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Science Council of Canada

Report 30
June 1979

Roads to Energy Self-Reliance

The Necessary National Demonstrations

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June 1979

The Honourable R. J. Hnatyshyn, PC, MP
Minister of State for Science and Technology,
House of Commons,
Ottawa, Canada.

Dear Minister Hnatyshyn,
In accordance with Section 13 of the Science Council of Canada Act, I take pleasure in forwarding to you the Council's Report No. 30, Roads to Energy Self-Reliance: The Necessary National Demonstrations.
Yours sincerely,

Claude Fortier,
Chairman,
Science Council of Canada

May 1979

Dr. Claude Fortier,
Chairman,
Science Council of Canada

Dear Dr. Fortier:

Not long after the publication of Report No. 23, *Canada's Energy Opportunities*, Council charged its Energy Committee with the responsibility of formulating sharply focussed, action-oriented instruments and processes that could be used to implement the recommendations. To this end, the Committee was restructured to ensure the inclusion of broadly based, yet expert advice from many sectors of energy interests and industries, and regions of the country. During the ensuing three years, the theme and directions developed by the Committee were presented to Council on a number of occasions for its consideration and advice.

As stated in *Canada's Energy Opportunities*, this country had reason to be optimistic about its long-term energy future, if our highly developed technological skills were applied to the realization of our energy resource potential. The main thrust of this Report is that amongst the vast array of actions that we should, as a nation, be undertaking now to ensure adequate long-term future energy supplies, it is essential to focus a substantial part of our scientific and engineering efforts on relatively few demonstration projects. These projects should be designed and undertaken to assess and demonstrate the commercial and social viability of the technologies and the industries required to assure access to known energy resources and in addition, to develop the capability to convert them to the forms required by users. Only by doing so, will we be able to reduce the uncertainties now clouding Canada's energy future.

In all, eleven specific demonstration projects are recommended in conjunction with a description of the methodology employed to select them. They range widely in scope, scale, anticipated duration, and in the structures recommended for their financing and management. While several other projects might have been included, those selected are considered to be amongst the most important and serve as illustrations of the scale of funding required and of the close cooperation between government and private enterprise that is necessary.

Without the expert staff work of Mr. E.R.Q. Stoian, in support of the Committee's activities, it would not have been possible to assemble and assess with confidence, the myriad factors necessary for the development of the Report. This task was made all the more difficult by the rapidly changing conditions influencing this country's energy situation and future prospects.

It is important for us as a nation to know both what we can and what we cannot do to meet our anticipated long-term energy needs. This Report is commended to Council and to our policy makers with the conviction that implementation of its recommendations will contribute to the displacement of uncertainty and speculation and to their replacement by understanding and committed action, both necessary for the attainment of future energy self-reliance.

Throughout the final stages of the preparation of this Report, I have attempted to ensure that it reflects the recommendations of the Committee while incorporating the views and instructions of Council. Now, it is my pleasure to formally convey Report No. 30, *Roads to Energy Self-Reliance: The Necessary National Demonstrations* to Council.

Yours very truly,

A.A. Bruneau,
Chairman,
Science Council Committee on Energy Scientific Policies.

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Preface

Since its inception, the Science Council of Canada has been actively involved in energy matters from several broad perspectives. In general, the range of Council interests attempted to match the complexity and pervasiveness surrounding energy itself. Report No. 23, *Canada's Energy Opportunities*, published in March 1975, set the framework for such discussions. The Report put forward the argument for a national policy, and emphasized the urgent need for federal and provincial government involvement. Various Canadian energy options were identified, and the case was made for an integrated research and development program to keep all essential options open. The recommendations are still considered valid today.

From 1958 to 1963, both the federal and the provincial governments intervened in the energy system to bring about required structural changes (such as creation of the National Energy Board and Hydro Québec). This was the beginning of the era during which a national oil policy was designed to obtain the simultaneous advantages of relatively cheap oil imports for the East and higher-priced oil exports to the United States for the West (the so-called Ottawa Valley Line).

Subsequent realization that Canada's conventional oil and gas reserves were not as great as once expected, combined with the OPEC oil embargo and price escalations of 1973–74, necessitated urgent reconsideration of our national oil policy. Although affected in different ways, all the oil-importing, industrialized countries were forced to re-evaluate their positions and revise their national energy policies.

In *An Energy Strategy for Canada*, published in 1976, the federal government identified self-reliance as central to any future energy policies, of which important components would be the urgent need for conservation and the development of renewable energy sources. During the winters of 1976–77 and 1978–79, Canadians were again reminded of the importance of reliable and relatively cheap energy supplies.

During the period of re-orientation toward self-sufficiency, a number of economic and structural problems were encountered:

1. General economic downturn.
2. Inadequate oil and gas pipeline capacity to serve markets in Québec and the Maritime Provinces.
3. Excess refinery capacity in Eastern Canada, and an inability to upgrade Western heavy oil to pipeline oil.
4. Sale of residual oil surpluses in Eastern Canada at arbitrarily low prices, because an inability to process it further had an artificial and negative effect on the development of Eastern natural gas markets.

Recently, because of higher prices, new oil and gas discoveries in Western Canada have resulted in re-orientation away from disappointing frontier exploration toward established producing areas and conventional supplies — not excluding the new forms of hydrocarbon resources ("tight sands", "deep basin gas", and especially "*in situ*" oil sands).

With industry's emphasis on the concept of excess capacity ("gas bubble") rather than surplus assured reserves, Canadian governments (federal and provincial) are again exposed to pressures for natural gas exports. In the absence of an adequate framework for longer-range and more consistent national decisions, Canada runs the risk of jeopardizing the policy of self-reliance for the more immediate intention of defending its dollar.

At the same time, there is a real and growing concern about Canada's ability to meet its energy-related social and environmental costs. In this context, a number of energy options must be identified and studied, and it is therefore the primary objective of this Report to propose a set of Energy Demonstration Programs which would greatly increase confidence in those crucial decisions on which our future energy position must be based.

In formulating these recommendations, the Science Council of Canada received valuable advice from a committee whose collective expertise covered a wide range of energy technologies. The Science Council is indebted to the Committee on Energy Scientific Policies for its major contribution to this ongoing examination of Canada's energy opportunities and technological requirements for self-reliance.

Summary of Conclusions and Recommendations

The Arab oil embargo of 1973–74 and subsequent OPEC price escalations have led Canadians to recognize that their energy supplies are finite and that Canada, like many other countries, has become overly dependent on oil. Canada has been depleting conventional oil resources at an accelerating rate and will be forced to import more expensive oil in substantial quantities, for the forseeable future. Oil imports cost Canadians several billion dollars each year. If this expense is to be controlled and if Canadians are to meet longer-term energy requirements, with self-reliance as the goal, Canada must increase its energy options. The key to new energy sources is Research, Development and Demonstration, with the major emphasis on a well-organized and strategic program of *technological demonstrations*.

If Canada is to (a) avoid the economic disruptions caused by large imports of increasingly expensive oil; (b) minimize the impact of politically motivated interruptions of this dominant resource, and (c) systematically develop long-term sources and technologies leading to self-reliance, it must:

- In the *short term*, find effective ways to minimize oil imports by conservation, substitution by alternative fuels, improved energy conversion processes, and more effective recovery of other hydrocarbon resources.
- In the *long term*, explore those energy opportunities most appropriate to satisfy Canada's projected match of requirements and resource contributions. A number of energy use and supply technology options must, therefore, be studied simultaneously.

This Report:

1. Documents the need for a national energy demonstrations program and recommends that certain vital technology demonstrations be undertaken without delay.

2. Recommends prompt implementation on the basis of currently available information, with periodic reassessment and priority determination as the demonstrations program progresses.

A number of Research, Development and Demonstration (R, D & D) activities are in progress, but the urgency of the present energy situation dictates better determination of strategies, in which certain well-targeted demonstration programs are given *priority*. Preparatory research and development must be carried out on the broadest front. In some cases demonstration programs should be undertaken before the entire R & D base matures. Certain industrial-scale energy demonstrations could commence immediately, although they should proceed with caution in order to minimize risk. The experience thus obtained will steadily reduce the uncertainties associated with alternative energy sources. Key technologies will be developed and will permit a better assessment of relative costs and ultimate commercial viability. In addition, realistic demonstrations will play an important role in projecting environmental and social impact.

The Science Council of Canada therefore recommends that the following demonstration programs be undertaken.

Fossil Fuels

Oil and Gas

1. Technological capability for exploration and production of oil and gas in ice-congested waters.
2. Transportation of hydrocarbons from the high Arctic by marine mode.
3. Exploration and production of oil and gas in very deep waters.

Coal

4. Fluidized-bed technology.
5. Land reclamation after coal is strip-mined.

Nuclear Energy

6. Irradiated fuel management and disposal systems — inclusive of adequate R & D.
7. Feasibility of the thorium cycle — inclusive of economic and systems aspects.

Renewable Energy

8. Generation of gaseous and liquid fuels from forest and agricultural residues — with an assessment of economic and commercial factors related to biomass energy technology.
9. Solar water and space heating systems.
10. Energy generation from solid wastes.

Conversion Technologies

11. Co-generation of electricity and heat — inclusive of economic and management aspects.

(Details of these demonstration projects are provided in the Annex. See page 83.)

The funding estimates for the recommended demonstration programs in millions of 1978 dollars are as follows:

Energy Type or Technology	Initial Funding (First Five Years)	Total Funding (Cumulative to Completion
Oil and Gas	650	900
Coal	35	255
Nuclear Energy	147	2200
Renewable	21	136
Conversion Technologies	6	270
Total*	860	3760

*Because of rounding, groups do not add up to totals.

The total $3.8 billion (1978) would be spent over the next 30 years. This would provide for essential diversification of Canada's energy options, while involving more industrial sectors and marshalling more human-resource capabilities.

Put in perspective, the federal government projects an expenditure of $3.0 billion for R, D & D by the year 2000, based on the 1977–78 level. It has been estimated that by 1990 the capital investment for Canada's energy production industry will be as high as $200 billion. Costs associated with demonstration aspects of the programs recommended in this Report, therefore, represent less than 2 per cent of overall capital requirements. Moreover, these funding requirements are considered modest when compared to costs of anticipated oil imports.

Next in importance to the selection of demonstrations are the problems of implementation. Clearly, government support will be required for the transfer of technology to final commercialization. Several means of managing and funding these projects, which are more generally applicable to demonstrations, are indicated in Chapter V. Nevertheless, certain demonstrations are very site-dependent and must be linked to specific commercial opportunities.

The scale and diversity of the effort involved will seriously test the management techniques of Canadians. A wide range of institutions, from designated private organizations to government-owned corporations, have initiated a number of successful management innovations. Such institutions can be used to stimulate the development of Canadian industrial expertise in those sectors in which this country has a comparative advantage.

If the private sector is to benefit from the opportunity to commercialize new energy technologies, governments will have to ensure that the industrial environment is conducive to the optimal transfer of technology, from demonstration to commercialization. This will require long-term financial incentives and a regulatory framework that will foster maximum industrial development. Only in this way will Canada be able to develop fully the technological capabilities in the energy field which are required to support our economic and social aspirations.

Abbreviations and Acronyms

AECB	Atomic Energy Control Board
AECL	Atomic Energy Canada Limited
AOSTRA	Alberta Oil Sands Technology and Research Authority
API	American Petroleum Institute
Btu	British thermal unit; sometimes BTU
CANDU	Canadian Deuterium Uranium Reactor
CANMET	Canada Centre of Mineral and Energy Technology, EMR
CIM	Canadian Institute of Mining
CPA	Canadian Petroleum Association
DOE	Department of Environment, Canada; Department of Energy, US
ECE	Economic Commission for Europe
EMR	Energy, Mines and Resources Department, Ottawa
ERCB	Energy Resources Conservation Board of Alberta
ERDA	Energy Research and Development Administration, US
E exa	quintillion or 10^{18}; e.g., 10^{18} joules or one exajoule approximate one quad
FBC	fluidized bed combustion
FIRE	Forest Industry Renewable Energy
GNP	Gross National Product
INFCE(P)	International Nuclear Fuel Cycle Evaluation (Program); initiated May 1977 at the Western Summit meeting in London, UK
IPAC	Independent Petroleum Association of Canada
IREC	Institute of Research of Hydro Quebec, Varennes
LNG	Liquefied Natural Gas
LPG	Light Petroleum Gases; Liquefied Petroleum Gas
NEB	National Energy Board
NPT	Non-Proliferation Treaty
NRC	National Research Council of Canada
OR	Operations Research
OPEC	Organization of Petroleum Exporting Countries
PASEM	Plan of Assistance to Solar Energy Manufacturers
PRI	Petroleum Recovery Institute, University of Calgary Campus
PUSH	Purchase of Solar Heating
Q	quintillion of Btu's, 10^{18}
q	quad; quadrillion of Btu's, 10^{15}
R, D, D, & D	research, development, demonstration and deployment
SNG	synthetic or substitute natural gas
TCF	trillion cubic feet

I. Introduction

Events, Trends, and Uncertainty

The Arab oil embargo of 1973 and the subsequent dramatic increase in OPEC oil prices during the early 1970s were sobering lessons. These events have brought home convincingly:

1. The supply of foreign oil, regardless of price, is uncertain in a politically unstable world.
2. The cheap energy era, based on a uniquely versatile and efficient fuel, is ending.

Yet even six years later, oil remains the dominant energy factor globally, because it has achieved an unsurpassed degree of supply concentration.*

In spite of serious concerns with respect to an assured supply of oil, in terms of political pressure or war, Canada can still expect the supply of crude oil and natural gas to remain in reasonable balance with requirements, for the next few decades. Clearly, however, a new energy era is dawning. Among other things, this will mean that decisions, consistent with federal-provincial and regional political realities, are required to improve the security of the oil supply. Also new technologies, in relation to these political decisions, will play an important secondary role in:

- diversification of foreign sources of supply;
- geographic proximity and international transportation factors;
- strategic storage, an insurance to the extent that "it costs less than without";
- a "piece of the action" in development and control of transhipment pipelines, tankers, and deep-water harbours.

Due to the relatively high cost of domestic energy alternatives to oil, this new energy era will also mean that:

1. Imports of foreign crude oil, no matter how expensive, will be needed for some time.
2. Delayed or slow development of alternative fuel options will not only prolong this dependence on foreign oil, but dangerously extend the period of uncertainty and jeopardize the nation's future.
3. Whether or not offshore oil is ultimately available, governments in Canada must increase their efforts to encourage conservation as an important stabilizing factor, to cushion the deteriorating balance-of-payments situation, and to buy the time required for establishing domestic energy-delivery systems.
4. All systems must function at maximum efficiency, in order to reduce energy losses.
5. Domestic oil, natural gas, coal, wood, and other forms of energy must be substituted for imported oil without delay. This will require local and long-distance delivery systems. In the short run, substitution of any other fuel for imported oil is desirable, provided there are both energy and foreign exchange savings.

*During the six-year period since the OPEC price revolution of 1973, the price of the "market" crude (34° API Saudi Light) increased from under $2 to $12.70 per barrel.

In brief, Canadians must be realistic. Political conflict in some form is likely to continue for some time and if trends continue, balance-of-payments problems will become prohibitive long before global resources are exhausted, unless a policy of self-sufficiency in oil is more vigorously implemented. As an industrial country with an ample supply of natural resources and a small population, Canada stands a better chance than most of becoming self-reliant.

Uncertainty is the greatest enemy of forward planning, both by industry and governments. It appears to be widening the credibility gap and generating social and international alienation. The energy "crisis" is one manifestation. To a large degree uncertainty constitutes the rationale for a national strategy and determines the selection of its instruments.

The basic concept underlying this Report is the postulated increase in the *range of Canada's energy options*. The main thrust is not to make rigid decisions, but — because of uncertainty — to advance a diversified and broadened supply options base, and thus provide, with greater confidence, more choices for future decisions. An important by-product will be an increase in the system's stability. In addition, an increased differentiation in accordance with regional characteristics and needs will be expected, and further implementation of renewable forms of energy will follow during the next century.

Role of National Energy Demonstrations

National demonstrations are suitable instruments for progressively reducing uncertainty. Demonstration results, being invested with the "authority of actual presence for all to see", will bring R & D objectives into better focus. An alternative to this approach would be the selection of a scenario for the future and choice of the path toward its eventual implementation.

The role of Research, Development, and Demonstration (R, D & D) is to perfect selected technologies and thus assure choices for the future. Ideally, available options can be developed only after all forms of energy have been adequately researched. At times, however, the situation may seem out of phase when specific sequences are examined; parts of the same R, D & D activity being performed in different geographical regions and by different levels of government or sectors of industry.

More specifically, the selection and design of the national demonstrations recommended in this Report reflect the technological experience of a group of experts who in the period 1976–78 and within the framework of the study have been consistently confronted with the problem of ranking the various technologies in accordance with technical, economic, and socio-political criteria.

The recommended national demonstrations must be viewed, therefore, as extensions and amplifications of the technologies ordered by priority. They are, however, not described in order of importance; instead, they are grouped in accordance with the energy technology classification used. Together, they represent the necessary core of a national energy agenda. The development of priorities for energy and for the technology sets occurred naturally within a need-oriented framework, where expertise and judgment played qualitatively modifying roles. These priorities have been determined for both the short-term period ending in 1990 and the long term. It is worth repeating that need-for-energy considerations are basic to every R & D strategy judgment. Without an increase in future energy demand, there will be no need to construct facilities other than those for replacement.

Demonstration programs are expensive. Certainty about new technologies and related resources will be attained only at high cost. Precision and the requirement for a high level of confidence will add to this cost. Well-planned demonstrations, however, have proved cost-efficient. They avoid commercialization of inadequate technologies. In addition, diversification and broadening of Canada's energy supply capabilities can be expected to improve our international balance-of-payments position.

The search for improved and new energy technologies that increase Canada's supply options will have important consequences. These should be clearly understood. First, it should be remembered that energy pricing considerations largely determine the nature of the ultimate energy system. We have seen that the relatively low cost of crude oil, even decreasing in real terms during the 1950s and 1960s, coupled with petroleum's unique end-use versatility, has resulted in its attainment of a position of supreme dominance. Similarly, underpricing of natural gas, especially in the United States, has distorted its use in both economic and environmental terms and has led to shortages. These temporary shortages and related longer-term supply and resource prospects have, in turn, led to greater government involvement. In the case of coal, a number of important external costs have been consistently ignored.

It is now suggested that support for new energy alternatives must be based, not only on direct economic and social costs, but, in an "about-face" regarding distortions and a rational allocation of resources, also on a "second-best" cost. Any diversification of Canada's supply options, and the securing of stability through variety and reliability through redundancy, are not possible without a mechanism for accepting newer or "second-cheapest" forms of energy. This is a fundamental and most important consideration. Change must be encouraged through planned modification and intervention in the supply mix, with optimization of trade-offs wherever possible, in accordance with multigoal objectives. This will offset, at least partially, the intervening higher costs. Simplistic decisions based on single or isolated objectives and doctrinaire "all or nothing" solutions are clearly no longer permissible.

Performance of the energy system depends not only on strategies, including R, D & D strategies, but also on structure. Both in the short and the long term, Canada must ensure that natural resources, reserve capacities, processing plants, transportation systems, refineries and related technologies do not become disjointed or out of phase. Technological "mismatch", as introduced into the system by chance developments or "discovery" and technological innovation must be minimized. At the same time Canada must prepare for both world stability and all varieties of political emergency.

It is obvious that Canada's future energy systems will be shaped as much by political and social concerns as by technical and economic considerations. Federal and provincial governments, industrial and financial organizations, and academic institutions must understand and agree on the roles each must play in planning Canada's energy supplies for the decades ahead.

In the 1990s the pivotal energy transition period will begin with a significant supply and use of heavy oils, oil sands, coal and nuclear energy. Conventional crude oil and natural gas will increasingly be allocated to critical and special uses. Early in the next century, Canada can expect substantial supplies, in aggregate, of liquid and gaseous hydrocarbons* from coal, as well as energy from biomass and solar radiation.

Emphasis must be placed on programs that will facilitate the necessary technical and economic transitions. Expansion of the energy resource and technology base will require massive investments, to pay for building supply and delivery systems, in addition to essential conservation and efficiency programs.

Sooner or later, the true cost of this critical energy-systems transition must be paid. Once the present slack is used up and the short-term objectives for conservation are attained, capital requirements will escalate. This must include more expensive and efficient production methods and the use of oil-sands production in arctic and deep off-shore regions, along with the building of new facilities for coal conversion.

If political leaders act solely on signals received from an uninformed public, two things may happen. First governments will assign a disproportionate amount of support for "simplistic and disjointed so called R, D & D", aimed at short-term expediencies which, at best, will reach the market prematurely. Due to the high cost, this action will needlessly distort the allocation of funds for basic research and longer-term development. Second, governments will over-invest in very complex technologies which will reach the market too late to be useful.

Elements of an Energy Policy

At the time of publication of *Canada's Energy Opportunities* by the Science Council in March 1975, Canada was still a net exporter of oil.[1] Since then, Canada has reverted to being an importer of higher-priced foreign oil: a situation that will continue for many years to come.

The high cost of energy is but another factor exacerbating Canada's already serious economic situation.[2] High energy prices have encouraged other commodity price increases which have led to double-digit inflation, double-digit interest rates, and seven-digit unemployment. As imports

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*For clarification of terms, please refer to the glossary, p. 69.

were reduced commensurate with a lower level of economic activity, an incipient slowdown of economic growth was transformed into a full-scale "recession" through a combination of primary and secondary effects. While not unlike other countries, Canada was now clearly living beyond its means.

At about the same time, confronted with less optimistic evaluations of energy resources, a sector of the Canadian public ceased to be complacent and for the first time seriously questioned the availability of unlimited cheap energy. Many, feeling misled both by big oil companies and official authorities, demanded the truth about the energy-supply situation. Government's first reaction was to reduce exports, but this is considered to have had little impact, for both the short and the long terms.

Canada needs to develop the technological capability to exploit existing, and as yet untapped, energy sources. Such resources are urgently required to offset, at least in part, the need for shorter-term crude oil imports and, in the longer term, to replace depleting conventional domestic oil and gas supplies. The major impediment to the introduction of new forms of energy relates to lead time. Patterns of supply and demand take a long time to change. New production and transportation facilities, and especially new types of energy-supply technologies, require time to develop, as do new or alternative patterns of end use. Yet public expectations are high — people expect instant solutions and demand that technology provide them.

Conditioned by recent experience, Canadians often believe they are entitled to energy as a right. Solutions to immediate supply problems, such as dependence on foreign oil, must be based more on political decisions than on science and technology. They require prompt and coordinated action by governments and industry to ensure that more conventional sources are found, developed, and transported to market. They also require increasing efforts by consumers to avoid waste — this cannot be attained without sacrifice.

Research, Development and Demonstration* are the keys to unlocking the new energy resources to meet Canada's long-term needs. Any failure to mount R, D & D initiatives immediately, as part of a Canadian industrial strategy and a sustained effort, will result in a recurring series of energy crises that will jeopardize our economic development and erode Canada's political freedom of action.

