, Quebec
Lewis, Mr. Jay, South Okanagan Environmental Coalition, Penticton, British Columbia
Lewis, Mr. Ray, Langley, British Columbia

MacKinnon, Mr. Charles, Victoria, British Columbia
Marlor, Mr. Lloyd, Sol-Term Research Limited, West Vancouver, British Columbia
Marshall, Mr. Gary E., OMNIUM Consultants Co., Ottawa, Ontario
Martin, Mr. Conrad, Wyoming, Ontario
Martin, Professor David, Lakehead University, Thunder Bay, Ontario
Matas, Mr. David, Winnipeg, Manitoba
McClure, Mr. Robert, Hamilton, Ontario
McCorquodale, Mr. R.P., Wetcom Engineering Limited, Scarborough, Ontario
McFadden, Mr. David J., LeRoy-Somer Canada Limited, Mississauga, Ontario

McKinley, Mr. B., Athans Chemicals, Ottawa, Ontario
Mehler, Mr. Ted, Yellowknife, Northwest Territories
Michrowski, Dr. Andrew, Planetary Association for Clean Energy Inc., Ottawa, Ontario

Newton, Mr. Ken, Ottawa, Ontario
Noble, Mr. G., IOTECH Corporation Ltd., Ottawa, Ontario
Northover, Mr. A.C., Newmarket, Ontario

Olivier, Mr. Mario, Bolé Inc., Quebec, Quebec
O'Shaughnessy, Mr. M., Ottawa, Ontario

Pallasch, Mrs. Elsie, Stoney Creek, Ontario
Perley, Mr. Daniel R., OMNIUM Consultants Co., Ottawa, Ontario
Pill, Dr. Juri, Toronto Transit Commission, Toronto, Ontario

Quittenton, Mr. R.C., Quittenton Associates, Saskatoon, Saskatchewan

Schneider, Mr. M.H., University of New Brunswick, Fredericton, New Brunswick
Shapiro, Dr. M.M., Montreal, Quebec
Sinclair, Mr. G., Laser Fusion Limited, Concord, Ontario
Smith, Mr. L.A., Stanfer Manufacturing Co. Ltd., Montreal, Quebec
Stepp, Mr. Math, Moose Jaw, Saskatchewan
Strang, Mr. D.K., Canadian Resourcecon Ltd., Calgary, Alberta
Street, Mr. R.J., Mohawk Lubricants Limited, North Vancouver, British Columbia

Teekman, Mr. Nicholas, Dynamo Genesis Inc., Charlottetown, Prince Edward Island
Thomson, Mr. William, Canadian Institute of Planners, Waterloo, Ontario
Thornton, Mr. S., Unionville, Ontario
Tidman, Mr. C., Nepean, Ontario
Turvolgyi, Mr. B.L., DuPont Canada Incorporated, Montreal, Quebec

Vandezande, Mr. Gerald, C.J.L. Foundation, Toronto, Ontario
Vigrass, Dr. Lawrence, University of Regina, Regina, Saskatchewan

Wilson, Mr. J.E., Ontario Hydro, Toronto, Ontario

APPENDIX E

Committee Travel

TRAVEL IN CANADA

The Committee visited every Province and the Yukon and Northwest Territories during the course of its study. In each capital city, in addition to holding public hearings, the Committee met with government representatives.The Committee also visited a number of facilities concerned with alternative energy development.

ALBERTA

Ministry of Energy and Natural Resources

Hon. C. Mervin Leitch, Minister
G.B. Mellon, Deputy Minister, Energy Resources
Thomas Ryley, Senior Analyst

BRITISH COLUMBIA

British Columbia Hydro and Power Authority

Joseph Stauder, Geothermal Energy Division
Bob Woodley

Ministry of Energy, Mines and Petroleum Resources

Robert W. Durie, Assistant Deputy Minister of Petroleum Resources
James Hill
Doug Horswill, Director, Policy Development, Energy Resources Branch
Harry Swain, Assistant Deputy Minister of Energy Resources

Ministry of Universities, Science and Communications

R.W. Stewart, Deputy Minister

FEDERAL GOVERNMENT AGENCIES

Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (CANMET), Department of Energy, Mines and Resources, Ottawa

E.J. Anthony, Fluidized-bed Combustion
R.W. Braaten, Automotive Fuel and Domestic Heating Technology
T.D. Brown, Manager, Coal Resource and Processing Laboratory
F.D. Friedrich, Research Scientist, Canadian Combustion Research Laboratory
V.A. Haw, Acting Director-General, CANMET
G.K. Lee, Manager, Canadian Combustion Research Laboratory
B.I. Parsons, Chief, Energy Research Laboratories
H. Whaley, Coal Combustion

National Research Council, Montreal Road Laboratories, Ottawa

The Committee's visit to the NRC facilities was combined with a public hearing and the participants are listed in Appendix B.