Any energy "future" must be designed to support national goals — security, prosperity, social equity, health, the environment — within Canada's physical, economic, social and institutional constraints. While Canadians may differ on the specifics of "how to do it", there is growing consensus on the direction that energy policy should take. The major elements entering into these discussions are:

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*The role of Research, Development and Demonstration has been defined on p. 17 and is elaborated further in Chapter III.

1. Need for a major national energy conservation program.[3]
2. Increased substitution for conventional oil by alternative fuels.
3. Accelerated exploration and continued production of national fossil fuel resources.
4. Improved and expanded utilization of electricity.
5. Increased use of nuclear power.
6. Renewed interest in and use of coal.
7. Expanded efforts in the renewable energy technologies, such as biomass and solar.

It is within this framework of energy policy requirements that R, D & D priorities will be considered.

The Science Council of Canada believes that the following list of objectives must be considered in the further delineation of R, D & D priorities. Energy R, D & D projects must:

1. Facilitate the development of reliable energy resources, commensurate with the cost of other social needs and services, and including appropriate allowances for environmental and social requirements.
2. Increase access to, and diversity of use of, the more abundant natural resources.
3. Improve technologies that convert, transport, and store energy.
4. Assist in the orderly transition from an era dominated by the use of non-renewable fuels to one based on greater use of renewable energy forms.
5. Maintain a reasonably wide range of possible options.
6. Disclose and document what is not feasible.

It is within this general policy framework that Council offers its R, D & D energy-program recommendations, with suggestions for funding and management of the national demonstrations. If implemented, these recommendations will, by design, substantially reduce uncertainty and raise the level of public confidence in decisions associated with the less readily discernible energy options.

To arrive at the recommended demonstration programs identified in Chapter IV, some 30 sets of energy sources and technologies (Table I.1) have been assessed in terms of their potential contribution (Chapter II), and measured against Canada's future energy requirements within the framework detailed in Chapter III.

Whether conservation is envisioned as the only solution to plentiful energy or an unpleasant and expensive consequence of energy scarcity resulting in social and political stress, its various ramifications are profoundly complex. In a first-order approximation, the energy equation can be balanced within reasonable limits by an aggressive approach to both supply and use.[4] In terms of energy use, a major and sustained national energy conservation program is required. Council has made urgent recommendations in respect to energy conservation in previous reports.[5] These recommendations are still relevant. Emphasis in this Report is on advancement of new energy supplies through diversifying and broadening the options available to Canada.

Where Canadian energy policies have changed significantly, implementation by industry and utilities has lagged substantially. Due to intrinsic administrative and technical structures, some of this lag is understandable. Nevertheless it is cause for increased concern. Moreover, where policies remain ineffective or simply inactive, there is need for reinforcement, consolidation, and possibly structural change.

Demonstration programs will provide the leverage to test new funding processes and management systems. This opportunity is greatly enhanced by the diversity of these programs. Each demonstration has its characteristic requirements pertaining to time frame, funding levels, participants, and ways of management. (See Chapter V.) Some programs may be completed in five to ten years, while others will require two to three decades.

It is essential that the program recommendations be carefully reviewed at the outset by those charged with implementation. Monitoring and re-evaluation is an important consideration in design and will be required throughout the life of the program. New information will lead to change in strategy as required.

Although only a small number of specific demonstration programs are emphasized in this Report, energy research and development must be fostered on a broad front. While independent programs and funding trends are an indication of a growing commitment, it is only through the demonstration process that such research and development can be properly focused and usefully harnessed.

ERRATA

Page 19, paragraph 7, line 4

For: seven-digit unemployment

Read: seven per cent unemployment

Page 27, Table II.1

For: 1975 Energy Balance

Read: 1973 Energy Balance

Page 41, paragraph 2, line 4

For: Baffin Sea

Read: Baffin Bay

Page 42, paragraph 4, line 3

For: Arctic Coastal Plan

Read: Arctic Coastal Plain

Page 77, Thorium

For: uranium 232

Read: uranium 233

Page 89:

Footnote refers to line 4, page 90.

Page 23, Table I.1

For: (4) Crude Oil: Enhanced recovery and extensions

Read: (4) Crude Oil: Enhanced recovery
(5) Natural Gas: Enhanced recovery and extensions

Page 27, Table II.1

For: 1975 High Protection

Read: 1975 High Projection

Page 186, item d, line 3

For: 0.33 x 66 x 300 000

Read: 0.33 x 66 300 000

Table I.1 – Energy Sources and Technologies Studied

A. Energy "Production" Technologies	B. Energy Conservation and Efficient Use: Technologies	C. Energy Conversion and Delivery Technologies
I. Non-Renewable Technologies	(20) Transportation Efficiency and Electric Transport	I. Energy Conversion Technologies
(1) Oil and Gas: Exploration	(21) Industrial Process	(24) Efficient Energy Conversion
(2) Crude Oil: Production	(22) Commercial and Residential Buildings	(25) Effective Utilization of Conversion Energy
(3) Natural Gas: Production	(23) Consumer Products: New materials and recycling	
(4) Crude Oil: Enhanced recovery and extensions		II. Energy Transportation Technologies
(6) Heavy Oils: Production and enhanced recovery		(26) Electric Power Transmission and Distribution
(7) Oil Sands: Mining		(27) Transportation of Energy: Non-Electric
(8) Oil Sands: In situ		III. Energy Storage Technologies
(9) Coal: Direct utilization		(28) Energy Storage: All forms
(10) Coal: Conversion to liquid and gaseous fuels		IV. Energy Substitution Technologies
		(29) Portable Fuels: Hydrogen systems
II. Nuclear Energy Technologies		
(11) Nuclear: Fission		
(12) Nuclear: Fusion		
III. "Renewable" Energy Technologies		
(13) Hydro: Electricity		
(14) Energy from Biomass and Solid Wastes		
(15) Solar Space and Water Heating		
(16) Solar Electric Power		
(17) Geothermal Energy		
(18) Wind Energy		
(19) Tidal Power		

Source: E.R.Q. Stoian, Science Council of Canada, a forthcoming background study.

II. Energy Requirements and Potential

In Canada, energy requirements have been satisfied in the past by oil and gas, hydro-electric power, and coal. Nuclear power is now emerging as an important source of energy.

Encouraged by relatively low prices, oil consumption has increased ninefold and natural gas use thirty-fold since World War II. Coal was displaced by oil and gas, and the Arab oil embargo of 1973–74, with its subsequent price escalations, made the oil-importing countries realize how dependent they had become. Actions of the Organization of Petroleum Exporting Countries (OPEC) have forced the oil-importing nations, including Canada, to reassess their energy needs — both individually and collectively, in the framework of the International Energy Agency. This has led to joint plans for the development of new energy technologies, to lessen dependence on imported oil.

In Report No. 23, the Science Council stated that a reduction of 15-20 per cent in projected energy needs to the year 2000 was possible without adversely affecting our economic system. As shown in Table II.1, more recent forecasts place Canada's energy requirements by the year 2000 much lower than predicted in Report No. 23. However, over the last several years the depletion of our oil reserves has been more rapid than the expansion of known fields and new discoveries.

To reduce the demand for energy to levels indicated in the more recent scenarios would require a major energy conservation effort and increased efficiency in energy use. The Science Council, in the report on the economic and social implications of a conserver society, suggested ways to use our energy resources more efficiently.[1] However, even with a substantial reduction in energy demand, Canada must contend with an immensely complex fuel-replacement problem.

This Report fully supports more effective energy conservation measures. To what extent the appetite for energy can be curbed before our political, social, and economic well-being is adversely affected has yet to be answered. Economic growth, level of industrial activity, regional development, equitable distribution of wealth, environmental impact, and personal freedom of choice are inextricably involved. Because of geography and climate, as well as economic history, Canada's very survival as an independent country will depend on energy.[2] To continue to play an international role as a first-stage processor of raw materials, such as aluminum, uranium, steel and nickel, Canada will require a higher per capita use of energy than countries such as Switzerland, Sweden, Germany and Japan — with which it has often been compared. Notwithstanding the understandable desire to upgrade exports, it is probably in the national as well as the global "interest" that Canada continue to maintain high energy content exports. This means that an appropriate level of unit energy consumption, consistent with our socio-economic aims, and probably not very different from today's level, will be required to preserve a socially acceptable quality of life.

Energy requirements are tied to economic and political aspirations. Canadians must keep all energy options open if these aspirations are to be

Table II.1 – National Energy Requirements

Year of Study	Scenario or Projection	Primary Energy Requirements in the Year 2000 (quads)*	Rate of Growth 1975-2000 (per cent)	Secondary Energy Requirement in the Year 2000 (quads)*	Rate of Growth 1975-2000 (per cent)	Source
1975	Energy Balance	28.0	4.7	20.2	4.5	EMR, *An Energy Policy for Canada*†
1975	High Protection	20.9	4.2	16.2	3.9	Science Council, E.R.Q. Stoian, a forthcoming background study†‡
	Standard Projection	15.6	3.4	12.1	3.1	
1976	Low Price Scenario	23.3	4.4	15.0	3.7	EMR, *An Energy Strategy for Canada*§
	High Price Scenario	21.0	4.0	13.5	3.3	
1977	Energy Conservation Scenario	12.9	2.0	7.2	1.2	EMR, *Energy Conservation in Canada*§‖
1978	Illustrative or Reference Demand	16.0	2.8	10.0	2.4	EMR, *LEAP: Energy Futures for Canadians*

Note: *In 1975 the national energy consumption was 7.9 quads of primary energy and 5.3 quads of secondary energy.
†Figures for 1975 are interpolated.
‡A review of energy requirements is made in the forthcoming background study.
§Figures for 2000 are extrapolated.
‖Gross-primary and end-use secondary figures were used.

fully satisfied. Economists, industrialists, financiers, politicians and other decision makers must understand that energy contributes to Canada's well-being, perhaps more so than in other countries.

Energy Potential

In-depth knowledge of the various energy technologies and resources is essential for informed decision making. In the establishment of a strategy for R, D & D, emphasis has been placed on those energy options that are qualitatively relevant, economically rational, and have the quantitative potential for meeting future energy needs.

The potential energy contributions of about 30 *technology sets* have been investigated.[3] The results are summarized in Table II.2. This potential reflects a positive if not optimistic view, based on a realistic assessment, and it is believed would not present unexpected financial, social, economic, political, or technological constraints, provided each contribution is considered on an individual basis. Viewed in the context of the anticipated supply mix, however, the sum of individual potentials in Table II.2 would represent an upper theoretical limit. The specific contributions have been defined and evaluated in detail and will be published in the forthcoming background study.

There are still many uncertainties related to energy development. While it appears that capital will be available for *bona fide* Canadian energy development,[4] the energy sector will still face a financing dilemma. Over-investment or premature investment in high-cost energy ventures could be especially burdensome, should prices of competitive products increase less rapidly than expected. On the other hand, deferment of investment could lead to a considerable loss of profitable opportunities for the industry and eventually result in higher costs to consumers.

Obviously, there are also substantial uncertainties in respect of research and development associated with each technology set; not to mention shifting public attitudes toward certain of the emerging energy technologies. This probably means that only a fraction of the potential of some technologies will ever be realized.

More specifically, if the national secondary energy requirement of 15 quads in the low-price scenario determined by EMR for the year 2000 (Table II.1) is compared with the aggregate potential of about 28 quads, supply could exceed demand by as much as 13 quads.* Since in practice, research, development, demonstration, and deployment of new technologies will normally attain a success rate of only about one-third, and assuming that about 25 per cent of the technologies involved do not require R, D & D, then potentially only half of the ideal aggregate can be realized. Thus, in a first order of approximation, Canada could become about 93 per cent self-sufficient by the end of this century and virtually self-sufficient by 2025. However, this is dependent on all energy technologies (regardless of the

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*An explanation of the units of energy used in this Report can be found in the section "Useful Units and Conversion Factors" on pp. 79-81.

Table II.2 – Potential Contributions of Individual Technology Sets

Source of Technology	1975	1985	2000	2025
A. Energy 'Production' Technologies		(quads)		
I. Non-Renewable Technologies				
(1) Oil and Gas — Exploration	0	—	5.2	3
(2) Crude Oil — Production	3.5	2.4	1.3	0.6
(3) Natural Gas — Production	2.25	2.8	2.4	1.1
(4) Crude Oil — Enhanced Recovery	—	0.08	0.4	0.8
(5) Natural Gas — Enhanced Recovery and Extensions	—	0.05	0.15	0.23
(6) Heavy Oils — Production and Enhanced Recovery	—	0.1	0.2	0.15
(7) Oil Sands — Mining	0.1	0.85	2	2.5
(8) Oil Sands — In Situ	0.01	0.2	1	3
(9) Coal — Direct Utilization	0.1	0.4	1.4	1.9
(10) Coal — Conversion to Liquid and Gaseous Fuels	—	—	0.01	0.85
I Sub-Total	5.97	6.88	14.06	14.13
II. Nuclear Energy Technologies				
(11) Nuclear — Fission	0.06	0.4	2.1	5.3
(12) Nuclear — Fusion	0	0	0	0.01
II Sub-Total	0.06	0.4	2.1	5.31
III. 'Renewable' Energy Technologies				
(13) Hydro — Electricity	0.7	1.1	1.5	1.8
(14) Energy from Biomass and Solid Wastes	0.12	0.42	0.98	1.78
(15) Solar Space and Water Heating	—	0.1	0.4	2.2
(16) Solar Electric Power	0	0	—	0.4
(17) Geothermal Energy	(0.0006)	0.002	0.05	0.3
(18) Wind Energy	—	0.004	0.016	0.05
(19) Tidal Power	0	—	0.02	0.08
III Sub-Total	0.82	1.63	2.97	6.61
A. Total	**6.85**	**8.91**	**19.13**	**26.05**
B. Energy Conservation and Efficient Use — Technologies				
(20) Transportation Efficiency and Electric Transport	—	0.4	1	1.9
(21) Industrial Processes	—	0.6	2	3.5
(22) Commercial and Residential Buildings	(0.2)	0.9	1.7	3.1
(23) Consumer Products — New Materials and Recycling	(0.025)	0.1	0.3	1
B. Total	**(0.225)**	**2.0**	**5.0**	**9.5**
C. Energy Conversion and Delivery Technologies				
I. Energy Conversion Technologies				
(24) Efficient Energy Conversion	—	0.25	0.78	1.75
(25) Effective Utilization of Conversion Energy	—	0.7	1.85	3.65
I Sub-Total	—	0.95	2.63	5.40
II. Energy Transportation Technologies				
(26) Electric Power Transmission and Distribution	—	0.03	0.1	0.23
(27) Transportation of Energy; Non-Electric	—	0.037	0.174	0.431
II Sub-Total	—	0.067	0.274	0.661
III. Energy Storage Technologies				
(28) Energy Storage — All Forms	—	0.2	0.8	1.9
III Sub-Total	—	0.2	0.8	1.9
IV. Energy Substitution Technologies				
(29) Portable Fuels — Hydrogen Systems	0	0	—	0.1
IV Sub-Total	0	0	—	0.1
C. Total	**—**	**1.217**	**3.704**	**8.061**

degree of their apparent initial relevance) being reviewed, monitored, assessed, and considered for research. A great number of interesting technologies must be developed, and it is evident that without early demonstration programs of the more promising leads, the goal of self-reliance will elude Canada indefinitely.

Moreover, a high success rate for the introduction of new technologies is critical for attaining self-reliance within a meaningful period of time. Obviously, this success rate will be dependent upon the quality of R & D, adequate funding, leadership, and appropriate management structures.

While it is known that energy can be used more efficiently in the future, it is also known that energy conservation and improved efficiency will not, in themselves, close the gap between energy demand and available domestic supplies.

R, D & D programs are the key to improving the capability to provide new energy sources and technologies as needed. A constant awareness of all innovations must be maintained, and interesting technologies must be carefully researched to determine which combination, following full deployment, offers the most promise of satisfying projected energy requirements. Based on considerations of "direct relevance", economics, and other applicable criteria,[5] the development and demonstration phases can then proceed with a much higher level of confidence.

III. A Strategy for Energy R,D and D

In the allocation of scarce financial and intellectual resources to R, D & D projects, it is essential to have a well-articulated but flexible strategy for their optimal assignment. Such a strategy for energy R, D & D must take into account not only short-term imperatives, but also consider the long-term opportunities and essential trade-offs required to meet varied and evolving national needs.

Any R, D & D program should be designed to include an on-going exploration of new energy technologies. Such information will help redefine R, D & D priorities as the perception of future energy requirements changes. These priorities are inextricably linked to future energy needs. While an R, D & D strategy needs to be resilient and flexible enough to respond to new information and evolving opportunities, committed programs must be assured continuity and sustained funding over agreed successive phases.

Assumptions and Criteria

In developing a Canadian strategy for energy R, D & D, it is essential to present the underlying assumptions and criteria on which such a strategy is based:

1. There are no independent goals for energy R, D & D activities *per se*. These activities must support energy policy as defined in Chapter I.
2. Relevance of R, D & D projects must be based largely on their potential for reducing the energy "gap" between predicted supplies and projected requirements.
3. Regional needs and opportunities must be respected.
4. A national energy R, D & D strategy must be consistent with Canadian economic, industrial and political interests.
5. R, D & D strategy must be flexible enough to adapt to perceived structural energy changes in the future and to knowledge gained through past research activities.
6. International cooperation is essential to ensure that Canada remains at the leading edge of scientific and technological research, to avoid unnecessary duplication of work done by others, and to develop the capacity to adopt and adapt foreign technology to its own advantage. In selected instances, especially when dealing with complex technologies, Canada need not "go it alone" because of concern that cooperation would result in a secondary role. On the contrary, Canadians should systematically assure equity in international developments through practical and responsible sharing, and through comparative strengths based on unique high leverage opportunities.

Short Term: Policies and Priorities

From the present time until about 1990, a major effort must be made to minimize oil imports.[1] This can be done through:

• **Conservation:** By selectively economizing scarce energy forms such as oil, the need for costly imports should be directly reduced and money freed for urgent energy supply developments;

• **Increased efficiency:** Primary energy needs must be decreased through enhanced conversion efficiencies and through improved utilization of by-product heat from these conversion processes;

• **Substitution:** Total substitution for oil-based products should be encouraged in selected cases; however, initial substitution may be only partial, using mixtures such as pulverized coal in oil;

• **Accelerated exploration and systematic development of other non-renewable resources:** Canada must develop timely access to its considerable sources of other hydrocarbons (e.g., natural gas, conventional oil, heavy oil, oil sands, frontier gas and oil, and coal). The production of liquid fuels through new technologies needs to be given particular attention.

More specifically, having regard in each case to the potential contribution and capacity for short-term build-up, and consistent with the principles enunciated earlier, it would appear relevant to pay increased attention to the following sources or technologies, in decreasing order of priority:[2]

1. Oil and Gas: Exploration
2. Oil Sands: Mining
3. Effective Utilization of Conversion Energy
4. Efficient Energy Use: Industrial processes
5. Nuclear Fission: Exploitation of design and operating practices
6. Efficient Energy Use: Commercial and residential buildings
7. Coal: Direct utilization
8. Efficient Energy Use: Transportation sector
9. Oil Sands: *In situ* recovery
10. Natural Gas: Production
11. Hydro: Electricity
12. Efficient Energy Conversion
13. Energy from Biomass: Including direct utilization of wood
14. Energy Storage: All forms

Long Term: Policies and Priorities

A stable energy supply must be assured in the long term. R, D & D programs must be selected that will reduce the present technical, economic, social, and environmental uncertainties related to the assessment of future energy technologies. Special emphasis must be placed on those opportunities unique to Canada. Work must begin immediately to determine R, D & D priorities in terms of technologies that:

• Hold promise of providing a *reasonably large energy contribution* — of the order of *one* quad or more per annum,* within the next five decades.[3] A number of realistic possibilities exist, including fossil fuels, nuclear, solar, biomass and hydro-electric power;

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*Canada's 1975 secondary energy requirements exceeded 5 quads.

- Contribute directly to *basic needs* such as agriculture and transportation, for example through the development of substitute portable fuels;
- Reduce the drain on available *physical and financial resources;*
- Provide direct *opportunities for Canadian industry;*
- Possess compatibility with our *physical and social environments;*
- Meet *regional needs;* particularly those energy technologies having site-specific impacts and thus perceived differently in various parts of the country. Regional diversification of supply options is expected to occur, particularly with regard to renewable energy.

In aggregate, selected R, D & D activities must permit equitable involvement of all regions of Canada. Not only are regional considerations of importance to funding but they are even more imperative at the demonstration level, because of higher intervening costs and greater assurance of commercialization of the technologies. The aim is not regional independence, but well balanced interdependence. In the long term, the objective of national demonstrations must be to assure the security of future energy supplies, while improving levels of employment and economic development in many regions of Canada, rather than favouring privileged areas, zones or sectors.

Based on these concepts and on the relative magnitude of potential future contributions, it would seem pertinent to recommend a tentative or preferred "shopping list" of sources or technologies.[4] Energy sources and technologies that must receive appropriate attention *now*, in order to have the required long-term impacts, can be ranked in decreasing order of priority:

1. Nuclear Fission: More efficient use of fuel resources
2. Oil Sands: *In situ* enhanced recovery processes
3. Effective utilization of conversion energy in planned situations such as industrial parks
4. Solar Water and Space Heating
5. Efficient Energy Use: New industrial processes
6. Efficient Energy Use: Continued commercial and residential building improvements
7. Coal: Conversion to liquid and gaseous fuels
8. Energy Storage: All systems
9. Energy from Biomass and Solid Wastes
10. Efficient and Advanced Energy Conversion
11. Transportation Efficiency
12. Portable Fuels: such as new hydrogen systems
13. Consumer Products: Optimized materials and recycling
14. Oil Sands: New mining technologies

Effect on R, D & D Programs

How does such a long-term strategy affect R, D & D programs? Its impact will be significantly different on the research, development, and demonstration components. As A.B. Kinzel noted in a Noranda lecture:

"For any given successful project if $1 is spent on basic research, $10 will be spent on product and process research, $100 to engineer it for plant and market studies and $1,000 for (building) the plant. Lots of $1 failures can be afforded; so can a few $10 ones; but there had better not be many $100 or $1,000 failures."[5]

In terms of energy R, D & D, such a statement can be interpreted as follows:

Research: There is need for a hard look at the entire research base, in order to "scan" for domestic energy opportunities and to evaluate advances in other countries. The universities have a crucial research role, but government should support long-term research.

Development: More expensive than research, this phase involves technological performance in addition to scientific feasibility. A high level of expertise needs to be sustained for a sufficient period to evaluate properly the candidates for demonstration programs and to participate in international activities of pertinence to Canada. This raises the difficult problem of providing long-term support in order to ensure stability. In addition, there is a need for close government and industry cooperation if technological opportunities are to be properly evaluated and developed.

Demonstration: This component or phase represents a few integrated, large scale, and high cost efforts showing the most promise over long periods of time; not only for the supply of energy at "affordable" costs but *also* for Canadian industrial development, through eventual deployment. Such demonstration programs require industrial participation, in order to provide a better evaluation of financial feasibility under national or regional conditions.[6]

While each demonstration program would be unique, projects should be selected, in part, for their potential commercial viability. While costs, either total or shared, would still be high for many companies, the necessary government subsidy should be considerably smaller than the private sector contribution. The government's role should clearly be that of an enabling agent, in most cases, using various economic techniques to reduce risk.[7]

With respect to the allocation of financial resources to various energy technologies, it is necessary to emphasize the inherent disparities between the cost of funding research, development and demonstration. For instance, a "good" technology in the development phase could conceivably receive less money than an "average" technology in the demonstration phase. In this sense, it would be tempting to question the funding process.

Report No. 23, *Canada's Energy Opportunities,* argued that large ventures should be organized as "major programs", since they require the participation of those who will finance them and those who will use them. While the focus of this Report is on demonstration, much supporting research and development will be required in order to assure that a chosen energy option becomes viable, as was the case with Canada's nuclear energy program. Certain criteria should therefore be satisfied by "major programs". They are:[8]

(a) the need to select clear goals for programs which have to be maintained over a long period of time;

(b) the need of a reliable source for the increasingly higher levels of funding that will be required for such a long-term program;

(c) the need to create a "systems management capability" for the overall control of such programs;

(d) the need to secure early involvement of those who will eventually be commercial operators;

(e) the need to obtain participation of the hardware manufacturers.

Demonstration programs must be performed within this strategic context. In turn, demonstrations will create new requirements and provide foci for new R & D activities, on a scale necessary for full evaluation of the emerging energy technologies.[9]

For best results, therefore, the scattering of objectives, fragmentation of R & D plans, and "atomizing" of demonstration programs must be avoided. Canada can afford to research all technologies but demonstrate only a few selected energy options at any one time.

IV. Recommended Demonstration Programs

The Context

Priority setting and resource allocation must obviously take cognizance of the nature, scope, scale and maturity of existing activities. It takes time to develop the manpower, management and physical facilities that can assure wise use of funding.

The federal government's energy R & D budget for 1977-78 was $138 million, with increased emphasis on energy conservation and renewable energy resources. Moreover, in July 1978 the federal government announced a major new program in the field of renewable energy, with a total of $380 million to be spent over a period of five years. Of this amount $114 million was specifically ear-marked for large demonstration projects in renewable energy and energy conservation, in cooperation with the provinces.

An important component of this renewable energy package is the FIRE program (Forest Industry Renewable Energy) which provides up to 20 per cent of the capital cost of new equipment for the conversion of wood wastes and forest products into useful energy. This cost-sharing program, expected to provide total funds of $150 million, is intended to encourage the substitution of mill and forest residues for purchased energy in the forest industry.

The PUSH program (Purchase of Solar Heating) provides $125 million for demonstration of solar space and water heating equipment in federal government buildings. A two-phase Plan of Assistance to Solar Energy Manufacturers (PASEM) is a companion program. Some 25 grants of $10 000 each will be awarded for solar equipment design proposals. Following assessment of these designs, up to 10 contributions of $200 000 -$300 000 each will be made to assist Canadian companies in developing solar heating equipment needed to support the PUSH program. In addition, R & D spending in the solar and biomass fields will be increased by about $38 million over the same 1978-1983 period.

Provincial governments' support of energy R & D is of the order of $35 million (1975-76). During 1977, electric utilities spent a little over $40 million on research projects, primarily related to the application and modification of existing technologies, in order to reduce costs, improve efficiency and system stability, and to assure electric generation under changing conditions.

Accurate information on energy R & D activities funded by municipal governments and industry is not readily available.

In addition to these predominantly R & D activities, a number of major demonstration programs of importance to Canada are now being undertaken by industry, utilities, and governments, in a variety of sectors. Canadian projects in the fields of nuclear energy, oil from oil sands, enhanced recovery of petroleum resources, offshore drilling in the Arctic from artificial islands, ice platforms and ships, energy conservation and others, hold significant potential for meeting Canada's future energy needs.

In some areas such as coal gasification and nuclear fusion, international research, development, and demonstration activities dwarf Canada's present efforts. Isolated and independent national programs are difficult to mount and fund in these areas. Nevertheless, we must acquire and maintain at least the foundation of a broadly based scientific research and development activity, in order to evaluate any candidate demonstration programs, and subsequently support in an adequate way those adopted for commercialization. (An evaluation of the required research and development, and of the magnitude of costs that might be incurred up to the first major demonstration in each technology area was conducted and will be published in the forthcoming background study.)[1]

R & D is essential for the development of Canada's energy supply and it should be carefully selected, strengthened, monitored, and pursued with determination. However, because of the urgency of the present situation, Canadians cannot wait for the entire R & D base to develop to full maturity before embarking on a number of well selected national demonstration programs, to complement those already underway. Based on this complementarity, it is believed that a consistent and coherent R, D & D program will emerge, with federal and provincial governments, industry and universities playing mutually supportive roles.

Sufficient energy R & D is presently being carried out in Canada to be able to make the following recommendations on the selection of national demonstration programs. These recommendations are consistent with the strategies set forth in Chapter III and the R, D & D objectives listed in Chapter I. They have been reached through a review of the energy technologies listed in Table I.1 and a critical examination of Canada's needs by a panel of experts assembled by the Science Council. (Members of the Science Council Committee on Energy Scientific Policies are listed on page 190.)

The Demonstration Programs

Demonstration programs which should be undertaken immediately fall into four categories — fossil fuels, nuclear energy, renewable energy, and conversion technologies. The rationale for these programs is outlined in this section, and the technical directions, level of effort, and estimated costs are developed in the Annex (pp. 83-189).

Fossil Fuels

Oil and Gas

Canada has been endowed with substantial resources of light and medium density oils and natural gas, and with a major portion of the world's low gravity oils and bitumen in the form of heavy oil and oil sands deposits. As suggested in Table II.2, Canada has sufficient domestic supplies to permit planning of an orderly transition from the petroleum-based energy system, over the next few decades. In the short term, however, it is of great importance that Canada take all necessary actions to minimize its growing dependence on expensive imported oil.

Canadians must determine, with a high level of confidence, both the extent and nature of the resources believed to be in place and, through synchronized and well rationalized R, D & D programs, develop the technologies that will allow use of our resources in the most advantageous and cost-effective way.

Considerable attention must, therefore, be given to the development and demonstration of those technologies required to ensure access to the vast oil sands and heavy oil deposits, on which Canada will be highly dependent well into the next century. Unless these huge resources, including substantial parts of the relatively low grade oil sands (in due course, perhaps even the limestone oil) are "unlocked" in a way that releases more energy than must be expended in the process and at an affordable cost, they will be of little use to our economy. The reason is that Canadian industries have been built largely on relatively low cost energy and must continue to seek more of the same.

Over the next decade, the light and medium gravity oils supply problems can be substantially alleviated by further development and production of conventional crude resources in established producing areas. This will be largely based on enhanced recovery programs, such as those undertaken by the Petroleum Recovery Institute in Calgary. An additional demonstration program could address itself, in parallel, to the development of the massive low grade gas deposits found in the "deep basin" of Western Canada.

Whereas there must be continued and improved exploration in the western regions of Canada, the new initiatives of the oil and gas industry in the Arctic and offshore frontier areas will require substantial R, D & D support. Severe ice conditions and drifting icebergs demand new exploration and production practices, as well as new types of transportation equipment. In deeper waters, new equipment and techniques are needed for even exploratory drilling. While considerable activity is presently underway, much of it is taking place outside Canada. Although this may be inevitable, it is of great importance to set in place coherent and stable policies that will facilitate the development of indigenous capabilities to exploit such frontier resources, on a time table of maximum benefit to Canada.[2] Timely access to these energy resources must be assured, by developing domestic industries capable of undertaking such massive projects.

Several such activities are already in progress, with respect to technologies for ice-congested waters, marine mode transportation of gas and oil, and drilling in deep waters. In addition there is the urgent requirement to move some technologies (at times exhibiting disruptive changes of direction) and capabilities more quickly and systematically, in order to integrate them into essential demonstration programs. Against this background, the Science Council recommends three demonstration programs as being of the greatest immediate importance.

1. The Demonstration of Technological Capability for Exploration and Production of Oil and Gas in Ice-Congested Waters

Many of the technological problems encountered in the more promising regions of the Canadian North and East Coast offshore waters are not fundamentally different from those occurring in other parts of the world. The basic technology necessary for exploration and production of oil and gas in marine environments is generally available.

There is, however, one important exception. The engineering properties of ice and its behaviour in a natural environment are poorly understood. Future oil and gas developments in frontier regions of the Beaufort Sea, Arctic inter-island areas, Baffin Sea, and offshore Labrador will have to contend with ice-congested waters. A thorough knowledge of the formation, migration and melting characteristics of sea ice is necessary. Acquisition and integration of data on the ice and water environment, into a systematic and dynamic reference base, must be an important and continuing activity. This must include a far better understanding of ice as a structural or engineering material and its interaction with other structures and systems. Long-term R & D of ice behaviour and ice technology needs to be expanded. In parallel, a demonstration program with supporting R & D must be mounted that will sustain future exploration and validate the engineering feasibility, capital requirements and costs of production, under specific site-determined conditions. This effort will need to be integrated with associated activities presently on-going or being planned by the Canadian petroleum industry.[3] (Directions and level of effort of the suggested demonstration program are given beginning on page 86.)

2. The Demonstration of Transportation of Hydrocarbons from the Arctic by Marine Mode

Significant natural gas reserves have been proven in the Arctic and are believed to exist in the offshore sedimentary basins of the Labrador Sea.

Moving natural gas in liquefied state or as methanol and eventually transporting oil from the Arctic by marine mode, using installations and vessels designed and built in Canada, would offer several important advantages:

- Early access to gas and oil, shorter pay-out times and a basis for sustained exploration and development activity;
- Increased industrial activity, based on marine technology for Canadian shipyards;[4]
- Substantial contribution to regional development relative to the location of construction operations and markets;
- Technological foundation for other northern resource developments and marine activities; and very importantly,
- A new dimension to Canada's sovereignty in the Arctic.

Canada is considering a 150 000 hp icebreaker that would derive 65 per cent of its power from nuclear steam and 35 per cent by gas turbines. A decision whether to build this ship will apparently be taken in 1980. While Canada is considering the feasibility of building its first nuclear icebreaker, the USSR has two nuclear ships, "Lenin" and "Arktika", already in service. A third icebreaker, "Sibir", has been under construction since early 1978, and upon completion will join the northern fleet.

Because of inherent flexibility, a LNG tanker system or alternatively one based on methanol, could play an important role, provided that associated technologies can be kept simple and safe and that R & D can substantially reduce costs.[5]

In view of the high costs allocated to this demonstration (i.e., funding for the LNG proposal of $507 million out of $860 million allocated for the first 5 years — 60 per cent of the total proposed program during the period) feasibility of the project must be carefully ascertained by engineering, cost, market and environmental studies. Both commercial benefits and the "public good" must be commensurate with the high cost of demonstration. Thus, depending upon consideration of the size of gas volumes to be ultimately transported, as well as tooling and production runs associated with the development of ice-breaking LNG or methanol carriers, the federal government should do its utmost to see that production, transportation and conversion systems and their associated technologies are developed in Canada. In this way, demonstration costs can be shared by the gas and transportation industries and at least two levels of government, commensurate with the benefits perceived. (This demonstration is described beginning on page 94.)

3. The Demonstration of the Ability to Explore for and Produce Oil and Gas in Very Deep Waters

According to industry plans and Energy, Mines and Resources (EMR) evaluations,[6] the geological prospects for petroleum resources in some of our deep offshore regions are most encouraging.

The continental slopes and rises off the Nova Scotian shelf, the Grand Banks, the Northeast Newfoundland and Labrador shelves, Baffin Bay shelf and slope, the Arctic Coastal Plan shelf and the Arctic inter-island areas all hold promise of substantial resources. Only with exploratory drilling can it be established whether the reserves are present in structures and quantities that can be economically exploited. Much of the drilling will have to be conducted in waters of 300 metres or deeper, requiring the development of new techniques and equipment.

While extensive R & D is being carried out by major petroleum companies into the problems of drilling in deep waters, the acquisition of this capability is of such national importance that Canada must undertake a demonstration, as early as possible. Specific to this activity, governments could contribute substantially by removing critical barriers and providing positive financial and tax incentives.

This demonstration is of international interest, in that it does not address only a Canadian problem, but one encountered by the petroleum industry worldwide. Nevertheless, because of site-specific circumstances, the situation is nordic and of interest to Canada. (The technological direction and level of effort for this demonstration are described beginning on page 101.)

Coal

Canada's coal resources as presently identified, although not great by world standards, represent a substantial source of energy and chemical feedstocks. These resources occur in a variety of physical forms and geological formations and have widely differing characteristics, which are of considerable importance in their end use. Most of Canada's coal is found in Alberta and British Columbia, with smaller amounts in the Maritimes. The major domestic coal markets for steelmaking and the generation of electricity are located in Ontario. In order to reduce coal imports and allow a wider use of this domestic energy resource, to offset the importation of expensive oil, Canada is now upgrading its western rail system and building coal handling terminals on the Great Lakes. This will facilitate the more economical transportation of large quantities of western coals, to the central and eastern parts of the country.

Two factors that presently limit more widespread mining and domestic use of coal, are related to its impact on the environment. Unless chemical emissions from combustion and other processes can be more acceptably controlled, and lands disrupted in the mining process restored to a productive state, the contribution of coal as a source of new energy will remain uncertain and fall short of its full potential. Another important, and related, consideration is the more efficient combustion of coals of differing physical and chemical characteristics.

Extensive R, D & D programs are presently underway on these and related aspects of coal mining, conversion and end use, especially in the United States. Despite important R & D programs undertaken in Canada, it is essential to assess and demonstrate further the applicability of appropriate technologies to the mining and utilization of Canadian coals. This should be undertaken as soon as practicable, in order to plan, with confidence, the medium- and long-term development of these strategic coal resources. While in the longer term, other demonstrations of coal conversion and use, such as liquifaction and gasification, may prove important to Canada, Council recommends that demonstration projects be undertaken as quickly as possible, in the areas of fluidized bed technology and land reclamation after strip-mining. These demonstrations are expected to broaden the supply base of energy, in general, and coal in particular, and to remove perceived impediments to the substitution of scarce fuels by coal and, eventually, biomass.

1. The Demonstration of Fluidized Bed Technology

Fluidized bed technology can be instrumental in a number of applications of our coal resources. Increased flexibility of use together with adequate combustion efficiency are generally more relevant objectives, from a Canadian point of view, than the removal of sulphur. It should be noted, in favour of fluidized bed technology, that while electrostatic precipitators are effective in removing particulate matter from coal combustion stack emissions, there is, as yet, no effective method for the removal of sulphur oxides with conventional combustion methods.

Fluidized bed technology (FBT) offers realistic near-term opportunities for the cleaner use of coal by electric power utilities and industry, in comparison with the use of scrubbers. Will FBT live up to the promises of its promoters who are seeking financial support? Will fluidized bed systems prove relatively more expensive? If unburned carbon emissions remain relatively high, how can further improved combustion efficiency be attained? Will FBT diversify and broaden our energy base, by allowing the use of poorer quality fuels, while solving environmental problems? More specifically, is FBT really insensitive to coal characteristics or is it appropriate only in very special circumstances? Can clean air standards be met, and if so under what conditions? Can FBT be perfected in time to take advantage of the progressive substitution of crude oil and natural gas by coal, and eventually biomass? In the production of electricity and heat, how will FBT fit into the present power system, and more specifically, will it be more suitable for base, peak, or intermediate load? Taking full advantage of technological developments in other countries,[7] a demonstration program specifically tailored to Canadian coals and their combustion characteristics should be undertaken to answer some of these questions. (See the demonstration of fluidized bed technology on page 112.)

Note: Following the period of deliberations of the Science Council Committee on Energy Scientific Policies, the Federal Department of Energy, Mines and Resources, in cooperation with interested provinces and other related organizations, has developed plans for the introduction of new coal-using technologies in Canada. Preliminary studies have been conducted under the auspices of the Canadian Coal Conversion Program, with funding through the Panel of Energy R & D, in order to assist interested operators of new coal technologies in identifying opportunities of mutual interest. Such shared-cost studies were funded for the most part at the 50 per cent government-industry participation level.

In the area of improved coal utilization for the generation of electricity and process heat, the following projects are being considered:

(a) Atmospheric pressure fluidized bed technology
Replacement of an existing boiler installation at the Department of National Defence Armed Services Base, in Summerside, PEI, is being studied. The size of this unit (18 000 kg steam/hr) makes it an appropriate first step for the introduction of FBT in Canada. Two engineering firms are currently (1978) preparing alternative conceptual designs.

Reconstruction of an existing 22 MW(e) unit of the New Brunswick Electric Power Commission (NBEPC) at Chatham, NB, is under consideration, as a national test centre for fluidized bed combustion technology — especially as applied to the high sulphur coals of that province. The unit size is appropriate for the first practical demonstration of this process and the steam rate (of the order of 60 000 kg/hr) is on a scale of interest to other industries contemplating the use of this technology. The particular advantage of fluidized bed combustion technology, in this case, is the opportunity to test various coals, oil shales, and other fuels, because this generating station serves only in a stand-by capacity in the NBEPC network. The Canadian Electrical Association is funding the first phase.

Under Canada-US oil replacement agreements, the Nova Scotia Power Commission is giving consideration to the installation of a 40 MW(e) fluidized bed combustion unit, for use at a Cape Breton generating station, in order to study the use of washery rejects and certain strip-mined coals, exhibiting difficult combustion characteristics. This unit would

2. The Demonstration of Land Reclamation after Coal is Strip-Mined

As Canadians rely increasingly on domestic energy sources to replace imported oil, huge quantities of coal will be produced and used across Canada. As a consequence, during the next 50-75 years, large areas of rural and agricultural land will be affected by coal mining, especially in the Western provinces. Although surface coal mining activities will be regulated and land reclamation mandated under provincial and federal laws, research must be carried out, within integrated demonstration programs, on the methods and criteria for interrelating environmental protection, land use planning, mining and reclamation — as well as on the determination of acceptable costs. Timely research must be carried out in order to develop mining practices for minimization of undesirable environmental effects. These practices, obviously, must be both acceptable to the public and economical for the developers.

To reduce the undersirable effects, the coal industry has already developed or adopted specific practices. Following stripping, the disturbed land is normally graded to its original condition or to contours that are sometimes more acceptable than the original. Strict environmental regulations on strip mining have already given an impetus to this research in both Alberta and British Columbia. One reclaimed area, which is frequently referred to as a model, is located near Luscar, Alberta.

Since there is no world issue more fundamental and urgent than that of meeting mankind's needs for both food and energy, any decisions on trade-offs between agricultural land and strip-mining will not be easy.

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demonstrate the use of coal, virtually without quality control of the feed, and would be large enough to estimate the costs for larger units. This scale-up would be a reasonable next stage, to the Chatham, NB, facility.

(b) Coal-in-oil combustion technology
Coal can be used in furnaces designed to burn oil by preparing finely ground suspensions, so that a coal-oil slurry can be pumped to special burners. In 1978, the first trial of this process was conducted in the Chatham No. 1 unit and further trials are planned. It is of interest to note that this second series of studies will incorporate the National Research Council's "spherical agglomeration" separation process, which utilizes properties of the oil itself, to effect a partial rejection of mineral and sulphur-bearing constituents of the coal. These trials were planned to begin late in 1978. Related studies are being conducted by the Ontario Research Foundation (grinding, emulsification, burner modifications and emissions) and the Saskatchewan Research Council (rheology of coal-oil suspensions). Application of this technology to the iron blast furnace is being assessed by the Steel Company of Canada. Most of this work is in part supported by Energy, Mines and Resources.

(c) Advanced coal-to-electricity processes
Two western utilities have showed interest in this process, as applied to the low-cost, high-moisture/low-energy coals of their region. BC Hydro and Power Authority has examined the potential of the pressurized fluidized bed combustion process and the Saskatchewan Power Corporation is evaluating related processes of interest, again with partial support from Energy, Mines and Resources.

These plans, studies and individual projects, combined with the national demonstration programs on coal recommended in this Report, deserve attention because they illustrate how differing activities can complement each other, adding up to a successful summa: substitution of scarce energy resources, namely oil, by widening the role of existing or new forms of energy.

Demonstration programs must provide the prerequisite information to make decisions in this area with less difficulty and a higher degree of certainty. Government support will be necessary.[8] (The recommended direction and level of effort for this demonstration are outlined beginning on page 118.)

Nuclear Energy

Nuclear energy has the potential to supply a large part of Canada's energy needs in the years ahead. In fact, nuclear energy has the potential for providing much, if not all of the projected additional electricity requirements. Electricity, representing "work", keeps our factory wheels turning and therefore its significance is inordinately greater than the mere calculated fraction of the total energy supply. The Science Council has advocated the development of this energy technology for some time.[9] Operational nuclear power plants, together with those currently under construction in Canada, have a projected capacity of approximately 15 000 megawatts of electricity, and utility plans suggest that cumulative installed capacity may reach 20 000 megawatts by 1990 and 60 000 megawatts in the year 2000.[10]

The nuclear plants employ the CANDU reactor system developed in Canada. This reactor system is "different" in that CANDU fuel does not require enrichment in order to obtain reasonably economical operation, although it would obviously be of some advantage. In any case, Canada must continue to play the lead role in the R, D & D necessary for further development of CANDU — for at least the next two to three decades — since practically all other nations have focused their attention on other reactor systems.

The technical, environmental and economic viability of the CANDU reactor system, using natural uranium, has been demonstrated by some 20 reactor-years of experience at the Pickering Nuclear Generating Station alone. The present challenge is to consolidate and exploit this technology further, as a necessary contribution to Canada's long-term energy needs.

However, growth of nuclear energy is likely to be dependent on social acceptance of progress in developing satisfactory nuclear waste management and disposal systems. Current practice involves storage of irradiated fuel wastes, which comprise most of the radioactivity, in special water-filled bays at reactor sites. Interim storage at more centralized points away from reactor sites will provide additional lead time. Irradiated fuel wastes according to the present view, however, must eventually be immobilized in an insoluble form and emplaced in a disposal facility, located deep underground in geologically stable strata.[11]

In addition to fission product wastes, the irradiated "waste" fuel contains considerable potential energy in the form of plutonium, which could be separated and recycled to conserve resources. Consequently, present storage methods for waste management must leave open the option of permitting future separation and recovery of plutonium fuel and, eventually, uranium 233. The current approach to nuclear wastes, both fuel and those resulting from reactor operations, is to store them retrievably until a permanent repository has been demonstrated. Also both types of waste will be suitably immobilized before being consigned to the repository.

CANDU reactors operate on the simplest possible "fuel cycle", that of natural uranium on a once-through basis with a 1000 megawatt electricity plant requiring about 4100 tonnes of uranium over a 30-year plant life. Canada's estimated uranium resources, used in this way, have the energy equivalent of 28 billion barrels of oil and are sufficient to provide lifetime fueling for all the Canadian nuclear capacity committed for this century.

The simplest form of fuel recycling, the recovery of plutonium from spent fuel and its return to the reactor with fresh uranium, would roughly double energy output from any given uranium supply. Introducing a thorium cycle could at least double again the energy available from nuclear fuels. Furthermore, operation of CANDU reactors using the thorium cycle, could be modified to extend the fuel resource base virtually indefinitely, at a cost penalty of no more than 25 per cent of current unit energy costs.