MANITOBA

Department of Energy and Mines

M.A. Chochinov, Director, Energy Management Branch
L.P. Haberman, Director, Conservation and Renewable Energy Branch
Paul E. Jarvis, Deputy Minister

Manitoba Energy Council

William McDonald, Secretary

NEW BRUNSWICK

Hon. Richard Hatfield, Premier

Department of Natural Resources

Robert Watson, Coordinator, Policy Planning
John Williamson, Energy Secretariat

Ministry of Finance and Minister Responsible for Energy Policy

Hon. Fernand G. Dubé, Minister

New Brunswick Coal Limited

L.S. Armstrong, President and General Manager

New Brunswick Electric Power Commission

Hon. G.W.N. Cockburn, Q.C., Chairman

NEWFOUNDLAND

Department of Mines and Energy

Hon. Leo D. Barry, Minister
Doug Inkster, Director, Hydro-Electric Division
John H. McKillop, Deputy Minister
Edward Power, Assistant Deputy Minister, Energy

Newfoundland and Labrador Hydro

Victor Young, Chairman

NORTHWEST TERRITORIES

John Parker, Commissioner of the Northwest Territories

Department of Renewable Resources

Jim Cumming, Chief, Energy Conservation
Peter Hart, Special Assistant on Energy to Minister of Renewable Resources

NOVA SCOTIA

Department of Mines and Energy

Hon. Ronald T. Barkhouse, Minister
John French, Director, Energy Management
Vaughn Munroe
Carey Ryan, Senior Engineer
W.S. Shaw, Deputy Minister

ONTARIO

Ministry of Energy

H.F. Bakker, Renewable Energy Program
Richard Fry, Renewable Energy Program
R.M.R. Higgin, Director, Renewable Energy Program
Syd Johnson, Renewable Energy Program
I.B. MacOdrum, Executive Coordinator, Conventional Energy
W.W. Stevenson, Executive Coordinator, Strategic Planning and Analysis
Bunli Yang, Senior Advisor, Transportation and Renewable Energy

Ministry of Natural Resources, Kemptville

P.E. Anslow, Regional Forester, Eastern Region
B.A. Barkley, Program Forester, Hybrid Poplar Program
A.J. Campbell, Nursery Superintendant
J. Carrington, Information Officer
D.P. Drysdale, Energy Co-ordinator for the Ministry
R.W. Evers, Program Forester, Hybrid Poplar Program
B.E. Hollingsworth, Program Technician, Hybrid Poplar Program
R.K. Keane, Program Technician, Hybrid Poplar Program
J.R. Oatway, Regional Director, Eastern Region
W.E. Raitanen, Regional Forestry Specialist

Ministry of Transportation and Communications

K.O. Sharratt, Manager, Transportation Energy Management Program

Ontario Energy Corporation

Peter Lamb, Executive Vice-President

Ontario Hydro

J.E. Wilson, Manager, Public Hearings

Ontario Hydrogen Energy Task Force

Arthur C. Johnson, Chairman

Solartech Limited

Scott Griffin
David Wood, President

PRINCE EDWARD ISLAND

Hon. J. Angus MacLean, Premier

Ministry of Tourism, Industry and Energy

Hon. Barry R. Clark, Minister

QUEBEC

Brace Research Institute, Faculty of Engineering, Macdonald College of McGill University, Ste-Anne-de-Bellevue, Quebec

T.A. Lawand, Director

Hydro-Québec, Magdalen Islands Vertical Axis Wind Turbine

Ministère de l'Énergie et des Ressources

Pierre Baillargeon, Adjoint aux affaires intergouvernmentales
Jean Guérin, Directeur, Direction de l'analyse économique et financiare
Denis L'Homme, Directeur, Direction générale des energies conventionnelles
Gilles Toussingnant, Directeur, Direction de la production et de l'approvisionnement
Gilles St-Hilaire, Directeur, Direction des programmes des energies nouvelles

SASKATCHEWAN

Saskatchewan Mineral Resources

Fred Heal, Director, Office of Energy Conservation
Jim Hutchinson, Assistant Director and Coordinator, Energy Research and Development, Policy Planning and Research
Ron Sully, Director, Policy Planning and Research
Menna Weese, Energy Policy Advisor, Policy Planning and Research

YUKON

Ministry of Tourism and Economic Development

Hon. Dan Lang, Minister

INTERNATIONAL TRAVEL

The Committee divided into subcommittees for the international travel to obtain as broad an input as possible from the public and private sectors in the countries visited, and to cover a variety of alternative energy facilities.