Through use of recycled fuels and acceptable irradiated fuel management and waste disposal systems designed appropriately for the CANDU reactor, we can be assured of adequate fuel supplies and the availability of nuclear energy well into the future. This demonstration program will have many phases and if pursued to completion, would take 25 to 30 years. It is vital that the initial phases be started immediately, in order that prospects for the system can be better assessed — including safety and security implications as related to future development work. Council recommends the following two programs:

1. The Demonstration of an Acceptable Irradiated Fuel Management and Disposal System

CANDU reactors, presently operational or under construction, employ the once-through uranium "fuel cycle" producing irradiated waste composed of plutonium, fission products, and some unburned uranium.

A portion of the plutonium can be recovered from the spent fuel and recycled, thereby increasing total available energy. CANDU spent fuel, therefore, represents an important additional energy resource and any decision to recycle this irradiated fuel must precede implementation of "permanent" disposal. Because demonstration of the management of radioactive wastes is crucial, R, D & D must provide clear answers to many aspects of waste storage and disposal without unnecessary delay. Ultimately, operational reactors will have to be dismantled and radioactive components safely disposed of. Here again, AECL has a lead role to play (See page 124.)

2. The Demonstration of Feasibility of the Thorium Cycle

Any decision to implement the thorium cycle in a CANDU reactor requires a major analysis, based on an imaginative but technically sound assessment and including the broadest possible economic evaluation. This is not a simple program leading to early demonstration. A critical milepost must be passed, which would mark an historic departure with profound significance to Canada's future energy supplies and industrial structures.

A fundamental question, which must be answered, relates to incremental developments, such as the use of thorium and reprocessing of CANDU fuel, and whether they make economic sense as long as uranium is in plentiful supply at "reasonable prices", at home and on the world markets. Secondly, and more important, is the question of whether, when uranium supplies really begin to run out, the broader fuel characteristics and improved efficiency of heavy water reactors will be of continued economic interest. Clearly, the crucial question is that of (a) opting for full utilization of the U238 — and perhaps joining the international mainstream of nuclear development concentrating on breeder reactors, or (b) deciding to stick with incremental or evolutionary improvements based on CANDU technology with or without the thorium cycle.

As an evolutionary system, the CANDU reactor will undoubtedly attain greater efficiency, improved flexibility, and a broadening of its fuel base. The introduction of more advanced systems is a matter of economics and social acceptability. The demonstration of feasibility for the thorium cycle is predicated on the assumption of improvements in industrialization and commercialization of the existing CANDU system, planning for nuclear installation and support systems in Canada, and the expansion of exports required to maintain a continuous and significantly enhanced technical capability at home, in spite of slower economic growth.[12]

The development of nuclear power is largely oriented toward future requirements for electricity. Any planning for increased electricity capacity must take into account both traditional factors and new directions:

- There is little doubt that electricity will play an important role in the required substitution for crude oil and natural gas.
- Electricity can, within limits, further expand and consolidate its position in the residential sector.
- Economic growth in the foreseeable future, however, is expected to be slower than during recent decades and the real cost of electricity is expected to continue to rise sharply.
- Transportation, the sector most critically dependent on oil, requires special attention. Electricity can play an important role in the areas of electric rail and transit vehicles. Independent of success achieved in these sub-sectors, electric transportation will still be a relatively limited part of total transportation. Railway electrification, because of required high investment costs, is expected to occur only selectively and incrementally. Electric road transport, unless more efficient storage batteries or converters are developed (and at the present time progress is slow), will be limited to relatively small vehicles designed for use over short distances.
- In the stationary use of electricity in industry and for residential purposes, the electric motor and related electrical devices are convenient, versatile and efficient. However, the conversion processes for primary energy to electricity, in thermal plants especially, entail very large losses.

Hence, electricity is an extremely useful, but relatively expensive, form of energy, although initial installation costs are sometimes quite competitive.

A very crucial consideration, requiring resolution soon, is coordination among R, D & D, a nuclear energy policy, and the viability of the Canadian nuclear industry. The present state of the domestic nuclear industry does not augur well for future development. Consideration of the proposed thorium cycle demonstration must somehow relate to rationalization and/or sustained activity in the Canadian nuclear industry.[13] In its present framework, widening Canada's nuclear energy supply options, in the face of limited domestic development programs, is a laudatory objective but one apparently surrounded by international constraints requiring complex solutions — such as increased exports of nuclear reactor power systems and/or the establishment of power export capabilities.

Demonstration of the feasibility of the thorium cycle, in its very first phase, must provide answers to the fundamental questions outlined, and may require reconsideration of the cycle's commercial feasibility or reassessment of the scale of demonstration. This information is considered essential for any long-term decision regarding full development of an advanced cycle in Canada. Moreover, a demonstration of the magnitude proposed would require full participation by electric power utilities, particularly Ontario Hydro, as a very important test for validating such large expenditures.

Any program, therefore, with the ultimate goal of demonstrating the commercial and industrial viability and social acceptability of a thorium cycle CANDU reactor would require much preliminary work and a number of major phases. Some of the most important aspects of the program are:

- Better definition of the physics parameters of irradiated thorium fuel;
- Development of thorium reprocessing technology;
- Acquiring more expertise in remote fabrication techniques and possibly new fuel fabrication methods;
- Demonstration of irradiation performance of the proposed recycled fuel.

It is an advantage that the existing CANDU reactor system can utilize the thorium cycle, with relatively minor modifications. Atomic Energy of Canada Limited (AECL) is well placed to perform the research and to develop and demonstrate, in a safe and acceptable manner, the feasibility of recycling "used" fuel in association with the electric utilities. In addition, AECL is in the best position to assist the utilities involved with the appropriate storage and transport required. Moreover, it should be recognized that AECL developed a successful design of a nuclear reactor through single-minded concentration on a selected technical option. This performance was realized in spite of temptations to dissipate its limited resources on alternative options. An equally concentrated dedication to a selected advanced fuel option is required, to repeat success factors and outcome. AECL must demonstrate both (a) increased awareness of, and control over, costs with respect to evolving design parameters, and (b) continued vigour when faced with program dislocations or temporary upsets. Only by aiming at a challenging goal will AECL be able to maintain its position at the forefront of this complex and expensive technology. (The demonstration of the feasibility of the thorium cycle, which would significantly extend Canada's nuclear fuel resource base, is outlined beginning on page 135.)

Renewable Energy

Canada, through extensive use of hydrogeneration of electricity, obtains a significant portion of its commercial energy from a renewable source. While this energy is indirectly derived from solar energy (as is energy associated with wind, waves, and ocean thermal gradients, as well as fuel derived from biomass and other photochemical reactions) the renewable source with the greatest long-term potential is solar radiation which can, for the moment, be best used in heating. (See Table II.2.)

Technologies required to utilize several renewable sources, have been developed, but typically they are still more expensive than established systems and supplies. Large scale commercial deployment of any technology takes considerable time and requires as prerequisites: an industrial base, economic advantage, and environmental and social attractiveness.

It is, therefore, of great importance that continuing R & D, organized around major demonstration programs, be undertaken in a number of selected areas so that the role of appropriate renewable sources in future energy systems can be planned with greater certainty. Extensive R, D & D programs are underway in many parts of the world which can provide valuable background information, on which to explore and demonstrate their applicability to Canada.

While Council recognizes the significance of such "renewable" sources as wind, tidal, and geothermal energy, and the need for continued R & D, we recommend at this time depending on regional implications, that demonstration projects be undertaken in the conversion of biomass to gaseous fuels and in the use of direct solar radiation for heating. Council further recommends a demonstration of energy generation from solid wastes, as much because of the growing problems of waste disposal confronting urban centres, as for the relatively modest amounts of derived energy.[14]

The proposed demonstrations, involving renewable energy sources, represent approximately $21 million out of the $860 million required for the first 5 years — or less than 3 per cent of total funding for the same period. This portion may seem small, even at this early stage of "renewables" development, however many additional projects have been proposed by industry, government, municipalities and universities.

It is essential that renewable energy R, D & D projects assist in the transition from non-renewable fuels. In this delicate process, neither a premature nor belated transition would occur with impunity. Although this transition would "be better too soon than too late" for obvious reasons, because of the present status of renewable technology it is deemed still necessary to operate sequentially within the R, D & D formula, i.e., begin with the transition from research to development and only then proceed from development to demonstration.

Since in a first approximation the funding from R to D increases by an order of magnitude and the transition from development to the second D increases again by an order of magnitude, the apparent low funding for demonstration of bio-renewables should not be construed as a contradiction of their value — or worse still as an endorsement of the permanent dominance of non-renewable energy technologies. The renewable energy program is deemed of great importance, even though it does not require funding, at this time, of the order of magnitude required for the non-renewables.

Two reasons for a "walk before run" posture are:

1. Too early demonstration would ready energy at costs the market could not yet bear, such as the demonstration of alternative liquid fuels from biomass.
2. Technological demonstration, without information from a first phase, could risk permature industrial engagement — as possibly in the case of space heating systems in individual homes.

It is, therefore, a matter of considerable concern that pressure to undertake demonstrations is sometimes accompanied by resistance to the economic investigations, and R & D programs required to assure an orderly transition.

Directions for the following demonstrations, reflect the overall intention that renewable energy technology, regardless of transient pressures will develop at an optimal pace within a mix of diversified programs.

1. The Demonstration of the Feasibility of Generating Gaseous and Liquid Fuels from Forest and Agricultural Residues

With important forest product and agriculture industries, Canada could be one of the privileged industrial nations, able to obtain important quantities of gaseous and liquid fuels from wood and plant residues, at least on a regional basis.

Commercial development of fuels from wood and agricultural wastes would have certain strategic advantages:

- Partial replacement of expensive imported petroleum and oil products;
- Establishment of a new and appropriate industrial base;
- Increased regional employment opportunities;
- Reduction of undesirable environmental impact resulting from the burning of fossil fuels;
- Facilitation of the transition from non-renewable to sustainable renewable forms of energy.

Gaseous fuels look promising. They rank immediately behind the direct utilization of biomass. Some technologists foresee sets of closely coupled modular gasifiers, that would permit the conversion of oil and natural gas burning equipment to wood-gas. This, however, may be an optimistic view. Indeed, any great expectations regarding the supply of forest-based wood gas — technology availability not withstanding — have yet to be validated by more extensive study of forest renewability, in terms of both capacity for growth and soil sustainability.

At first glance, methanol appears to be a remarkably versatile liquid fuel, that, in the long term, might be produced economically using already established technology. Alcohols have demonstrated high performance and clean combustion in spark ignited engines and turbines. Automotive tests have revealed that alcohol-gasoline blends can be used satisfactorily in at least some regions of the country, with only minor engine modifications.

Agriculture is not only vitally important in itself, but it is one of the critical users of petroleum products in Canada, consuming about one-tenth of all gasoline and diesel fuels. Alternative sources of energy for agricultural production could be derived from crop residues and animal wastes. Evaluations and projections of economically viable wastes are extremely variable, because of differing resource base assumptions.

While these statements are essentially correct, they could be misleading. At present, the production of alcohols from biomass is not economically competitive in Canada. As long as government is not prepared to intervene in the market, alcohol will not be available in fuel quantities. Alcohol, however, is a "fuel with a future" and the difficult act of balancing economics against preparedness is required in shaping its associated R, D & D. (The direction and level of effort for this "sensitive" demonstration program are detailed beginning on page 153.)

2. The Demonstration of Solar Water and Space Heating Systems

Solar energy has the potential for satisfying substantial space and water heating needs of the residential and commercial sectors.[15] This energy source can be described as permanent, environmentally acceptable and readily accessible in all regions, except perhaps in densely populated urban areas. There is no doubt that solar energy will play a role in Canada. Uncertainty remains only about "how soon" and "to what extent".

Preliminary evaluations indicate that the potential offered by solar energy, even in a northern country such as Canada, is relatively attractive. Because of environmental conditions, however, a coherent Canadian effort is necessary in order to validate more strategic aspects relative to the diverse expectations of Canadians. This should be based on a two-pronged approach, consisting of several hundred specific solar heating projects, complemented by a few large scale solar heating demonstrations.

Solar heating presents important new business opportunities. According to one assessment, the manufacture and sale of solar collectors could amount to several billion dollars between now and 1990, with benefits flowing to a variety of industries.[16]

The first solar energy research and development program, initiated in 1976-77 and coordinated by the National Research Council, consisted of more than a dozen heating projects in selected, single-family residences across the country. Several projects, initiated in 1977-78, concentrate on multi-family residences and on large public buildings and commercial developments. Moreover, additional impetus was created by new federal initiatives announced in the summer of 1978.

Various parameters of solar heating technology, such as types of collectors, circulating fluids, storage units, heat distribution and control systems, must be tested under various geographic conditions. The recommended development and demonstration programs will also provide some data on the "commercial" cost of maintaining solar heating systems. As in the case of other emerging technologies, solar heating techniques should be encouraged and tested, with projects selected initially, for the most favourable conditions. Such conditions would be found in existing, or preferably new, medium-density residential buildings, such as new housing or low-rise apartments containing between four and 16 living units, shopping centres, schools and other large public buildings. Due to the importance of space cooling in most modern commercial buildings, the impact of solar heating will be less than in residential buildings.

In brief, the most promising type of building appears to be the multiplex dwelling, in the low-rise apartment or town house configuration, because of the added contribution of solar heating to relatively high residential, hot water needs. More specifically, it is the scale effect of a large and continuing summer demand for hot water, in addition to space heating requirements, that makes a multiplex more attractive than a single dwelling, for solar heating applications.

Moreover, in respect to experimental projects, the scope of any enquiry should be extended to cover associated opportunities. As an illustration, Canadian homes would need supplementary heating on extremely cold or dull days where solar-heating systems lack storage capacity for more than a few days. Indeed, to many Canadians the possibility of heating their homes with solar energy during the long, dark winter months seems somewhat farfetched. The situation during summer months, however, can be quite different. Consequently, a case can be made in support of the testing of "annual storage tanks", with strong preference for very large apartments or entire residential developments, that would lower the overall cost of the system by eliminating the need for either private or public utility back-up heat systems. Obviously, maintenance of costly stand-by capacity or supplementary heat would be inconsistent with minimal capital outlay. There are already indications that the storage of heat from summer into winter in a water storage tank, can be cost-effective if large installations were involved. Few experts, however, will agree that annual storage is the ultimate answer to solar heating in Canada. To decrease the economic penalty, storage — and even solar energy captured through collectors — may have to be centralized by solar district, town, or village. At present, whereas collectors have become quite sophisticated, storage technology is not as far advanced.

Certain regulatory obstacles to the widespread use of solar heating must be overcome. Who has the legal rights to solar radiation? Will the user have to pay fixed charges on both a private or local solar installation and for an inordinately high share of the stand-by capacity required by the public utility to support such a system? Alternatively, supplementary energy would have to be provided by oil or natural gas burned in a furnace in the dwelling, which would increase the front-end capital cost of the home. Any demonstration program, in addition to covering the purely technical aspects, would need to address these more fundamental questions. (For a description of this demonstration, see page 164.)

3. The Demonstration of Energy Generation from Solid Wastes

In direct energy delivery, the quantities produced from Municipal Solid Wastes (MSW) would contribute only a small fraction of our total energy supply "mix". However, several factors make it important that Canada pursue a course designed to test and assess the technologies required for the direct combustion of MSW and possibly for the conversion of these solid wastes to gaseous and/or liquid fuels.

Clearly, ecological and environmental considerations and the urgent need to conserve agricultural land render our present mode of waste disposal — designated landfilling — less than desirable. At the same time, the opportunity to substitute this energy for some of the more scarce liquid and gaseous fuels makes a demonstration program in this area interesting. In addition, and perhaps more importantly, a waste management system approach could include the extraction of non-combustible materials (mainly ferrous and non-ferrous metals, and glass) and offer an opportunity to recycle and reduce the strain on non-renewable primary resources, provided the cost of such salvage is competitive.* Consequently, a demonstration program of energy generation from municipal wastes should determine the cost of energy production and delivery, in terms of various relevant parameters, under acceptable safety and environmental conditions.

Essentially, two combustion processes exist for the reclamation of energy from municipal solid waste: (1) incineration (direct burning) with recovery and utilization of heat, and (2) pyrolysis, which is the thermal decomposition of organic material, brought about by the action of heat in an oxygen deficient atmosphere, and resulting in the production of a liquid or gaseous fuel. Each technology has its advantages and the need for R, D & D is accentuated, because final selection will depend on factors such as cost, efficiency, integration with other waste disposal systems, and environmental and social acceptability. It appears that either system must include a preparatory process for removal of the inorganic materials and shredding and drying of the organic wastes, of which almost half is paper. This facilitates the recovery of metals and other materials and leads to more efficient and cleaner burning of RDF. Collection systems for the

*The processed material is referred to as Refuse Derived Fuel (RDF).

solid wastes must also be evaluated. (The technical direction and recommended level of effort for this demonstration are developed beginning on page 175.)

Conversion Technologies

In all processes employed to convert one form of energy to another, there are losses which arise from natural inefficiencies and limitations imposed by design capabilities and materials. In addition, these processes must conform to certain economic and environmental realities.

Large hydroelectric plants can convert over 90 per cent of energy available in the water above the dam to electrical energy, while modern fossil fuel plants usually convert only about 40 per cent of the heat they produce to electricity. Nuclear plants are even less efficient, presently operating at little over the 30 per cent level, but they are improving. Gas turbines are slightly more efficient, and diesel power plants eject about as much heat as the electricity they produce.

Thus, thermal power stations discharge a very large amount of heat, usually directly into the environment. If plants were designed to use the waste heat, in addition to the electricity produced, a doubling of overall plant efficiency could be achieved.

Many energy-efficient technologies, usually applied to individual units, such as a car, building, appliance, or one heat exchanger, can only be used on a decentralized basis. In such applications, many small decisions will be necessary in order to conserve a substantial amount of energy. Yet these amounts are important because of their aggregate impact. By comparison, the co-generation of electricity and heat when implemented by industry and utilities in a coordinated way, has the potential for major savings.

In the longer term, conversion processes founded on magnetohydrodynamics* or fuel cell technology may have substantial potential, but much basic work is required before national demonstration programs in these areas become appropriate.[17]

1. The Demonstration of Co-Generation of Electricity and Heat**

Co-generation of electricity and heat is an important component of the proposed national energy R, D & D strategy, representing as it does one of the important conversion and storage technologies.[18]

As the contribution of thermal electricity to total energy consumption increases, the associated heat losses of conversion from primary to secondary energy will also increase. Hence this is an important area of both concern and opportunity.[19] Just a small improvement in the overall

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*In view of its present status and long lead times in relation to desired applications, this technology may have missed its opportunity of playing a significant role.

**This section does not specifically cover topics that are sometimes confused or associated with co-generation of electricity and heat. These are: (a) combined gas turbine and steam turbine cycle plants; (b) total energy concepts and engineering; (c) heat pumps; (d) 'closed' or 'advanced' cycle operations.

conversion efficiency will represent significant primary energy savings. Electricity as a percentage of consumption, will increase significantly by the year 2000, and in an incipient "electrical society" it could represent some 40 per cent of total Canadian energy needs.

Co-generation of electricity and heat could assist with both energy and capital cost savings, through substitution for the scarce primary energy sources of oil and gas. Because of improved efficiency, costs per unit of co-generated heat are estimated to be substantially less than costs of separately produced heat (only about 55-70 per cent for nuclear co-generated heat). If, however, the "thermal" customer is remote from the source of generation, capital costs associated with heat transmission may offset this advantage.

Depending upon specific conditions, co-generation of steam and electricity would increase the thermal efficiency from about 33-40 per cent to 70-85 per cent, thereby saving energy, using the plant and equipment more efficiently, and reducing emissions of smoke and waste heat.[20]

In Canada, although some industries already do so, many other industrial groups could benefit from the concept of co-generation (e.g. primary metals, petroleum, chemicals, pulp and paper operations, dairies, breweries, and sugar mills).[21] A comprehensive plan exists for district heating using co-produced heat.[22] Ontario Hydro in a contribution to the Toronto District Heating Study, has included a plan wherein steam is used as a heat transmission medium in order to make the energy supply compatible with existing group-heating systems. New district heating systems, however, would probably use hot water as the heat transport medium because of specific advantages.

Although there are uncertainties about the scope and potential of this technology in some very "Canadian" respects (single-family houses may be connected, economically, to large district heating schemes only under very favourable conditions), the long-term prospects appear promising. Heat would probably be provided as the primary product and electricity as a by-product. Canada now co-generates an insignificant fraction of its electricity consumption. New institutional arrangements will be needed as well, in order to ensure that optimal benefits are obtained. (This demonstration is described in the Annex, beginning on page 182.)

Principal Strategic Elements in the Energy Demonstration Programs

By proceeding immediately with the recommended national demonstrations, Canadians could move toward determining their own energy future, rather than allowing it to be imposed by others. Principal strategic elements expected to be met, over the relevant time-frames, by the recommended energy demonstration programs are listed in Table IV.1.

Table IV.1 — Principal Strategic Elements

Demonstration Programs	Medium Term	Long Term
A. Fossil Fuels		
Oil and Gas		
1. The demonstration of the technological capability for exploration and production of oil and gas in ice-congested waters;	delineation of resources ensurance of critical supplies	continued contribution of critical oil and gas supplies assertion of sovereignty in northern areas development of necessary industrial capability
2. The demonstration of the transportation of hydrocarbons from the Arctic by marine mode;	timely delivery of supplies to areas dependent on foreign oil	spin-off of marine technology and related industrial development creation of a base for international transportation of natural gas maintenance of sovereignty
3. The demonstration of the ability of exploring for and producing oil and gas in very deep waters.	maintenance of correlative rights offshore extension of the energy resource base	extension of critical oil and gas supplies assertion of national rights
Coal		
1. The demonstration of fluidized bed technology;	utilization of additional and marginal resources substitution of oil and gas	maintenance of versatility in utilization of diverse forms and grades of fuels extension of inter-fuel substitution maintenance of acceptable environmental standards
2. The demonstration of land reclamation after coal is strip-mined.	resolution of conflicting goals assessment of coal's contribution in terms of environmental acceptability	acceptance of increased coal strip-mining mitigation of undesirable social impacts improvement of land use management practices
B. Nuclear Energy		
1. The demonstration of an acceptable irradiated fuel management and disposal system.	elimination of main concerns regarding safety of nuclear practices	continuation of environmental and social acceptability of nuclear energy
2. The demonstration of the feasibility of the thorium cycle.	extension of nuclear resource base ensurance of progress in nuclear energy supply	assurance of a necessary and large energy contribution creation of a capability for advanced nuclear systems
C. Renewable Energy		
1. The demonstration of the feasibility of generating gaseous and liquid fuels from forest and agricultural residues;	economic evaluation of the utilization of biomass residues contribution to energy self-reliance of vital industries partial substitution of oil and gas	utilization of biomass resources in an appropriate extended and sustainable fashion continued protection of the environment increased regional employment opportunities
2. The demonstration of solar water and space heating systems.	introduction of a sustainable form of energy some substitution of oil, gas and electricity	evolutionary technological enhancement of solar heating systems satisfaction of energy needs on a local basis — development of national industrial opportunities — improvement of legal and social aspects of solar energy — assurance of an acceptable environment
3. The demonstration of energy generation from solid wastes.	improvement of urban solid wastes disposal — substitution of primary energy	satisfaction of disposal requirements of urban environments — contribution to energy needs — support of recycling programs
D. Conversion Technologies		
1. The demonstration of the co-generation of electricity and heat.	enhancement of conversion efficiency — extension of energy resource base	potential for large energy conversion savings — reduction in environmental impacts of energy supply

V. Management and Funding

A large number of energy R, D & D activities have been funded in the last several years, within existing management structures. Among these, research and development type projects predominate. More recently, an impressive number of larger projects with considerable R, D & D content have been contemplated. These major energy developments were discussed at the Federal-Provincial Conference of First Ministers in February 1978.[1] Initiation of such projects will depend on financial, jurisdictional and regulatory arrangements as shown in Table V.1.

Funding for existing R & D activities needs to continue and to increase if supply strengthening and diversifying activities are to proceed on a broad front. But current funding is not sufficient. As an illustration, the Science Council recently recommended that the federal government increase its funding for renewable energy activities to at least $50 million per year.[2]

The pace at which expertise can be assembled in any particular case, and the infrastructure put in place, will be a major limiting factor in the rate of R & D increase. The capability of the recipients of R & D funds, to undertake a chosen program, is another important consideration in the determination of level and pace of funding. There is a need for selective diversification of management expertise. Canada cannot afford to squander scarce financial resources on poorly managed programs and inadequate implementation mechanisms, despite pressure to move in several directions and "get on with the job".

Sizeable funds will need to be directed toward demonstration programs identified in Chapter IV. Table V.2 summarizes these funding needs. In order to avoid confusion about the nature of funding figures, the following clarification will prove useful.

(a) "Funding" does not necessarily cover all costs related to the proposed national demonstrations. Funding is that fraction of total program costs which can be identified directly with the objective of a proposed R, D & D program. The difference (total cost less total funding) in all cases is to be paid by users or beneficiaries of the eventual affordable energy. In addition, beneficiaries must share in the basic funding requirements.

(b) "Initial funding" and "total funding" are fractions of corresponding overall costs expected to be incurred over the first five years and the full life of the program, respectively.

(c) Required funding, because of risks, must preferably be shared among industry and/or utilities and the federal, provincial and municipal governments.

(d) The fraction of funding which must be raised by users of the technology may be referred to as users funding. Almost without exception, *bona fide* future users or beneficiaries must risk some of their own resources on those R, D & D programs which will assist them to reduce the uncertainty surrounding important decisions and eventually to produce energy for commercial purposes. In fact, a stipulation could be made that any of the proposed programs should be contingent on participation by the parties who will ultimately sell or use the energy developed.

(e) In a first order of approximation, governments should participate in the risk funding of R, D & D in proportion to the Gross Domestic Product they control, preferably allocated on a regional basis. More specifically, several concepts described in this section would apply to participation in funding, and many decisions would be viewed realistically as the result of a bargaining process. Indeed, there are various shared government-industry management funding possibilities.[3] The formal sharing can only superficially be indicative of concepts of equity, since trade-offs occurring in different areas are both necessary and desirable.

(f) Only a fraction of total funding of the proposed demonstration programs is expected to come from the federal government. Provincial governments, because of extensive control of resources are more than *ex-officio* participants. Government funds, however, will be difficult to obtain. The Science Council believes that the first priority for taxes and royalties derived from the energy sector, should be used to ensure a continued supply of energy. That is, the first call on these funds should be for energy programs, particularly the high-cost energy demonstration programs. In this way, stability of funding and entry of new companies could be assured. Self-financing of energy demonstration programs can be enhanced through increased prices for energy, which will not only generate the necessary funding base, but also encourage energy conservation.[4]

While directions for demonstration programs and costs are given in this Report for illustrative purposes, the first step in addressing a particular program should be to (a) clearly identify and detail those technological, environmental, economic and social aspects that require demonstration; (b) evaluate the total effort necessary for a given demonstration program to be successfully completed, and (c) ensure the availability of funding required for the initial phase (first five years) of the program.

In view of a number of problems related to past spending excesses, it is mandatory that any expenditure proposed at this time be subjected to most careful scrutiny. This important requirement bears repetition. Thus, up-to-date engineering and economic studies must ascertain and show conclusively that expenditures associated with any or part of the proposed demonstrations are acceptable on a sound scientific, engineering and economic basis. More specifically, demonstrations must lead directly to timely and viable commercial developments, and potential gains must justify the risks.

Large-scale programs, be they demonstrations or commercial ventures, are difficult to initiate, organize, and carry to completion. They necessitate not only adequate management structures but also a

Table V.1 – Status of Selected Energy Projects

Project	Description	Status	Construction Schedule	Construction Total Cost
1. Polar Gas Project	The 3762 km pipeline will bring gas from Melville Island to an interconnection with TCPL at Longlac, Ont. Initial capacity would be 1.35 bcfd.	An initial filing, dealing primarily with facilities and environmental and social matters, is now being made to the NEB.	1982–87	$6.5 billion
2. Arctic Pilot Project	Melville Island LNG (250 M Mcfd) will be shipped to US or Canadian East Coasts	Feasibility studies in hand. Regulatory applications expected in 1978.	1979–82	$900 million (Sourcing uncertain)
3. Eastcan Exploration Program	Offshore exploratory drilling	Stalled pending resolution of jurisdictional issues. Good natural gas prospects. (Restarted in 1978)	................N/A...............	
4. Oil Sands III	Oil Sands Mining Plant, 125 000 bbl/d (Barrels per day)	Shell negotiating with potential partners, awaiting governments' decisions on fiscal terms.	1980–85	$3 billion
5. Syncrude Expansion	Increase Capacity from 129 000 bbl/d to 190 000 bbl/d	Possibility contingent on operating experience of plant, fiscal terms etc.	mid-1980s	N/A
6. Cold Lake	*In Situ* Recovery plus upgrading plant, output of 125 000 — 140 000 bbl/d	Technical plan filed with regulatory agency. Imperial awaiting govts' decision on fiscal terms.	1981–86	$2.1–3.7 billion

Note: Selected from background material for statement by Hon. A. Gillespie, Federal-Provincial Conference of First Ministers, February 1978, Doc 800-7/61. Brief reference is made also to various R & D programs and proposed projects in connection with pipeline activity in the western arctic regions (e.g., Canadian Arctic Gas Pipeline Limited and Foothills Pipelines (Yukon) Limited).

favourable and stable financial, political and regulatory environment.

Table V.2 presents the R, D & D demonstration programs which constitute the key elements of this Report. These programs are either

Table V.2 – Funding Required for Individual Technology Sets, in $000s (1978)

Priority Demonstration Programs	Initial Funding (First 5 years)	Total Funding (Cumulative to completion)	Total Years
Fossil Fuels			
Oil and Gas			
1. Exploration and Production of Oil and Gas in Ice-Congested Waters	81 600	176 000	10–15
2. Transportation of Hydrocarbons from the Arctic by Marine Mode	507 000	617 000	5–10
3. Ability of Exploring for and Producing Oil and Gas in Very Deep Waters	62 500	111 000	5–10
Sub-Total Oil and Gas	651 000	904 000	
Coal			
4. Fluidized Bed Technology	34 200	254 000	10–15
5. Land Reclamation after Coal is Strip-Mined	660	740	5–10
Sub-Total Coal	35 000	255 000	
Nuclear Energy			
6. Irradiated Fuel Management and Disposal System	52 000	444 600	20–25
7. Feasibility of the Thorium Cycle	95 000	1 750 000	25
Sub-Total Nuclear Energy	147 000	2 194 600	
Renewable Energy			
8. Feasibility of Generating Gaseous and Liquid Fuels from Forest and Agricultural Residues	3 950	37 000	10–15
9. Solar Water and Space Heating Systems	15 150	40 000	10–15
10. Energy Generation from Solid Wastes	1 510	58 000	10–15
Sub-Total Renewable Energy	20 610	136 000	
Conversion Technologies			
11. Co-Generation of Electricity and Heat	6 100	270 000	10–15
Sub-Total Conversion Technologies	6 100	270 000	
Totals	860 000	3 760 000	

Note: Funding figures are rounded and years are indicated by intervals; for more detailed but still illustrative data refer to the appropriate sections of the Annex.

newly suggested or already proposed in some modified form. They must be placed in the context of several high R, D & D content energy projects, already underway, securely assured of realization or only suggested (Table V.1). The demonstration programs listed in Table V.2 must be viewed as a partial, but essential, "shopping list" for a well-balanced program of demonstrations to be deployed throughout the nation.

The above observations strengthen a previous recommendation by the Science Council, for national coordination of energy R & D projects.* Independent of origins or directions, individual programs should be screened by a central analysis and coordinating group, so that opportunities, costs, and risks could be evaluated on a common basis, thus resulting in a more balanced program.

With respect to implementation of R, D & D, government's traditional role, in a free enterprise system, has been to create an environment in which the private sector can better undertake necessary demonstration programs, without unreasonable risk (e.g., provision of a favourable tax structure).[5] More specifically, in countries with a well-developed private industry sector (structure) and adequate industrial policy (strategy), the private sector can perform more effectively than government in developing, demonstrating, and deploying new technologies. Academic institutions, usually well endowed in these circumstances, can also make important research contributions. However, in instances in which governments have already participated in energy projects in Canada, a number of interesting management innovations which may be applicable in new demonstrations programs have arisen. These include:

- Crown corporations (e.g., Atomic Energy of Canada Limited, AECL);
- Public-private consortia (e.g., Pan Arctic);
- Designated private firms (e.g., Alberta Gas Trunk);
- Public utilities (e.g., Hydro Québec);
- Public research management and contracting organization (AOSTRA).

In a mixed economy, the range of management possibilities is indeed varied.** Difficulty arises not from lack of adequate structures, but in their timely and effective deployment by industry and government.

In Europe, *Groupement européen de recherche technologique sur les hydrocarbures* (GERTH) is a further illustration of a program whereby governments, in the EEC, provide funds in conjunction with industry to

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*Reference is made to "option analysis" and intergovernmental staff to serve ministerial meetings of federal and provincial governments. See Science Council of Canada, Report No. 23, *Canada's Energy Opportunities*, Information Canada, Ottawa, 1975, pp. 41-44.

**Petro-Canada has an important research role to play and in addition the Alberta Energy Company (AEC), 50 per cent owned by the Alberta Government, is very interested in research opportunities.

perform R & D. The main objective of this program is to put in place offshore technologies related to exploration in deep and ice-congested waters. A similar organization, Canadian Offshore Petroleum Technology Research Authority (COPTRA) has been proposed in Canada to provide the technical assistance and risk capital required to develop the technical capabilities of this embryonic industry.

Each of these institutions and management structures presents certain advantages, with respect to the eventual application to national demonstrations, which in turn depend on the particular strategy of deployment. Socio-political and economic considerations are also important.

As an illustration, fossil fuels have historically been developed by the private sector in Canada. Recognizing this, the designated private firm (or the public-private consortium) is likely to be the chosen instrument for demonstration programs and the principal source of funds. In the nuclear energy field, the Crown corporation, AECL is obviously the most appropriate institution. In areas of provincial responsibility, the chosen instrument could be one of the management structures already mentioned or possibly variants, depending on the political philosophy of the provincial government involved.

When an industry or a business firm is identified or designated as the chosen instrument for implementation of an energy policy, the onus is on government to play an enabling role through provision of financial support, the setting of an appropriate regulatory framework, and the use of ancillary government agencies to support and monitor the activity. When a government agency receives the mandate, however, the onus is on that agency to implement government energy and industrial policies in the relevant area, with timely involvement of industry for the adequate transfer of technology.

This recommended approach is best understood through examples. The Canadian petroleum industry should play a leading role in demonstration of the technological capability to explore and bring to production, oil and gas resources in ice-congested and deep waters. Since the offshore and northern regions fall within federal jurisdiction, the federal government must design and enforce direction-setting regulations and encourage its agencies, such as Petro-Canada, or influence its partners, such as Pan-Arctic, to increase and coordinate their efforts in developing the necessary technological capabilities. This will enable early access to oil and gas resources and ensure significant transfer to Canadians of the benefits accruing from such industrial development.

On the other hand, AECL is clearly the chosen instrument for demonstration of the feasibility of a thorium cycle nuclear reactor. In this case, AECL will need to ensure that Canadian industry becomes involved at the outset, so that an indigenous technological capability and structure of appropriate size is in place by the time the new reactor reaches the stage of commercialization.

One particularly innovative management structure is the Alberta Oil Sands Technology and Research Authority (AOSTRA), which was set up to capture, hold and manage the intellectual property surrounding *in-situ* oil sands, R, D & D. It has an initial fund of $100 million to allocate among contractors, for industrial research and pilot projects related to *in-situ* extraction and production of hydrocarbons from oil sands. AOSTRA is, thereby, a powerful instrument for the implementation of the policies of the Alberta government.

The sharing of responsibilities with respect to transportation, storage and disposal of irradiated fuel, is an illustration of cooperation between federal and provincial government organizations.

Merging government expertise, at federal and provincial levels, with industrial expertise in energy-related demonstration projects, will ensure that Canada is able to develop and maintain technological sovereignty in key areas of the energy sector. This sector is, in turn, inextricably tied to economic, social and political sovereignty.

Text Notes

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3. Science Council of Canada, *Tenth Annual Report*, 1975-76, a proposal for such a program was made by Dr. J. Kates, Chairman.
4. Science Council of Canada, Report No. 23, *op. cit.*
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Glossary

Actinides group name for the radioactive series of heavy elements starting with the element actinium of atomic number 89, and continuing to element 103, lawrencium. Obviously, the name is taken from actinium, the first member of the series. In order of ascending atomic number, the members of the series known so far are actinium, thorium, protactinium, uranium, neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium (102) and lawrencium. Possibly, yet higher elements in the series may be identified. The higher members of the series, however, have short half-lives, are intensely radioactive and have been produced only in very small quantities.

Anaerobic digestion a type of bioconversion in which the micro-organisms decompose or digest the waste material in the absence of oxygen.

Base-load operation at constant output with little hourly or daily fluctuation; e.g. electric power.

Bench-scale model small scale laboratory test or model of a process; an early phase of development.

Bioconversion transformation of organic material into methanol by micro-organisms.

Bituminous coal most widely used type of coal; its heating value ranges from 11 000 to 15 000 Btu per pound. Usually has little ash but frequently a high sulphur content, say 1-3 per cent.

Bottoming cycle a method of recovering, i.e., capturing and using excess heat produced by industrial processes.

Breeder reactor nuclear reactor in which more fissile material is produced than is consumed. A true breeder reactor should produce the same fissile species as that which it consumes. An example is a reactor which uses Pu^{239} as fuel and produces more Pu^{239} from neutron capture in U^{238}. The EBR-1, an experimental fast reactor, is not strictly a breeder reactor since it uses U^{235} as fuel and breeds Pu^{239}. A thermal breeder reactor may use U^{233} as fuel and Th^{232} as the fertile material.

Btu British thermal unit, usually a measure for heat energy.

Christmas tree surface installation of a production well consisting of several pipe connections and valves.

Coal gasification conversion of coal, coke, or char to gaseous products by reaction with air, oxygen, steam, carbon dioxide, or a mixture of these. Products consist of carbon dioxide, carbon monoxide, hydrogen, methane, and some other chemicals in a ratio dependent upon the particular reactants employed and the temperatures and pressures within the reactors, as well as upon the type of treatment which the gases undergo subsequent to their leaving the gasifier.

Coal liquefaction conversion of coal to synthetic crude oil, a product suitable for use as a refinery feedstock and for petrochemical production. The technologies now considered comprise one direct approach, two pyrolytic methods, and four solvent extraction or dissolution processes.

Combined cycle designation of a power plant which uses two technologies to generate electricity; usually applied to gas-turbine and steam-turbine combinations.

Core area of nuclear power installations where nuclear reactions occur.

Deep basin an area immediately east of the foothills belt, extending from Alberta to British Columbia where the Mesozoic sedimentary section thickens rapidly westward and, although it exhibits low permeability, is considered to be widely gas-saturated; e.g., by Canadian Hunter Exploration Limited.

Demonstration plant large-scale test facility; usually the last phase before a process or system is commercialized.

Disposal emplacement or release of waste material without the intention of retrieval. Disposal may be totally irreversible or retrieval may be possible; but it is the absence of an intention to retrieve which defines disposal. In general, disposal does not require continuing surveillance, although surveillance may be appropriate for limited time periods.

Electrolysis process of breaking a compound into its chemical components by passing an electric current; e.g., one method of producing hydrogen.

Energy conversion efficiency — a measure of how complete a process converts the energy contained in a particular resource (e.g., primary energy) into usable energy (e.g., secondary energy; end-use energy); usually expressed as a percentage of the input energy.

Energy demand — secondary includes all energy used by the various sectors of the economy (residential, commercial, industrial, and transport).
–primary is the total energy required to meet all secondary energy demands. It includes that used by the energy supply industries and associated conversion losses, as well as secondary energy demand.

Entrained bed — combustion process in which pulverized coal is carried in a gas stream.

ERDA — Energy Research and Development Administration, a US federal agency formed in January 1975 to coordinate, oversee, and disburse funds for the development and demonstration of new energy technologies; now absorbed in the Department of Energy (DoE).

Exergy — concept related to thermodynamically available energy and useful work; a term commonly used in Europe and associated with technical capability to perform work.

Exothermic process — chemical change accompanied by liberation of heat; e.g., combustion.

Extraction-turbine — a steam-turbine from which steam for process work or heating is tapped at a suitable stage in the expansion.

Fertile — a non-fissile element, more specifically, any element not fissionable by thermal neutrons, which can capture a neutron to become fissile, is called fertile. The most common example is U^{238} which can capture a neutron to yield U^{239} which decays to Np^{239} and then produces fissile Pu^{239}:

$$_{92}U^{238} - n \;—\; _{92}U^{239} - \gamma$$
$$_{92}U^{239} \;—\; _{93}Np^{239} - \beta$$
$$_{93}Np^{239} \;—\; _{94}Pu^{239} - \beta$$

Another relevant example is fertile Th^{232} which, after capturing a neutron, decays through Protactinium Pa^{233} to U^{233}.
The breeding of fissile nuclei from fertile nuclei is of great importance in both thermal and fast reactors. In

thermal reactors the Pu^{239} produced can help to replace the U^{235} used in operation and so keep the reactor critical. In fast reactors the escaping neutrons can be absorbed in uranium or thorium blankets to produce useful fissile material for other reactors.

Fertile materials materials which are employed in breeder reactors to produce fissile material by neutron irradiation. An example is thorium (or its compounds) employed in reactor blankets to produce uranium 233.

Fissile materials materials which are capable of undergoing fission by thermal neutrons. The chief fissile materials in use are uranium 233, uranium 235, and plutonium 239.

Fission a process wherein an isotope of a heavy element such as uranium or plutonium breaks up into two medium mass elements, the combined mass of which is less than the original mass; energy thus released in the form of neutrons appears ultimately as heat which can be recovered from a reactor by modified conventional means.

Fluidized bed layer of solid particles with a gas blown through it; a means of burning coal in boiler installations for direct utilization of coal as heat and/or electricity.

Fossil fuel hydrocarbon fuel formed by the temperature and extreme pressure exercised on organic matter over millions of years; natural gas, oil and coal are fossil fuels.

Frontier areas areas of northern Canada, such as the Mackenzie Delta-Beaufort Sea and the Arctic Islands, and mainly the eastern offshore areas, which have a potential for oil and gas but no history of production.

Fuel cell a device which produces electricity by combining a fuel, such as hydrogen or natural gas with oxygen or air, without burning the fuel.

Fusion a process of releasing energy by forcing together light nuclei, such as isotopes of hydrogen, helium, lithium or boron, under conditions of controlled temperature and fuel density over time.

Gas bubble expression used in connection with a transitory gas surplus in Alberta; this is a reserve surplus of a few trillion cubic feet caused by increased and successful exploration activity.

Geopressurized a situation in which huge quantities of water under substantial pressure in deep sedimentary basins contain a type of geothermal resource such as dissolved methane.

Halogens chemically related elements flourine, chlorine, bromine, iodine, and also astatine.

Heavy oils high density oils usually viscous but still mobile at reservoir conditions; oils of "low" API gravity; feedstocks requiring upgrading before pipelining and conventional refining — in this latter sense oil recovered *in-situ* by some methods from oil sands such as in Cold Lake, is also referred to as heavy oil. Heavy oil, as used in this Report to designate a resource, includes heavy oils of the Lloydminster type but excludes "heavy oils" recovered *in-situ* from oil sands such as in Cold Lake deposits.

Hog fuel forest wastes or residuals; bark, shavings, sawdust, low grade lumber and rejects resulting from the operation of pulp, saw and plywood mills.

Hydrocarbon chemical compounds containing mainly hydrogen and carbon; natural gas, oil and coal are hydrocarbons.

Hydro-generation addition of hydrogen to an organic substance; e.g., a step common in coal liquefaction processes.

In-situ in the original or natural position of discovery within the physical environment; usually associated with subsurface conditions and difficult or costly access.

***In-situ* recovery** expression used to denote a method of processing or extracting a fraction of the resource in place; e.g., recovery of bitumen of oil sands in the Cold Lake deposits or heavy oil recovery without mining; coal gasification or oil-shale retorting underground. Extracted gas or oil are pumped or forced out by pressure of displacing fluids.

Isotope any of two or more forms of an element having identical or very closely related properties and the same atomic number but different atomic weights (or mass numbers); e.g., U^{235}, U^{238} and U^{239} are three isotopes of uranium.

Lignite a type of low-grade coal having a heating value of 5500-8000 Btu per pound; usually it has a high ash content but generally contains little sulphur, e.g., less than 1 per cent.

Low gravity oils	oils of "low" gravity when measured in degrees API; e.g., Lloydminster 16° API; Cold Lake 11° API; Athabasca 10° API; by contrast high gravity oils have API gravities traditionally in excess of 30° API; e.g., light Alberta typical crude 42° API; upgraded or "synthetic" crude 39° API:.
Magnetohydro-dynamic (MHD) conversion	a topping-cycle concept of generating electricity by driving a hot gas through a magnetic field.
Methanation	chemical reaction between carbon monoxide and hydrogen to form methane.
Methane	clean-burning gaseous hydrocarbon fuel; principal component of natural gas.
Nuclear breeder reactor	a reactor which produces more nuclear fuel than it consumes.
Nuclear fusion	process of joining under controlled pressure-temperature conditions of certain light atoms, such as of hydrogen in the deuterium-tritium or D-T fuel cycle, to form heavier atoms, resulting a smaller total mass of fusion products and thus, in a release of energy from converted matter; also referred to as thermonuclear fusion.
Oil sands	a loose sand or a semiconsolidated sandstone impregnated with a heavy asphaltic crude oil or bitumen which is too viscous to be recovered by conventional methods; also referred to as tar sands or bituminous sands.
Ottawa line	In the early 1960s there was considered to be surplus oil in western Canada and thus the Canadian government supported policies to export crude to the US where prices were relatively high. At the same time, overseas foreign oil was cheap and because there was no high volume delivery system to eastern Canada from the west, it was decided to import foreign crude oil to satisfy the needs of eastern Canada. Consequently, in 1961 a national oil policy was established whereby areas west of the Ottawa Valley were supplied with crude from western Canada while regions east of the Ottawa Valley received imported oil. Hence, the "Ottawa line" was established and defended by the federal government for more than 10 years.
Otto-cycle engine	a prime mover or combustion engine based on a thermodynamic cycle, prevalent in automotive type internal combustion engines; uses a volatile liquid fuel and requires a "spark" to induce combustion of compressed fuel.