BRAZIL

Vice-President of the Republic of Brazil

Antonio Aureliano Chaves de Mendonca, Vice-President and Director of National Energy Program

COALBRA - Coque e Alcool de Madeira S.A., Sao Paulo

Renzo Dino Sergente Rossa, Technical Director

Committee of Mines and Energy, Brasilia

Deputy Génesio de Barros, Chairman

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria), Brasilia

Dr. Ademar Brandini
Dr. Flavio Couto
Dr. Porto

Ford Brazil, Sao Paulo

Luc de Serran, Chief Engineer
Lyn Folstead, President
Robert Gerrity, Vice-President
Larry Kazanoushi, Director
Wellington Young, General Planning Manager

Forum das Americas/Brasilinvest

David Dana, Director, Formas das Americas
de M. Junqueira, Project Director, Brasilinvest
Samsao Woiler, Executive Director, Brasilinvest

Fundacao de Tecnologia Industrial (Division of Ministry of Industry and Commerce), Rio de Janeiro

Alexandre Henriques
Nancy Iueiroz de Anaijo
Ferga Rosenthal

Petrobras, Rio de Janeiro

Rolf Brauer
Dieter Brodhun
Dr. Ivo
Marco Luiz dos Santos
Ileana Williams, Head, Product Development Division

Secretaria da Industria, Comerico, Ciencia e Tecnologia, Sao Paulo

Vincente Chiaverini, Executive Vice-President, Science and Technology Council

Secretariat of Industrial Technology, Brasilia

Marcos Lima Fernandes, Executive Director of the National Executive Alcohol Commission (CENAL)
Lourival Carmo Monaco

Sondotecnia Engenharia, Rio de Janeiro

Jamie Rotstein, Directore-Presidente

Universidade Federal do Rio de Janeiro

Paulo Gomes, Director, Coordenacao dos Programas de Pos-Graduaco de Enginharia
Flavio Grynszpan
Carlos Russo

FRANCE

Commissariat à l'Energie Solaire, Paris

M. Yves Perras

L'Agence Pour Les Economies d'Energie, Paris

M. Maillard, Economics of Renewable Energy
M. Jean Poulit

La Centrale de Chauffage Urbain de Paris

M. Triboulet, Plant Manager

La Rance Tidal Power Station, Dinard

M. Julliard, Electricité de France

Organization for Economic Cooperation and Development (OECD), Paris

Ambassador Gherson, Canadian Ambassador to the OECD
Dr. Eric Willis, Director of Research, Development and Application of Technologies, International Energy Agency

Solar Furnace, Odeillo, Pyrénées Orientales

Centre National de la Recherche Scientifique (CNRS)

ICELAND

Ministry of Energy and Industry

Pall Flygenring, Secretary General of Ministry of Energy
Hon. Hjorleifur Guttormsson, Minister

National Power Company, Reykjavik

Johann Mar Mariusson, Head of Engineering

State Electric Power Works, Reykjavik

Steiner Fridgeirsson, Head of Planning Division
Kristjan Jonsson, Managing Director

IRELAND

Bord na Mona, Dublin

John Crowe
Derry Greena, County Kildare
Bob Laird, Senior Administrative Engineer
P. McEvilly, General Works Manager, Head Office
Dennis O'Rourke, Manager
Tom Quinn, Manager, Clonsast Bog
Lewis Rhatigen, Managing Director

Eamon Kinsella
Tom O'Flaherty, Kinseally Research Centre

ITALY

Dr. S. Verrie, Duomo Imports Limited, Milan

SWEDEN

Secretariat for International Affairs

Carl Ivar Ohman, Director
Lars-Ake Erikson

Commission for Energy Research, Stockholm

Sigfrid Wennerberg

Department of Industry

Harold Hagermark

UNITED STATES

Mr. Harry Horne, Canadian Consul General, San Francisco

Congress of the United States, Energy Research and Production Subcommittee, Washington, D.C.

Congressman Mike McCormack, Chairman
Staff of the Subcommittee

Congressional Research Service, Washington, D.C.

James E. Mielke, Analyst in Marine and Earth Sciences
J. Glen Moore, Analyst in Energy Technology
Lani Hummel Raleigh, Energy, Aerospace and Transportation Section Head
Migdon Segal, Analyst in Energy Technology

Department of Energy, Washington, D.C.