Photochemical conversion — method of breaking down water to produce hydrogen and oxygen involving the absorption of light by chemical dyes; a possible long-term method of producing hydrogen.

Photosynthesis — a fundamental process of nature by which green plants use energy of light to produce various substances; a method of producing hydrogen.

Pilot plant — an experimental facility usually larger than a laboratory-scale model; generally used to test continuous operation of an energy-conversion technology.

Plate tectonics — a theory proposing that land masses or blocks of rigid materials in the upper mantle are in motion relative to one another and through collision explain the occurrence of volcanic, seismic and orogenic activities at plate margins.

Pyrolysis — chemical decomposition whereby a substance is heated in the near-absence of oxygen to prevent total combustion.

quad — one quadrillion Btu (10^{15} Btu), equivalent to 172 million barrels of crude oil. One quad approximates 10^{18} joules or one exa joule.

Radioactive nuclides, natural — natural radioactivity is that exhibited by naturally occurring substances. Natural radioactive nuclides are classified as (i) primary, (ii) secondary, (iii) induced and (iv) extinct.

Members of the first class have life-times exceeding several hundred million years, and which presumably have persisted from the earliest to the present time. They include the alpha emitters U^{238}, U^{235}, Th^{232} and Sm^{147} and the beta emitters K^{40}, Rb^{87}, La^{138}, In^{115}, Lu^{176} and Re^{157}.

Members of the second class have geologically short life-times and are decay products of members of the first class. All known members of this class belong to the uranium or radium series, the actinium series or the thorium series.

Induced natural radionuclides are products of nuclear reactions occurring currently or recently in nature. A good example of this is C^{14} produced by cosmic ray neutrons in the atmosphere. Another example is Pu^{239} produced in uranium minerals by neutron capture.

Extinct natural radionuclides are those which have life-times that are too short for survival from nucleogenesis to the present, or long enough for persistence with measurable effects only up to early geological times. I^{129} is a suspected member of this class.

Radionuclide a synonym for radioactive nuclide.

Radium Ra^{226}, is formed by the alpha decay or ionium and in turn is the parent of radon, a gaseous emanation. Radon is alpha active and decays to produce radium A.

Radon a strong alpha emitter gas of half-life 3.825 days. Its decay products include both alpha- and beta-active bodies and they account for the apparent radioactivity acquired by other substances when placed near radium preparations. Radium and radon are "daughter elements" of uranium.

Reactor an atomic pile or confining equipment for control of a nuclear reaction intended to produce energy.

Reactor types there are three basic types of reactors, each characterized by the average energy of the neutrons which produce the fissions:

(1) Thermal reactors, where the neutrons causing fission are in equilibrium with the moderator of the reactor and thus have energies corresponding to the temperature of the moderator.

(2) Intermediate reactors, in which the neutrons have energies in a broad band between those for thermal and fast reactors, i.e., 1 eV to 1000 eV.

(3) Fast reactors, in which the average energy of the neutrons is several hundred thousand electron volts.

Reamer, reamed a tool which when incorporated in the drill string maintains bore-hole gauge in certain formations; expandable blades or cutters would permit the enlargement of a section of the hole drilled in a hard formation beyond the diameter of the drill bit.

Reprocessing as used in reactor engineering, the chemical and mechanical processes by which material removed after use in a reactor, such as plutonium 239 and the unused uranium 235 are recovered and prepared so that they may be reused.

Rheology the study of the deformation and flow of matter.

Selective coating special coating applied to solar collectors to enable increased heat-trapping.

Self-reliance as applied to Canadian self-reliance in energy, ability to depend on its own resources to meet its own energy requirements; at limit, it may be interpreted to mean self-sufficiency.

Shredder mechanical equipment used to reduce the size of solid waste in trash-to-energy system.

Solar collector device which traps solar radiation energy as heat; representative collector types are flat-plate, tubular and concentrating.

Solvent extraction a process in which one or more components are removed by intimate contact usually with a liquid, e.g., coal is dissolved in a solvent under high temperatures and pressures and then filtered, thus considerably reducing the ash and sulphur content of the original coal.

Storage emplacement of waste materials with the intention of retrieving them later. Storage is in principle temporary, though possibly of extended duration, and normally implies continuing surveillance.

Syncrude liquid fuel obtained by processing bitumen from oil sands, oil shale, coal and in some cases organic waste.

Synthetic or substitute fuel liquid, gaseous or solid fuel produced by a man-made process; e.g., bitumen upgrading, coal gasification and oil-shale retorting.

Thermonuclear energy a term employed for energy derived from a nuclear fusion reaction; e.g., based on a deuterium-tritium fuel cycle.

Thorium fertile material recently associated with "alternative nuclear fuel cycles"; e.g., Thorium 232, nearly 100 per cent of the naturally occurring element, will convert to fissile uranium 232 on capture of a neutron.

Tight sands reservoirs mainly containing gas, e.g., Elmworth area in the Deep Basin, with low porosity and especially poor permeability requiring several thousand wells and application of massive fracturing techniques, for recovery of gas.

Topping cycle a technique which supplements generation using conventional steam turbines by intercepting the energy of fuel before it is used to drive the conventional turbine; e.g., use of gas turbines to generate additional electric power.

Transmutation name given to the transformation of one element into another, taking place spontaneously with some, e.g., the radioactive elements, or induced by nuclear particles bombardment with others.

Trough collectors a type of solar collector which usually uses semicylindrical mirrored troughs to reflect solar heat on a longitudinal pipe and heat a circulating fluid. In a recent design the trough-type parabolic collector reflects solar energy onto steel absorber tubes plated with black chrome and placed at the parabolic focal lines of reflectors. The absorber tube is contained within an insulated housing, with an etched, tempered low-iron glass window. The reflector is an aluminum honeycomb sandwich with an adhesive-backed aluminized acrylic film.

Uranium natural uranium contains only 0.7 per cent of the isotope uranium 235 which is fissible. Uranium compounds may, however, be enriched in uranium 235 content, e.g., by gaseous diffusion processes, thus increasing the proportion of fissile material in a given quantity of uranium. Natural uranium comprises mainly the fertile isotope uranium 238, which on neutron irradiation leads to the production of plutonium. For a plutonium-producing reactor both these isotopes are necessary. U^{235} undergoes fission and thus provides neutrons which interact with the U^{238} to form plutonium.

Uranium oxide The most common oxide of uranium which is found in typical ores (U_3O_8).

Waterwall incinerator a solid waste combustion chamber containing tubes in its walls; e.g., when trash is burned steam is generated in the wall piping system.

Useful Units and Conversion Factors

Care has been exercised to ensure that definitions and units of energy used in the Report are clear and consistent. Several points are relevant:

1. Energy quantities, unless otherwise specified, refer to gross energy, not net energy.

2. Electrical energy, unless otherwise qualified, pertains to secondary energy, i.e., a conversion factor of 3412 Btu equals 1 kW.h may be applied in an equivalent or 100 per cent efficient conversion.

3. In primary-secondary electricity conversions we stress that whereas a quantity of energy of one kW.h converted to heat is equivalent to 3412 Btu, one kilowatt hour of secondary electricity produced by a thermal process is assumed to require, on the average, 10 000 Btu of primary energy. Thus, in terms of capacity or power, one GWt related to thermal primary energy may be equivalent to only 0.3412 GWe of secondary electricity.

4. In primary-secondary conversions of energy from all sources in a region, many factors are important, such as: mix of types of energy, vintage and size of plant and equipment, amount of rainfall — and therefore maximum utilization of hydro, and so forth. All-purpose conversion factors have been developed and used throughout this study.

5. In a transition period from the traditional inch/pound or imperial system of measurement to the universally accepted metric system now taking place in Canada, some problems of comprehension are understandable. For this reason both systems have been employed in this report.

Regarding the Established Units

1 quad or 10^{15} British thermal units of energy, equals for the purposes of this Report:

(1) 172 million* (i.e., 10^6) barrels of crude oil; note that 1 quad per year is approximately equal to half a million barrels of oil per day; or more precisely, 1 quad per year equals 472 110 bbl per day; or

(2) 1 trillion* (i.e., 10^{12}) cubic feet of natural gas; or

(3) 44 million* short tons of bituminous coal; or

(4) 293×10^9 kW.h of electricity, i.e., 293×10^6 MW.h (megawatt hours) or 293×10^3 GW.h (gigawatt hours)

**Note:* These values represent an average of recent production in Canada and may vary in the future with the quality and mix of fuels actually considered (i.e., produced or imported).

Regarding Metric Units (SI)

1 joule (J) is equal to:

(1) 1 W.s (watt second) of electrical energy

Thus:

1 kW.h = 36 MJ (megajoules)

and:

1 Btu = 1055 J

or: 1 Btu = 1.055 kJ (kilojoules)

Note: 10^{18} joules = approximately 1 quad

or

(2) 1 N.m (newton metre) of mechanical work (approximately 0.738 foot-pound).

Since: 1 quad = 1.055 EJ(exajoules)

and

1 tcf = 28.32 km^3

(trillion cubic feet) (cubic kilometres)

Regarding Useful Conversions

1 barrel (35 imperial gallons)	=	0.159 873 m^3 (cubic metres)
1 cubic foot of natural gas (14.65 psia and 60° F)	=	0.028 173 56 m^3 (101.325 kPa (kilopascals) and 15° C)
1 cubic foot of natural gas (14.73 psia and 60° F)	=	0.028 327 84 m^3 (101.325 kPa and 15° C)
1 long ton (2240 pounds)	=	1.016 t (metric tons)
1 short ton (2000 pounds)	=	0.907 t

Respecting one cubic foot of natural gas, note that 1000 Btu* equals 1055 kJ (kilojoules).

Prefixes used:

Prefix	Multiple	Symbol
kilo	10^3	k
mega	10^6	M
giga	10^9	G
tera	10^{12}	T
peta	10^{15}	P
exa	10^{18}	E

**Note:* The heat content of one cubic foot of "average" natural gas is actually some 1070 Btu, however, a calorific value of 1000 Btu is used in this Report.

Thus, in respect to electric power capacity:

1 MW	=	1000 kW	=	1 000 000 W		
(megawatt)		(kilowatts)		(watts)		
		and				
1 GW	=	1000 MW	=	1 000 000 kW	=	1 000 000 000 W
(gigawatt)		(megawatts)		(kilowatts)		(watts)

Note: 1 quad is 10^{15} Btu
(quadrillion)
However,
1 Q equals 10^{18} Btu
(quintillion)

Annex

Demonstration Programs

Fossil Fuels

Oil and Gas

1. The Demonstration of the Technological Capability for Exploration and Production of Oil and Gas in Ice-Congested Waters

The Relevant Context

Consistent with a policy of energy self-reliance, Canada as a northern country must acquire the technological capability for exploration of oil and gas in its arctic regions. Sufficient exploration has already occurred to confirm, at least, near-economic quantities of natural gas; moreover, insufficient exploration information exists at this point to discount the presence of commercial quantities of crude oil. It is certain however that ice will play an important role in the exploration and production of oil and gas.

As a vast circumpolar country, Canada will attempt for generations to come to "push" the endless expanse of ice northward. Indeed, a frontal attack on such ill-defined forces would be "donquixotesque" despite coordinated thrusts by industry and government. The northern climate cannot be manipulated; arctic waters cannot be heated to melt the ice. Even admitting this possibility, the consequences would be undesirable. Clearly a strategy, based on an understanding, and subsequent control, of ice properties, should be followed to develop and to aid in the successful completion of major national programs. Conceivably, ice could eventually be used as a *bona fide* construction material. In the short term, however, technology can be used to liberate petroleum, fishing, and shipping activities from the constraints of ice.[1]

Obviously, an appropriate ice technology must be developed. Canada must concentrate its resources on those areas where it enjoys comparative geographic advantage. Cold ocean technology is one such area.[2] Adequate ice technology would not only assist Canada's northern population to cope with its particular environment,[3] but would also serve vital transportation needs in arctic regions.[4] For example, icebreakers with great power and ample fuel could provide much needed flexibility (e.g., large nuclear icebreakers).

More specifically, the main directions to be followed are:

1. Continue to develop necessary pollution prevention and contingency systems, but allocate resources and direct efforts to establish an appropriate balance between "development" and "protection" activities.[5]
2. Strengthen research programs for the measurement, analysis, and understanding of ice characteristics in order to establish ice as a useful base material and building block for arctic systems.[6]
3. Increase efforts to develop and demonstrate equipment, technologies, and strategies for either avoidance of ice forces or reduction of the constraints imposed by ice.
4. Support applied research to enable effective, economic exploration and mapping of geological structures by seismic methods from both above and below ice, and in both ice-congested and iceberg-frequented waters.
5. Develop systems and processes for drilling exploratory wells in ice and iceberg infested waters and, eventually, through "shafts" in the permanent polar ice cap.
6. Design and test production, gathering, storage, processing and transfer systems for oil and (liquefied) natural gas which can be interfaced with either marine or land receiver terminals of long distance transportation systems. Production systems, depending on ice conditions and water depths — such as

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The notes for each demonstration appear at the end of its particular section.

island type, sub-bottom, submersible or bottom resident, but surface operated — must be continuously improved.

7. Expand the exploration season to the maximum period which is consistent with the optimal utilization of overall resources and plan for eventual year-round production operations. Low temperature metallurgy has developed christmas tree valves suitable for sustained use at -60°C (-75°F) and pipeline valves at -62°C (-80°F).[7] Equipment for workovers of wells is already available, which is self-sufficient and remains in operating conditions at -51°C (-60°F). Arctic operations at -60°C (-75°F) represent an extreme low limit.[8]

8. Research new ways of industry-to-industry and government-to-industry cooperation since sharing is the only means of making advanced and complex systems economically feasible.

In addition to the "hard facts" of energy self-sufficiency and long lead time, the world is in a period of expanding marine limits (eg., 200-mile limit) and consequent sovereignty negotiations.[9] The implications for Canada are obvious and the effect on the timing of a demonstration program must be considered.

This demonstration examines two complementary programs.

1. Ice Technology
2. Offshore Petroleum Technology

1. Ice Technology: Direction

Some aspects of ice technology which must be demonstrated are:

(1) Systems for continous collection and dissemination of environmental data for offshore ice-congested waters.[10]
(2) Measurement of ice properties.[11]
(3) New developments in echo sounding design for use in ice-congested waters.
(4) Systems for remote sensing of drifting sea ice.[12]
(5) Long-range iceberg tracking systems; completion of development and demonstration.
(6) Profile of the underwater portion of icebergs.
(7) Systems for interception of, and connection with icebergs (e.g., by penetration heads and cable).
(8) Iceberg towing technology.
(9) Assessments if ice scours. (Scraping along the bottom could dislodge wellhead installations and pipelines.)
(10) New developments in ice breaking techniques.

The relative importance of these aspects change with each specific exploration and production program. Hence, the ordering by priority also changes from case to case.

Ice conditions in the Arctic can hamper the completion of seismic programs on irregular surfaces. At other times during the year the same areas are fairly ice-free, but the ice can move back and forth so that a vessel is either fighting or dodging ice. Several types of personnel-carrying vehicles have been developed for use on offshore "shoots". High-wheeled crew camps must be further tested and improved. On-line ice thickness measurements are essential.

The nature of ice technology is extremely complex, as may be confirmed by a literature search. (See notes 13-26.) Possibilities for innovation, however, could be unexpectedly high.[27]

2. Offshore Petroleum Technology: Direction

The principal aspects of the offshore petroleum technology that must be demonstrated are:[28]

(1) Systems for containment and clean-up of oil spills:
   (a) oil on water surface with ice;
   (b) oil on sea ice;
   (c) oil under ice cover;

(d) particulate oil in ice.
(2) Systems for diving in cold water.
(3) Demonstration of drilling systems specifically designed for ice-congested waters. This would be preceded by evaluations of several systems, e.g.:
  (a) artificial oil drilling island construction techniques (e.g., casson retained islands);
  (b) ice-strengthened conical vessel;
  (c) ice-strengthened drilling barge;
  (d) ice-breaking drillship;[29]
  (e) bottom-based drilling systems;[30]
  (f) amphibious air-cushion drilling systems, under the following arctic offshore conditions:
    (i) ultra-shallow waters
    (ii) short season open water areas
    (iii) landfast ice areas.
(4) Improved ice platform drilling.*
(5) Development and further testing of moorings systems.
(6) Systems for preventing pollution from drilling fluids.
(7) Testing and redesign of support ships for drillships.
(8) Systems for safe and rapid disconnecting and connecting surface structures with wellhead installations (e.g., "ice-disconnect" at top of silo).
(9) Development of advanced subsea systems.[31]
(10) Blow-out prevention systems for both drilling and production phases (e.g., underwater blow-out).[32]
(11) Construction of offshore petroleum production platforms; completion of development plan and demonstration.
(12) Protection systems against ice pressures for petroleum production platforms.
(13) Development of laying techniques for oil and gas-gathering systems on sea bottoms disturbed by ice.
(14) Pipeline and wellhead protection from sea-bottom ice scouring.[33]
(15) Evaluation of feasibility of undersea storage systems in ice-congested waters.
(16) Continuous monitoring of materials research relevant to a potential increase in the technological capability for exploration and production of oil and gas in ice-congested waters.

The priority of demonstration of these systems and the evolving practices would be evaluated according to the necessary components and their interaction within each particular program.[34] A systems approach is necessary since the components are inter-supportive and *in toto* must provide a well organized effort. In any case, technologies must be demonstrated that render the oil and gas industry environmentally and physically safe and more effective in severe climatic conditions. Careful planning and implemention of the proposed demonstrations will enhance Canada's offshore capabilities in ice-congested waters.[35]

Level of Effort

1. Reference Points

Ice Technology and Offshore Petroleum Technology

(a) Federal Science Programs 1977-78 by MOSST:
- "Total S & T expenditures on oceans and ice-covered or ice-infested waters will be over $45 million in 1977-78, an increase of 7 per cent over 1976-77." p. 14.

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*NRC scientists, in cooperation with a firm of consulting engineers, have already contributed significantly to the development of ice platforms to support drilling rigs for "offshore" oil exploration in the Arctic.

- "The Environmental Energy Branch has a $2.6 million S & T program in 1977-78 ($0.6 million in 1976-77) on oil spill countermeasures (including $2.3 million contracted out to industry), of which $1.7 million is dedicated to R & D in the Arctic." p. 33.

- "New funds of $1 million have been included in the NRC's Engineering and Natural Sciences Research Program for the development of ocean data collection; a significant part of this is relevant to offshore petroleum technology." p. 40.

(b) Department of Supply and Services, DSS File References:
- 02/k00-SS-6-3022 on Arctic Offshore Oil Spill Development Contract: $2 000 000 per year project;
- 01/k00-SS-6-3001 on Feasibility of Oil Containment or Channelling Devices for Use in the Beaufort Sea; and
- 01/k00-SS-6-3002 on Development of a Three Dimensional Prediction Model of the Movement of a Dispersed Oil Slick.

(c) Transport Development News, June 1977, p. 14: Oil Spill Technology Program — The Environmental Protection Service has undertaken a five-year $7 million technology program to counter oil spills in arctic waters.

(d) Canadian Petroleum Association current statistics — calculated averages from 1977, 1976 and 1975 data:

"Industry Expenditures in NWT and Arctic	
Exploration:	$273 000 000
Development:	$ 3 900 000
Land:	$ 3 100 000
Production Facilities:	$ 91 000 000
Total	$371 000 000"

Interpretation: In view of the uniqueness of the "working environment", R & D expenditures could be as high as some 3-5 per cent of industry expenditures, i.e., $10 000 000–20 000 000 per year.

2. Exploratory Calculations

Ice Technology — Continuous Program

(a) For this purpose a five-year program is considered for the period 1979-1983.
- Say 3 groups with annual average individual budget of $1.6 million:
  3 × 1 600 000 = $4 800 000 per year
- Alternatively say 25 scientists and technologists supported by adequate equipment and auxiliary staff:
  25 × 3 × 32 000 = $2 400 000 per year
- Comparisons with several equivalent ongoing programs: $2 100 000 per year
- Assumed target average $3 100 000 per year

The five-year program will require, therefore:

Total Funding $15 500 000

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*M.B. Todd, "Platform construction and operation, Cook Inlet, Alaska," *Journal of Canadian Petroleum Technology*, October-December 1969, pp. 165-174.

Offshore Petroleum Technology – Systems Assessment and Demonstration Program

(a) The following expenditures are expected for components of the program:

- Systems for containment and clean-up of oil spills: $ 10 000 000
- 3 Drilling Systems
  Total Cost: 630 000 000
  Cost directly applicable to proposed demonstration program at 20 per cent of total: $126 000 000
- Well Completion Systems
  Total Cost: $ 10 000 000
  Funding required at 30 per cent of total cost: $ 3 000 000
- 3 Production Platforms*
  Total Cost: $ 36 000 000
  Funding allocated at 50 per cent of total cost: $ 18 000 000
- Gathering, storage and supporting systems:
  Total Cost: $ 15 000 000
  Funding calculated at 20 per cent of total cost: $ 3 000 000

The offshore petroleum technology demonstration program will require:

Total Funding $160 000 000

The aggregate funding figures for the demonstrations of Ice Technology and Offshore Petroleum Technology are:

Grand Total: $176 000 000*

Time Frame

Ice Technology

(a) For the purpose of providing a notional time framework, the interval 1979-1983 is proposed.

(b) Assumed target average annual funding: $ 3 100 000

(c) Assumed illustrative time distribution of annual funding:

1979	$ 2 100 000
1980	$ 3 500 000
1981	$ 4 000 000
1982	$ 3 500 000
1983	$ 2 900 000
Total	$16 000 000*

Offshore Petroleum Technology

(a) Assumed illustrative distribution of annual funding:

1979	$ 5 500 000
1980	$ 8 800 000
1981	$ 13 200 000
1982	$ 17 700 000
1983	$ 20 400 000
1984	$ 22 100 000
1985	$ 21 500 000
1986	$ 19 900 000
1987	$ 17 100 000
1988	$ 13 800 000
Total	$160 000 000

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*Rounded

Ice Technology and Offshore Petroleum Technology

The time-profile of the disbursement of the cumulative aggregate sum for funding both ice technology and offshore petroleum technology demonstration programs can be obtained by simple addition:

1979	$ 7 600 000
1980	$ 12 300 000
1981	$ 17 200 000
1982	$ 21 200 000
1983	$ 23 300 000
1984	$ 22 100 000
1985	$ 21 500 000
1986	$ 10 900 000
1987	$ 17 100 000
1988	$ 13 800 000
Total	$176 000 000

Notes

Relevant Context

1. Several papers on cold ocean research, marine engineering, ice platforms, and submarine transports, *Engineering Journal*, July-August 1977, pp. 6-11; 13-15; 18-19 and p. 12.

2. *Science Policies in Smaller Industrialized Northern Countries: Proceedings of a Seminar*, Science Council of Canada, April 1978, 93 p.

3. Ian Reid, "Engineering for the Arctic Environment," *Engineering Journal*, January 1978, pp. 30-31; R.M. Hardy and Associates Ltd., *Research and Development for Civil Engineering in Cold Regions*, a report prepared for Department of Supply and Services, Science Procurement Branch, on behalf of National Research Council, 104 p; Kenneth M. Adam and Helios Hernandez, "Snow and Ice Roads: Ability to support traffic and effects on vegetation," *Arctic*, Journal of the Arctic Institute of North America, March 1977, pp. 13-27.

4. E.A. Mirosh, "Arctic gas pipeline soon a reality — Pipeline construction in the Yukon Territory is expected to begin on January 1 of 1981, the culmination of a decade of northern gas pipeline R & D," *Engineering Journal*, January 1978, pp. 22-28; "Canadian ships and shipping: Meeting the ice challenge provides scope for original Canadian technology," *Engineering Journal*, January 1978, p. 5.

5. Note 3, *op. cit.*; H.E. Howard-Lock, "Remote sensing from satellites: The best way to spot oil spills quickly," *Science Forum*, February 1976, pp. 20-23.

6. Note 1, *op. cit.*

7. D.W.G. White and J.D. Boyd, "A new family of steels for the North," *Engineering Journal*, January 1978, pp. 32-34; "Low temperature metallurgy outlined," *Oilweek*, 7 August, 1978, p. 62.

8. R.M. Hardy and Associates Ltd., *op. cit.*

9. David A. Ross, "The Importance of Marine Affairs," *Science*, 28 July 1978, 305 p.

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"Canadians design ice-going cargo vessel," *Engineering Journal*, January 1978, pp. 6-9.

A.R. Milne and Brian D. Smiley, *Offshore Drilling in Lancaster Sound: Possible Environmental Hazards*, Institute of Ocean Sciences, Patricia Bay, Department of Fisheries and Environment, Sidney, B.C., February 1978, 95 p.

A.E. Pallister, "New Petroleum Technologies in Canadian Arctic Seas," the 5th International Ocean Development Conference, 25-29 September 1978, Tokyo, 12 p.

Preliminary Offshore Environmental Study: A physical and biological environmental baseline study and environmental impact analysis of blowouts for the shelf zone of southeastern and southern Newfoundland waters, Report prepared by NORDCO and Northland Associates, Government of Newfoundland, Department of Mines and Energy, 1978, 344 p.

Ice Technology

10. G. Tsang, "An ice-oil boom," *Spill Technology Newsletter*, vol. 3, no. 2, 1978, pp. 7-14; E.C. Chen, B.E. Keevil and R.O. Ramseier, "Behaviour of crude oil under fresh-water ice,"

Journal of Canadian Petroleum Technology, Montreal, April-June 1976, pp. 79-83; R.G. Nagler, "Operational oceanographic satellites, SEASAT potentials for oceanography, climatology," coastal processes and ice, 1975, 22 p.

11. Kenneth Butt, "Creep measurement on arctic ice drilling platforms," *C-Core News*, April 1978, pp. 6-8; "Workshop on the Mechanical Properties of Ice," Calgary, 1977, proceedings, NRC, Associate Committee on Geotechnical Research, Ottawa, 1977, 167 p.
12. R.G. Nagler, *op. cit.*
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2. The Demonstration of the Transportation of Hydrocarbons from the Arctic by Marine Mode

The Context of Diverse Interests

Marine transportation is expected to become increasingly significant internationally, for many reasons. The importance of liquefied petroleum gases, i.e., mainly LPG-propane and butane, has increased due to the rise in energy prices in general and the renewed interest of OPEC in the export potential of these high-grade fuels.[1] Liquefied natural gas, methanol, and ammonia are transportable products which permit normal withdrawal from reservoirs in cases in which natural gas cannot be piped to local end users.[2]

The transportation of liquefied natural gas (LNG) by tanker may be the most economical solution to seasonal demand and especially to problems of distance between supply and demand.[3] Large baseload systems are usually in excess of one-third TCF per day. The current $800 million worth of LNG in international trade may grow ten-fold to $8 billion by 1985.[4]

The Arctic, except for the short summer, is a land with long stretches of ice. In this environment, long-term planning, detailed logistics, and effective transportation are vital. Several industry and government interests have developed plans for different transportation systems. Although the directions taken are diverse, high costs dictate that cooperation between sectors is highly desirable.[5]

During the short summer, the Canadian Coast Guard as a principal actor "is active 24 hours a day . . . shepherding transport and supply vessels to ports, settlements, research stations and resource exploration sites throughout the Arctic."[6] The presence of the Coast Guard in the North is a national imperative,[7] and the requirements placed upon it are both intensive and extensive.[8]

Another principal actor, the exploration companies in the Beaufort Sea (presently only Dome Petroleum Ltd. is directly involved), plan to use icebreakers to support drilling operations and to extend the summer activity period to four months or more.[9] Eventually, if production is assured, ships may bring oil and especially gas (as LNG) to market.[10] At the centre of this transportation concept is the Marine Locomotive, a Polar class 10 icebreaker. The icebreaker would assist the LNG tankers during the peak ice season and possibly for a period of up to eight months.

Due to the uncertainty surrounding location and size of reserves, in present and future pools in the Arctic and offshore, it may be advantageous — and perhaps the only way open — to use the marine mode to transport either oil or gas. Transportation by marine mode would require consideration of alternate systems such as:

1. Transportation of crude oil by:[11]
   (a) Icebreaking tanker;
   (b) Catamaran type semisubmarine icebreaking tanker;
   (c) Semisubmarine icebreaking tanker (SSIT).

2. Transportation of LNG by:
   (a) Icebreaking LNG tanker without support;
   (b) Ice reinforced LNG tanker with support;
   (c) Icebreaker — LNG barge combinations.

3. Transportation of oil by "dracone", the craft hauled by a marine tractor (e.g., submersible, flexible, collapsible, sausage-like oil container or barge for underwater towing).

4. Transportation of oil by combined pipeline-tanker system. For example, Panarctic considered construction of a 10-inch diameter pipeline from Cameron Island 160 miles east to Bathurst Island and the transportation by supertanker to a deepwater port in the Maritimes.

5. Transportation of oil by icebreaking barge (e.g., pusher-ship-barge combination).

6. Transportation of oil by subsea tanker capable of operating under the arctic and polar ice (e.g., advance concepts developed by General Dynamics, Electric Boat Division).

7. Transportation of oil by N-powered sub (e.g., General Dynamics).

Petro-Canada and Alberta Gas Trunk Line Co., Ltd. have proposed a pilot project to transport LNG from Melville Island in the Arctic to Canadian and US markets, using a self-propelled barge and pusher tug combination.[12]

Natural gas is expected to be the main area of concentration. Some 70 per cent of the gas discovered in the Arctic is offshore and covered by ice. Small gas pools, containing as little as 2-4 tcf of marketable gas may be connected in a 2-stage process to either the markets on-shore or to the receiving storage of a pipeline, which usually may extend over distances not exceeding 150-200 miles. Larger gas fields in the range of 6-12 tcf, may be served by LNG tankers operating over longer distances. A pipeline across relatively manageable terrain may connect a gas region containing as little as 8-10 tcf, provided that the distance is not excessive. A long pipeline over difficult "terrain" would require threshold reserves of some 20 tcf.[13] In respect to oil, depending upon site-specific conditions, marine mode may be of interest for individual offshore reserves in the range between one-third and one billion barrels.

In the past, several companies (e.g., Tenneco Inc.) have expressed interest in importing LNG into Canada, regasifying it, and then exporting all or some of it to the US.[14] Regasification plants and other installations could be, at least partly, incorporated into a project for bringing LNG from the Arctic. Defering construction of proposed LNG terminal installations, however, could have a detrimental effect on the timing of an LNG arctic project.[15]

Finally, producing and transportation companies have indicated their interest in extending pipeline facilities to bring natural gas from Alberta to various points in Quebec and/or the Maritime Provinces.[16] Clearly in this case, market conditions for LNG from the Arctic would be affected in some yet undetermined way.

Technological Directions

The following questions appear pertinent in respect to the proposed demonstration of hydrocarbons from the Arctic by marine mode:

(a) How much oil, and especially gas, is present in the high Arctic?

(b) At what price can gas be distributed and marketed, and at what costs can it be extracted, converted and transported?

(c) How does LNG transport compare economically, mainly in terms of relative costs, with methanol and gas pipeline systems? Are there complementary co-existing functions?

(d) Has the economic exploitation of high arctic gas been deferred in view of the recent updating of western Canadian gas reserves and potentials?

(e) How valuable is the flexibility of marine transportation within an evolving oil and gas supply strategy?

(f) Are sensible ecological and environmental considerations a barrier to the development of LNG transportation technology, in general, and as it pertains to arctic regions in particular?

Technological solutions to physical requirements would tend to support the marine mode:

- Rather small scattered gas accumulations, offshore and mostly under ice, isolated from both markets and one another by considerable distances.
- Relatively great uncertainty in predicting the economics of the field development program.

The main characteristics of marine mode which should be considered are:

(a) Evolutionary, flexible, incremental, and modular development.
(b) Realizable at the earliest possible date.
(c) Streamlined and economic, but vigorous and safe.
(d) Leading to maximum Canadian content, and compatible with (b) and (c).

The critical components of a demonstration program are:

1. Gas Liquefaction Plants
Possibly all liquefaction equipment will be assembled in southern, more hospitable climates and mounted on barges. Emphasis would be on rather large plants employing simple cycles and reliable equipment (e.g., optimized cascade cycles, simple-cycle gas turbines, rotating compressors). The freezing of aqueous solutions should be avoided. Also, special steels resistent to low ambient temperature may have to be used. Modularity and mobility are important aspects to implement.

2. Port Facilities at Point of Origin
The safe approach to the docking site and the loading of LNG under dynamic, arctic conditions would pose serious, but not insurmountable problems.

3. LNG Ship Configurations[17]
Difficult choices pertain to the type of carrier to be used: for example, Class 7 or 10 ice-breaking carrier[18], a more conventional carrier with icebreaker support, or self-propelled barges with or without pusher-ship support. Also, the trade-offs between power and speed of pusher-cargo units would have to be optimized under conditions that are difficult to predict.

4. Design of LNG Ships[19]
Among critical aspects, requiring special consideration for the challenge of arctic situations, are:

(a) Ship form; hull and bow profiles and design.
(b) Technological evaluation of containment systems; safety at impact with ice.
(c) Special cargo transfer facilities in low ambient air and sea water temperatures (e.g., loading, unloading and possible intership transfers).
(d) Effective on-ship piping and control systems; considerations of wind factors and icing of bridge installations.
(e) Appropriate power for "LNG icebreaker"; type of screw (e.g., quadruple).

5. Terminal Facilities
Location of existing facilities will play an important role. Several critical parameters would have to be identified and evaluated using realistic economics.

Level of Effort

1. Reference Points

(a) Petro-Canada Annual Report, 1976, p. 15:
"The Corporation's investment in 1976 of $7.0 million included payments

required to equalize the Petro-Canada expenditures with those of the other participants."

Interpretation: Annual cost of pre-application feasibility study 7 000 000/0.45 equal about $16 000 000.

Also: Petro-Canada Arctic Pilot Project, 23 p.

(b) Proposal by Dome Petroleum Limited for the Development of an Integrated Arctic Marine Transportation System, January 1977, various paging.

(c) The Shipment of Liquefied Natural Gas from Melville Island to the Eastern Seaboard, An interim report prepared by Melville Shipping Ltd., April 1977, 43 p.

(d) Panarctic Oils Ltd.; Annual Report 1976, p. 8; LNG Pilot Project — Examination of the Feasibility of Marketing LNG; possibly followed by marketing project.

(e) Application of Lorneterm LNG Ltd., to the National Energy Board (NEB), vols. 1-3; TransCanada PipeLines (New Brunswick) Limited. Application; Canadian Lowell Gas Ltd. Application; Tenneco LNG Inc., Response to additional information; interventions. The proposed project, now in a state of abandonment, covers the Canadian section of a $5.1 billion scheme to bring Algerian liquefied natural gas to Lorneville near Saint John, vaporize it and use a pipeline to transport it to the Tenneco gas system in the northeastern United States.

(f) Proceedings of the Seminar on Natural Gas from the Arctic by Marine Mode; 21-23 February 1977: Sponsored jointly by the Science Council of Canada and the Atlantic Provinces Economic Council.
   - p. 54: Cost of a 2000 MMCF per day liquefaction plant: $400 000 000
   - p. 234: Cost of site preparation and regasification plant construction: $316 000 000
   - p. 79: Cost of LNG tankers;
     125 000 m^3 - $184 000 000
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(g) Working session papers for Arctic Transportation Systems, Arctic Systems Conference, 18-22 August 1975, Memorial University of Newfoundland, St. John's.

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(k) A.A. Bruneau, Communication of 27 February 1978: A combination of 3 ships instead of two, would lower the interest costs accrued during construction. A rate of 250 MMCF per day would be appropriate for an LNG pilot transportation system.

2. Exploratory Calculations

(a) *Engineering Study*

The following figures are based on average consultants fees expressed in percentage of plant costs.

- Port facility and gas liquefaction plant: $ 55 000 000
- LNG Tankers: $ 48 000 000
- Regasification Installations:* $ 34 000 000

Total Funding: $137 000 000

(b) *Pilot Demonstration Approximate Costs:*
- Technical Concept:
Average throughput equals 250 MMCF per day or 91.25 BCF per year. Three tankers of some 100 000 m^3 each making up to 15 round trips a year.
- Port facility and gas liquefaction plant: $550 000 000
- First 3 LNG Tankers: $480 000 000
- Regasification and Terminal Facilities: $340 000 000

Total Cost: $1 370 000 000

Because of indirect beneficial economic impacts[20] and the assumption that the demonstration would result in an economically viable commercial activity, it may be assumed that only a partial but significant amount of the total cost, say 35 per cent, is applicable to this demonstration:

Total Funding: $479 500 000

Grand Total: $617 000 000†

Time Frame**

An illustrative distribution of this grand total over a relatively compressed time interval 1979-1985 is as follows:

1979	$ 13 700 000	– 10 per cent of costs of engineering study
1980	47 950 000	– 35 per cent of costs of engineering study
1981	130 000 000	– 55 per cent of engineering costs and some procuring
1982	195 350 000	– regulatory and conditional contracts
1983	120 000 000	– contracts and completions
1984	80 000 000	– completions
1985	30 000 000	– completions and start-up
Total	$ 617 000 000	

Notes

Context

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*An LNG terminal of economic size may cost as much as half a billion dollars (e.g., Lorneville, N.B. proposed terminal: $636 million).

†Rounded

**The *raison d'être* of hydrocarbon (either oil or gas) transportation by marine mode from the Arctic is an early completion of the delivery system in conditions of extreme uncertainty with respect to size and distribution of future reserves. Deferments, therefore, appear counter-productive. "Dome icebreaker date delayed," *Oilweek*, 16 October 1978, p. 10.

5. *Ibid;*
"LNG Safety: A Matter of Scale," *Technology Review*, February 1978, pp. 56-57; "No Offshore LNG Ports," *Technology Review*, January 1978, p. 25.

6. Ken Webb, "A ship for all seasons," *North*, May-June 1978, pp. 20-27; Jacqueline April, "*La garde cotiere canadienne*," *Nord*, July-August 1978, pp. 20-25.

7. Yuri Filatov, "Arktika at the North Pole," *North*, March-April 1978, pp. 16-21; Yari Shnitnikow, "Soviet icebreaker reaches the North Pole," *Canadian Geographic Journal*, February-March 1978, pp. 34-37.

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9. "Dome receives bids for icebreaker," *Oilweek*, 23 February 1978, p. 22.

10. *Ibid;* Jeff Carruthers, "Dome thinks Arctic crude oil tanker system would be cheaper than pipeline," *Globe and Mail*, Toronto, 23 November 1977, p. B5.

11. Robin Burton, "Breaking the Arctic Ice," *North*, March-April 1977, pp. 32-35.

12. "LNG Pilot has far reaching implications." *Energy Analects*, 6 May 1977, p. 2; "Petro-Canada, AGTL defer LNG transport project decision," *Oilweek*, 24 July 1978, 17 p; "Petro-Canada offers to finance proposed Dome Arctic icebreaker," *Oilweek*, 22 May 1978, p. 4.

13. "Pipelines from Arctic Islands being studied," *Oilweek*, 28 February 1977, p. 36.

14. Ross Ingram, "The Liquefied Natural Gas Terminal near Saint John, N.B.: A Highly Explosive Issue," *Atlantic Advocate*, August 1977, pp. 8-10.

15. "Lorneville LNG in limbo," *Oilweek*, 24 July 1978, p. 12; "N.B. puts on brave face after Algerian gas sales;" and "Development hinges on Algerian decision: N.B. may lose huge gas project," *Citizen*, Ottawa, 5 and 6 July 1978.

16. See 2; "Gas producers differ on pricing problems, expansion of markets," *Citizen*, Ottawa, 29 May 1978.

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18. According to a still unconfirmed announcement, Dome Petroleum has already let tenders for a $100 million Class 10 icebreaker able to handle ice 10 feet thick. William Richards' announcement at Petroleum Tax Association Meeting in Banff, Fall, 1977.

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"The super-ships: A plan to carry Arctic gas," *Financial Times of Canada*, 28 February 1977, p. 14.

Level of Effort

20. M. Gibbons and R. Voyer, *A Technology Assessment System: A Case Study of East Coast Offshore Petroleum Exploration*, Science Council of Canada, Background Study No. 30, Information Canada, March 1974, 114 p; A selection of background papers prepared for the 1974 colloquim of the Institute of Social and Economic Research, ISER, on the potential impact of development of offshore oil and gas on Newfoundland Contributors are drawn from consulting, government and the university sectors; M.J. Scarlett, ed., *Consequences of Offshore Oil and Gas: Norway, Scotland and Newfoundland*, ISER Publication, Memorial University, St. John's, Newfoundland, 1977.

3. The Demonstration of the Ability of Exploring for and Producing Oil and Gas in Very Deep Waters

Scientific and Technological Context

Some of the reasons why a capability for exploration and production of oil and gas in very deep waters must be developed are briefly outlined:

1. Verification of scientific concepts which may assist in the broad evaluation of potential offshore resources (e.g., theory of plate tectonics; theory concerning the continuous formation of volcanic mountains into the "Ring of Fire" on the Pacific perimeter; theory on the source of Japanese earthquakes).[1] Testing of these theories can only be done by deep-sea drilling, and on the basis of the information acquired more meaningful regional studies can be initiated in respect to coastal processes, sedimentation, and accumulation of economic quantities of hydrocarbons. These tests, although now few and far apart, may eventually facilitate the mapping of deep geological structures by seismic methods.
2. Timely examination of resource possibilities, appropriate design of drilling and production programs, in addition to making realistic evaluations of the economics of deep-ocean exploitation activities involving long lead times, new challenges and uncertainties. As an illustration, the drilling of exploratory wells off Newfoundland and Labrador and more northerly to Baffin Bay would involve water depths of 1000–2000 metres.
3. Maintenance of correlative rights along provincial and international borders in very deep waters.[2] Clearly, Canada should not depend heavily on international technological sources in exercising its obligations in this area.

Jurisdictional control of waters to the 200-mile limit or of the continental shelf extending 400 miles east of Newfoundland to the Flemish Cap, requires realistic and accurate position fixing of both patrol boats and oil and gas structures. In addition, eventual production of oil and gas in deep waters would require observance of strict traffic lanes near platforms, and probibition of bottom trawling over pipeline routes.

Several activities, some more relevant than others, will undoubtedly assist in acquiring the ability to explore for and produce oil and gas in very deep waters. Taken together, these activities act as a comprehensive launching program and could provide specific technological support of a very broad nature.

The activities are:

1. *Environmental base line studies.*[3] Base line environmental studies must be extended in accordance to needs and must be performed without delays until completion, in all regions including the sea. The main areas of interest are oil and gas, transportation, and fisheries. For instance, detection, containment, and cleanup are among the oil spill counter measures which should be studied. In regard to transportation, collisions which may be caused by extended periods of low visibility, with serious environmental consequences, are cause for concern, especially off the east coast. The possible impact on fisheries indicates that base line surveys must include not only physical and biological inventories, but an entire marine life assessment. Next to environmental impact, effects of weather on worker performance and health are important physical and biological environmental factors. Also, the social impact of oil and gas operations on native peoples and on the outsiders, and changed and intensified inter-relationships are important considerations.

2. *Development of related strategic sea and weather data through comprehensive, on-line gathering and quick swaps of information.*[4] Both hydrographic and meteorological information must be made readily available.

First, a basic understanding of hydrography is a prerequisite to the design, construction, and operation of drilling and, especially, production structures in very deep waters. Among other items, hydrography deals with wind, wave, tidal, and residual current information. Well coordinated across the country, hydrographic surveys, have produced many useful nautical charts and publications. These charts, in a convenient way, depict currents, pressures, air and water temperatures and other parameters of Canadian hydrography. The Canadian Hydrographic Service, integrated into the network of the oceanographic organizations all over the world,* is expected to continue to act as an identifier and coordinator of national hydrographic information, while focussing with increased detail and precision on offshore regions of interest.

Second, the need for weather information must be included since meteorology is equal in importance with hydrography. As is well known, meteorology deals with parameters such as atmospheric temperature, barometric pressure, humidity, cloud cover, wind speed, visibility and precipitation (i.e., rain and snow). Depending upon site-specific conditions of oil and gas operations, the requirements for oceanographic and meteorological observations, and forecasting, may be provided by the Atlantic Weather Central in Halifax, Arctic Weather Central in Edmonton and, of course, the Atmospheric Environment Service in Ottawa. In a vast network of automatic weather stations it is necessary to coordinate and integrate routine measurement of all interrelated data (e.g., bathymetric, climatological) with periodic survey data in order to provide specific aids to location, shipping and other transportation services to and from oil and gas operation sites.

3. *Consequences for drilling and production operations of encountering the constraints of water depth, wave height and climate "together" in the northern offshore environment.* A research program seems to be needed to coordinate the various information bases adequately: environmental, hydrographic, meteorological, and others. The best means of gathering, collating, and transferring existing and developing information on environmental aspects must be determined. This information must be verified, preferably though an information centre or clearing house, not only to the relevant government organizations but also to all those involved in planning oil and gas drilling and exploration programs in very deep waters: projects management, designers, engineers, research institutes and educators.

As an illustration, there is a need for a cohesive effort to present systematically all relevant information in a coherent fashion. For effective climatology, there is need for additional stations and an enhanced level of remote sensing including the use of data buoys and satellites. At a lower level of specificity, there is need for development of wave climatology. Climatological and environmental studies must be integrated. In addition, communications technology is important. Infrared techniques and Side-Looking Airborne Radar (SLAR), perhaps, deserve special attention. Navigation aids and position fixing procedures require increased precision. Surveying is an important support service. Also, the use of geotechnology may exercise significant influence on design considerations in most oil and gas activities (e.g., marine terminals). Finally, research into materials which can be used in very deep waters must be included.