C. Worthington Batemah, Under Secretary of Energy
Paul Brown, Director, Electric and Hybrid Vehicle Program, Office of Transportation Programs, Conservation and Solar Energy
Ambassador Halsey G. Handyside, Deputy Assistant Secretary for International, Nuclear and Technical Programs, International Affairs
James S. Kane, Associate Director for Basic Energy Sciences, Energy Research
Richard Passman, Director, Office of Coal Resource Management, Resource Applications
Michael Roberts, Director of Planning and Projects, Energy Research
Jack Solsberry, Deputy Director, Geothermal Energy Division, Resource Applications
Joel Weiss, Executive Assistant to the Deputy Assistant Secretary for Solar Energy, Conservation and Solar Energy

Electric Power Research Institute, Palo Alto, California

Ed DeMeo, Solar and Wind Energy
Shelton Ehrlich, Program Manager, Fluidized Combustion, Coal Combustion Systems Division
Walt Esselman, Manager, Strategic Planning Department
Neville Holt, Coal Gasification
Evan Hughes, Project Manager, Advanced Geothermal Systems
R. Rhodes, Member, Technical Staff, Policy Planning Division
Robert Scott, Program Manager, Fusion Power Systems Program
Ron Wolk, Coal Liquids

Georgetown University, Washington, D.C.

Dan Farrell
G. Shaff, Power Plant Manager
S.E. Winberg, Service Engineer, Foster Wheeler Energy Corporation

H-Coal Plant, Catlettsburg, Kentucky

James K. Farley, U.S. Department of Energy
Harold H. Stotler, Technical Manager

Lawrence Livermore National Laboratory, Livermore, California

Roger Batzel, Director
John Cooper, Co-principal Investigator, Metal-Air Battery Program
John Emmett, Associate Director, Laser Fusion Program
Mortimer L. Mendelsohn, Biomedical and Environmental Research Division
Richard Post, Deputy Associate Director, Magnetic Fusion Energy Physics
Erik Storm, Assistant Associate Director, Laser Fusion Program
Kenneth Street, Associate Director for Energy and Resource Programs

Office of Technology Assessment, Washington, D.C.

John Gibbons, Director
Lionel Johns, Assistant Director, Energy, Materials and International Security Division
Nancy Naismith, Project Director, Energy Program, Energy, Materials and International Security Division
Marvin Ott, Director, Congressional and Institutional Relations
Richard Rowberg, Energy Program Manager, Energy, Materials and International Security Division

Pacific Gas and Electric, The Geysers Geothermal Electric Development, California

Jack Trotter, Public Activities Representative, Geysers Project

Plasma Physics Laboratory, Princeton University, Princeton, New Jersey

K. Bol, Head, Princeton Demonstration Experiment (PDX)
H.P. Furth, Program Director
M.B. Gottlieb, Director

D.M. Meade, Head, Experimental Division
R.G. Mills, Acting Head, Engineering Program
P.J. Reardon, Associate Director for Technology
R.A. Rossi, Associate Director, Administration
J.A. Schmidt, Head, Applied Physics Division
M.L. Shoaf, Assistant Director
T.H. Stix, Associate Director for Academic Affairs
W. Stodiek, Head, Princeton Large Torus (PLT)

Sandia Laboratories, Albuquerque, New Mexico

B.E. Bader, In Situ Coal Gasification
James F. Banas, Line Focus Technology
R.H. Braasch, Wind Energy
William W. Marshall, Supervisor, Central Receiver Test Facility
A. Narath, Vice-President
Donald G. Schueler, Photovoltaics
James H. Scott, Director of Energy Programs
Gerald Yonas, Director of Pulsed Power Programs

Smith-Bowman Distillery, Reston, Virginia

John B. Adams Jr., Vice-President

Solar Energy Research Institute, Golden, Colorado

Denis Hayes, Director
Ken Touryan, Deputy Director and Head of Research and Development

Analysis and Applications Directorate

Charles Berberich, Information Systems Division
Roy Bracken, International Division
Dean Eaton, International Division
Murrey Goldberg, International Division
James Howe, International Division
Henry Kelly, Head

SPM Group Incorporated, Englewood, Colorado

Konrad Ruckstuhl, Chairman
Robert D. Schmidt, President

WEST GERMANY

His Excellency Klaus Goldschlag, Canadian Ambassador to West Germany, Bonn

Federal Ministry of Research Technology, Bonn

Herr Jacobs, Non-nuclear Energy Research
Dr. Marcus, Coal Technology
Wolf J. Schmidt-Küster, Head of Department

Ruhrkohle Oel und Gaz, Duesseldorf

Herman G. Krischke, Project Manager, Fluidized Bed Combustion
Josef Langhoff, Director

STEAG Corporation, Essen and Lünen

Dr. Reimer Fuchs
Dr. Hein, Lünen Coal Gasification Plant
Herr Schuster, Essen, Boltrop Gelsenkirchen District Heating System


COAL TECHNOLOGIES
NONCONVENTIONAL PROPULSION
FUEL CELLS
DISTRICT HEATING
ELECTRICAL GENERATION
HEAT PUMPS
HYDROGEN