A unifying research program in this general area to be effective needs adequate data bases. It is useful therefore to re-emphasize the need to proceed without unnecessary delays with the acquisition and systematic integration of base line data

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*The Service now plays a major role in the affairs of the International Hydrographic Organization (IHO).

in areas such as physical and biologic environments, hydrography, meteorology, general geology and geotechnical data and properties of materials. The Ocean Engineering Information Centre in St. John's Newfoundland, could provide coordination of the various information bases.

4. *Basic research in the earth sciences, geophysical exploration, scientific ocean drilling and geologic data collection.* An activity within the Deep Sea Drilling Project (DSDP) has spearheaded several useful techniques.[5] Coastal drilling has enhanced the procedures for obtaining good quality cores at depths.[6] Deep-sea-floor exploration initiated new concepts of deep ocean mining. Current programs of the International Phase of Ocean Drilling (IPOD) focus on geothermal and ridge coast areas, geothermal vent fields and deep ocean rifts.[7] The scientific planning for these programs is performed by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). Involved in international programs are countries such as the US, West Germany, the Soviet Union, Japan, United Kingdom, France, Denmark and Iceland. Glomar Challenger has carried out the DSDP for the US National Science Foundation.[8] Possibly, Glomar Explorer, a larger and more versatile ship will succeed HMS Challenger.[9] In Canada, Dalhousie University in Halifax has joined the International Deep-Sea Drilling Project and hopefully will act as an information coordinating and integrating organization, nationally.[10]

5. *High technology ocean mining and enhancement of the ability of exploring for and producing oil and gas in very deep waters.*[11] Among relevant technologies are the use of diving robots and computers, deep sea research by manned submersibles and undersea mining. Ocean mining systems related to increasing the scope of oil and gas operations are: underwater search and rescue systems; deep diving systems; improved methods of submarine coring; underwater vehicles and related operations, and miscellaneous man-underwater systems. Clearly, ocean mining will become an important component of ocean management in the future. At present, however, its techniques are limited. Depths to 200 metres are still challenging the deep-sea divers and 300-500 metre depths are difficult to attain although research with a wet and dry combination chamber has facilitated simulated dives to the 500 metre level and even deeper target levels.

A centre is required to monitor and relay progress of marine sciences research and the relevant development of ocean mining technology, internationally. Conceivably, ocean mining technology could be useful at "sea-bottom" in respect to site-specific bathymetry, morphology, geotechnical properties (e.g., engineering properties), seismicity and determination of sedimentary parameters (e.g., geological parameters). Moreover, at "sub-bottom" level ocean mining could be instrumental in providing information on structure, stratigraphy, and bed rock geology.

Directions in Exploration Drilling and Production

An important managerial consideration in the new, deep ocean oil and gas technology is to find a proper balance between planning functions and feedback in R, D & D.[12] Certain research has universal application whereas other R & D is site specific and indeed possible, only after the key parameters are determined (e.g., geological conditions are, of course, dominant). Drilling vessels and techniques have been developed for a broad range of deep-sea conditions. Elaborate planning of exploration drilling programs is possible on the basis of extrapolation of existing equipment. Planning is essential also because of long-term delivery schedules for equipment and the need for elaborate logistics.

When considering production, however, an adequate response to local requirements is necessary in terms of climate, water depth, wind and wave characteristics, presence of ice, subsurface pressures and temperatures, and corrosion conditions. Resource knowledge determines geographic location, indicates the nature of production (e.g., flowing oil wells), and identifies the design parameters. Moreover, in oil and gas production, as in most areas, it is difficult to establish R & D priorities in the total absence of a data base of related international experience and performance. In the North Atlantic, a fixed multi-well platform, even in less than 200 metres of water, may require more than 5 years to be brought into production after field discovery and delineation. For success, the oil and gas industry requires early government approval for exploration of deep water prospects, to reflect the long lead times for the development of drilling and, more particularly, production systems.

Basic research, of course, serves as a foundation for the scientific conduct of site-dependent projects. R & D is beneficial for the development of prevention, mitigation, contingency and other protection systems. Application research is fostered primarily through on-site demonstrations. Reduction of the time required for the development phases of future offshore production operations in deep waters depends on current R, D & D. In addition, development of adequate completion, production, storage, and transportation equipment and techniques is needed. In particular, pipelines, marine transportation systems, barges, and other support boats are needed for economic production. The importance of maintaining and supplying offshore installations in very deep waters and meeting emergencies should not be underestimated.

Difficult problems usually arise from unexpected situations. When working in very deep waters one must prepare assiduously to attain adequate technological capability, and to expect demanding challenges.

In summary, success may depend upon a judicious balance between effective integration of site-specific information pertaining to exploration, development and production operations[13] and up-to-date universal information to minimize the lead time required.[14]

Before describing the morphology of the proposed demonstration program, it would be useful to delineate existing exploration and production capabilities in deep waters. Present maximum water depth capabilities in ocean environments are:[15]

(a) In exploration drilling, except during severe weather seasons, "pick-ups" may be used to around 100 metres. Drillships and semi-submersible rigs may handle depths in the North Atlantic to some 300-500 metres, and in the Arctic (e.g., Beaufort Sea) to 350-500 metres during ice-free periods. Dynamically positioned drillships are now capable of confronting water depths of 765 to 915 metres. Some seven rigs are said to be capable of drilling in water depths of 1000 metres or more. Exxon's rig Glomar Pacific operated in 125 metres of water, 160 kilometres off the coast of New Jersey. A water depth of 1054 metres was achieved in the Andaman Sea off Thailand. Exxon reached water depths in excess of 1200 metres off Surinam.

Rigs are under construction which will be capable of operating in water depths of 1500 metres by 1980. According to current targets, systems which will be effective in depths up to 1800 metres or more, will be required within several years.

(b) In the North Atlantic, fixed platforms are regularly used in water depths of up to 180 metres. In a few years, platforms may easily handle depths in excess of 300 metres. In the Arctic (e.g., Beaufort Sea), concrete or steel cone structures to depths of 600 metres may be feasible, under very favourable conditions. Underwater completions (UWC) are now possible in the North Atlantic in depths of up to 370-460 metres. By 1980 UWCs may reach depths in excess of 900 metres.

A deep water well at the edge of the continental shelf, 135 miles offshore Nova Scotia, encountered water depths in excess of 900 metres (e.g., using the dynamically positioned drillship, "Ben Ocean Lancer"). On the East Coast, some 200 miles off the continental shelf, the water depths can approach 2500 metres. The CN Tower in Toronto could be submerged several times in waters of these depths. In conclusion therefore, Canadian environmental conditions appear to require a capability of almost international standards.[16]

In accordance with the preceding review of scientific, technological and strategic directions, it appears that a demonstration program in this area should incorporate:

1. Leasing, exploration, and drilling offshore according to an overall Canadian ocean administration policy (e.g., Outer Continental Shelf Operating Regulations);
2. Development of ecological safeguards for offshore drilling in deep waters;
3. Integrated assessment of several drilling systems programmed to explore for oil and gas under contract by a government agency (e.g., Petro-Canada);
4. Selection of one or preferably more drilling systems (e.g., dynamically positioned semi-submersibles or drillships), for further development, modification, and ultimately, demonstration, to cope more assuredly with Canadian continental shelf conditions;
5. Evaluation of suitable completion techniques and sea-bottom production equipment (e.g., safe connections and disconnections);
6. Assessment of mobile production platforms;
7. Development of reliable systems for movement of oil and gas from deep water wells to shore.

As depths increase the critical technological areas appear to be: (a) greater precision in the positioning of ships; (b) intricate design of advanced riser systems; and, (c) reliable command systems to seafloor equipment. The blow out preventer systems become increasingly complex and expensive. Inherent operational limits in working on seafloor at considerable distances from the command systems are also critical.

A decision recommending systematic offshore exploration should follow, or at least incorporate, the development of adequate drilling systems. Moreover, to maintain balance between planning and information gained, offshore exploration should be carried out apart from, and in advance of, decisions on how to develop the oil and gas fields which may be found. This consideration requires emphasis.

Level of Effort

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Exploratory drilling: $15 million per well.

(c) *Oilweek*, 4 April, 1977, p. 19, North Sea Operations:
Cost of one production platform: $68 000 000
Cost of new concrete gravity platform, biggest in world: $120 000 000

(d) EMR News Release, 11 February 1977:
Total Federal Energy R & D Budgets (1976-78):

	1976-77		1977-78	
	$M	%	$M	%
Fossil Fuels	14.0	(11.0)	(15.5)	(11.3)

2. Exploratory Calculations

(a) *Ecological Program for Safeguards*

Two groups at $350 000 per year-group for 5 years:	$3 500 000
Equipment development:	$2 500 000
Total:	$6 000 000

(b) *Technological Assessment of Three Drilling Systems*
Three groups of four professionals and support staff at $325 000 per group-year for 3 years: $2 925 000

(c) *Demonstration of Two Drilling Systems*
Two systems, each drilling five wells and ongoing improvements:
2 x 5 x $25 000 000 equals $250 000 000.

The amount applicable for the demonstrations may be assumed to be as high as 40 per cent because of the uncertainty and high risk involved, although the innovation and learning processes may not interfere significantly with drilling progress. Thus, applying 40 per cent, one obtains 0.4•250 000 000 or $100 000 000

(d) *Final assessment and "utilization activity"*
$1 700 000

Grand Total: $111 000 000*

This program, constitutes only a first phase of the recommended demonstration of exploring for and producing oil and gas in very deep waters. Dependent upon future resource delineations in regions underlain by deep waters, demonstrations would have to be mounted, at least for the most site-dependent production technologies.

Time Frame

An illustrative time profile for expenditures toward the demonstration of the ability of exploring for and producing oil and gas in very deep waters is as follows:

1979	$ 700 000
1980	1 675 000
1981	6 825 000
1982	19 000 000
1983	34 300 000
1984	34 300 000
1985	14 200 000
Total	$111 000 000

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*Rounded

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Coal

1. The Demonstration of Fluidized Bed Technology

International Context

Fluidized bed technology and its associated processes are being developed outside Canada for differing reasons and with varying degrees of success. Several industrial countries (e.g., Austria, Belgium, W. Germany, Italy, Japan, the Netherlands, Spain, Sweden and the US) are signatories of a coal technology project agreement within the framework of the IEA.[1] The project is being implemented mainly in the UK. A significant component of the program addresses fluidized bed technology. More specifically, a current IEA project envisages starting immediately with the design, construction and operation of a flexible experimental facility for investigating combustion, heat transfer, gas clean-up, corrosion and energy recovery in a pressurized fluidized bed system. The possibility of combined or dual cycle energy generation with gas and steam turbines will also be tested since provision for the addition of a gas turbine was included in the initial steam system design. Results obtained by the UK from this experiment at Grimethorpe in Yorkshire are intended to be useful in the subsequent design of commercial scale plants.

Due to current activity and the broad scope of international research and development, it appears unlikely that a Canadian technology base can or need be developed. This conclusion, however, must be qualified.

In order to realize coal's potential via direct utilization, Canada needs appropriate, that is effective and vigorous, conversion technologies. Fluidized bed technology is a distinct possibility. Indeed, in the search for and promotion of a capability to develop new forms of energy, particularly coal, Canada may view fluidized bed technology and its advantages over conventional coal combustion techniques especially valuable considering the environment, political, and social consequences for Canada. In order of importance, the potential advantages of FBT for Canada are: the ability to use a wider range of diverse fuels, a reduction in the size of installations and an efficient method of limiting atmospheric pollution.

Canada should, and probably will, monitor and evaluate appropriate international developments in order to maintain awareness of coal combustion processes. Because of specific and unique objectives, as well as particular emphasis on R & D and economic competition, it would be increasingly difficult for Canada to work more closely with other countries as specific commercial applications draw near.

Moreover, beyond technology assessment of combustion processes, Canada should research coal utilization techniques and coal substitution for other primary sources in both a national (e.g., use in oil sands development) and international context (e.g., with Japan). In exchange for its contribution Canada may receive assistance from other countries in coal utilization for the recovery, separation and upgrading processes of bitumen and heavy oils (e.g., recovery of oil sands from intermediate depths; separation by evaporation in huge kilns, using little or no water; solvent extraction; variants of hydrogenation; "counter-current" heat recovery and upgrading).

In Canada, a multi-step, multi-purpose broad program is necessary to demonstrate, within social and economic constraints, that we are able to burn any coal — either alone or in organic mixes — efficiently and safely.[2] Conceivably, fluidized bed technology can assist in developing boilers capable of burning various grades of coal and other combustibles. It is to be hoped that fluidized bed technology would permit the combustion of any type of coal — lignite to anthracite with, perhaps, as much as a 4 per cent increase in thermal efficiency.[3] During combustion of some high sulphur coals, particles of limestone chemically mixed with coal, would capture the sulphur in the coal. (This is the dominant, if not the sole purpose, of fluidized bed R, D & D in the US). Also the nitrogen oxide emissions are greatly reduced because of lower combustion temperatures than are present in current techniques. For these reasons a full-fledged demonstration of fluidized bed technology is recommended as a proxy and forerunner of future, eventually more flexible and efficient, advanced combustion processes.

The following steps may be considered indicative of the R, D & D activity required:

1. Over the next year, one or several companies should be identified by Energy, Mines and Resources (EMR), to complete the preliminary engineering work. Solutions to engineering problems, developed in the US, would be carefully examined in the Canadian context. Initially, the firms will prepare conceptual designs for alternate commercial 200MW power plants and the detailed design of a general purpose pilot plant. Areas of technology that require development in order for the pilot plant to be realized, will be identified during this phase. Co-production of electricity and heat in relatively smaller plants would also be a consideration. Simultaneously, an independent organization will prepare an evaluation of associated environmental impacts.

2. The next step, perhaps extending over a period of one year, will be to address the detailed engineering design of the pilot plant. Contrary to prevailing expectations, there are still very serious engineering problems to be solved.

3. The construction of the pilot plant will require 1-2 years. Relevant experience gained by BC Hydro and EMR should be incorporated.

4. During a two-year test period, the pilot plant performance will be monitored and data will be collected to evaluate the design phase of the commercial prototype. Two or more types of coals will be tested — various grade coals from BC, Alberta, Saskatchewan, and high sulphur coals from Nova Scotia.

5. A reassessment and finalization of the commercial design criteria in light of pilot plant experience will be made.

For the long term, the scope of the pilot project upon modification is to demonstrate one or several types of commercial plants in the practical size range of coal-fired electricity generation plants operating in the specific context of Canadian coal supply and transportation conditions. Eventually fluidized bed techniques should prove successful with a broad range of fuels: particularly high ash, low calorific value coals; forest industry wastes; Alberta oil sands; bitumen; and New Brunswick oil shales.

By working together with other industrialized countries on R & D and by using our engineering resources, progress could be made on a prototype plant in less than six years. It is hoped that commercial service would closely follow the onset of real scarcity and the accompanying high prices for natural gas and, in particular, crude oil.

Level of Effort

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Fluidized Bed Combustion

"Encouraging prospects for the environmental acceptability of coal come primarily from the technology of fluidized bed combustion (FBC). In principle, FBC should meet not only the emission limits on sulfur oxides, but those on nitrogen oxides as well, at less cost than conventional methods. The new technology has, however, been tested only on a small scale. It appears that the method of combustion would allow coal to compete with oil in a wide range of industrial uses, including cogeneration (the production of electricity along with industrial heat or steam), and central station electric power.

"A fluidized bed consists of a container partially filled with coarsely ground solids, which is 'fluidized' by the injection of gas through an apertured plate supporting the solids. The fluidized bed technique is widely used to obtain intimate contact between gas and solids in catalysis, heat treatment, and burning materials such as garbage. When the solids are a mixture of ground coal and limestone or dolomite (limestone containing magnesium) and the fluidizing gas is air, the coal can be burned efficiently and the sulfur removed at the same time.

"Fluidized bed combustion can operate at atmospheric pressure to provide steam in water-tube boilers or at elevated pressure (four to ten atmospheres) to provide hot gas for gas turbine or combined-cycle (gas turbine followed by steam) electrical generation. A 20 MWe plant is under test now, and designs are complete for another plant to drive a 70 MWe gas turbine. If these tests are successful, ERDA [Energy Research and Development Administration] plans to build a 250 MWe demonstration plant for testing on a larger scale."

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Coal Utilization	\$1 327 000

(e) Energy Research Reports; 21 March 1977, p. 2:
ERDA asked \$2 400 000 000 to \$6 000 000 000 a year for new coal-combustion technologies. In a first order of approximation, considering relative sizes of coal industries and desired efforts, fluidized bed technology in Canada should receive proportionately some

$$\frac{1}{20} \times \frac{1}{7} \times 4\,200\,000\,000 = \$30\,000\,000$$

(f) Energy Policy, June 1975, p. 96:
UK pilot plant, 20 MW = \$9 700 000

2. Exploratory Calculations

(a) Preliminary Monitoring and Research Cooperation:
2 years at \$750 000 per year = \$1 500 000

(b) Additional Experimental Research:
Say 3 areas for a total of \$1 200 000

(c)	Detailed Engineering Design: At 15 per cent of plant cost =	$6 000 000
(d)	Pilot Plant 30 MW-Capital:	$40 000 000
(e)	Pilot Plant Performance Evaluation: 2 years at $650 000 =	$1 300 000
(f)	Redesign and Extensions: 10 per cent of plant cost =	$4 000 000
(g)	Demonstration of Commercial Plant:*	$200 000 000
	Grand Total	$254 000 000

Time Frame

An illustrative "bi-modal" time profile of the expenditures required for a pilot plant and full-scale demonstration of fluidized bed technology, together with the preparatory R & D and monitoring is as follows:

1979	$ 750 000	– Monitoring and Evaluation
1980	1 100 000	– Cooperation and Experimental Research in Canada
1981	2 250 000	– Laboratory Research and Engineering Design
1982	7 000 000	– Detailed Engineering Design
1983	23 100 000	– Pilot Plant Procuring and Start of Construction
1984	13 500 000	– Pilot Plant Start-Up and Monitoring
1985	7 500 000	– Performance Evaluation and Re-Design
1986	10 800 000	– Plant Modifications and Extensions
1987	20 000 000	– Building and Testing of a Demonstration Plant
1988	57 000 000	on a Larger Scale (e.g., 250 MWe)
1989	57 000 000	
1990	38 000 000	– Continued Monitoring and Dissemination of
1991	16 000 000	Results
Total	$254 000 000	

Notes

Context

1. The Energy Research, Development and Demonstration Programme of the International Energy Agency, January 1977, 23 p.; also meeting with Dr. Milton Klein, Executive Director of IEA at EMR on 11 March 1977.
2. A fluid-bed reactor designed by BC Research is used for the study of engineering parameters and economics of gasification of wood waste and coal.
3. "Fluid-Bed Combustion: A sleeper awakes," *Science News*, vol. 112, p. 134.

Also

Assessment of Advanced Technology for Direct Combustion of Coal, Report HCP/T1216-0001, UC-90e, Prepared by Ad Hoc Panel on Direct Combustion of Coal of the Committee on Processing and Utilization of Fossil Fuels, Commission on Sociotechnical Systems, National Research Council, National Academy of Sciences, for the US Department of Energy, Washington, December 1977, 89 p.

D.H. Archer, D. Berg and E.V. Somers, "Fluidizing Bed Gasification and Combustion for Power Generation," 9th World Energy Conference, Detroit, 23-27 September 1974, 25 p.

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*Demonstration applicable funds are calculated at 50 per cent of total costs.

A. Bogot and R.C. Sherrill, "Principal Aspects of Converting Steam Generators Back to Coal Firing," NCA/BCR Coal Conference and Expo II, Organized by Bituminous Coal Research, Inc., Louisville, Kentucky, October 1975, C-E, Power Systems, 9 p.

H.E. Burbach *et al.*, "Compatibility between furnaces and fuels conducive to high boiler availability," *Power*, December 1977, pp. 41-46.

H.E. Burbach and A. Bogot, "Design Considerations for Coal-Fired Steam Generators," Annual Conference, Association of Rural Electric Generating Cooperatives, Wichita, Kansas, June 1976, C—E, Proposition Engineering, 16 p.

"Fluidized-Bed Energy Technology: Coming to a Boil," *INFORM*, 25 Broad Street, New York, N.Y. 10004, June 1978, 150 p.

"Fluidized-Bed Energy Technology Option for Clean Coal Burning," Seminar Organized by INFORM, New York City, 26 June 1978.

D.B. Henschel, "Emissions from FBC Boilers," *Environmental Science & Technology*, May 1978, pp. 534-538.

R.P. Hensel, "The Effects of Agglomerating Characteristics of Coal on Combustion in Pulverized Fuel Boilers," Symposium on Coal Agglomeration and Conversion, Morgantown, West Virginia, May 1975, C-E, Power Systems, 7 p.

E.H. Martin, "Coal Resources in the Hat Creek Valley and Plans for its Utilization," 29th Canadian Conference on Coal, Edmonton, 2-4 October 1977, Proceedings, Coal Association of Canada, pp. 47-55.

The Mitre Corporation, *Annual Report 1977*, pp. 52-53.

W. Patterson, "To Bed Betimes," *New Scientist*, 20 July 1978, pp. 180-181.

"Technology: Fluid-Bed Coal Combustors Commercialized," *Chemical & Engineering News*, 6 February 1978, p. 24.

R.D. Winship and F. Bender, "Ash Deposition Research on Canadian Lignites," Lignite Symposium, Grand Forks, North Dakota, May 1969, C-E, Design and Performance Department. 6 p.

2. The Demonstration of Land Reclamation after Coal is Strip-Mined

Environmental "Context"

If Canada's shift from present energy sources into coal is to be timed to economize on crude oil and natural gas for conversion into convenient energy forms such as gasoline and home heating fuels, the principal impediments to substitution by coal must be systematically examined.[1] Environmental concerns are of paramount importance, and various levels of government must be involved in the decision-making process.[2] Specific environmental policies, acts, and regulations are an important component of decisions to allow a substantial increase in the direct conversion of coal.

First, policy formulation must be consistent with the role of coal in a national energy strategy.[3] An inherent conflict exists between using more coal and maintaining or introducing very high environmental standards.[4]

Second, a selective, flexible, and "tailor-made" environmental policy is desirable. This approach would provide for high standards in crisis situations and for somewhat more selective standards when environmental problems are minimal.[5]

Third, environmental impact tends to have world-wide consequences.[6] Local solutions must take into consideration the global context.

Finally, it would appear that environmental, safety and health impacts of the various forms of energy would affect the "shopping list" of our future energy forms.[7] In particular, the rate of development and extent of coal supply, especially thermal coal for direct utilization, will be dependent upon the success of the technological and ecological solutions to environmental problems.

Much remains to be accomplished in terms of policy formulation.[8] Control of emissions into the atmosphere, and the protection of rivers, lakes, ground-waters and land, especially agricultural land, are of major concern. The control of NOx emissions can be improved through modification of the combustion process and its main parameters.[9] Assessment of the "greenhouse effect", caused by increasing use of fossil fuels and the associated build-up of carbon dioxide levels in the atmosphere, could determine the future of coal and the degree of its resurgence.*

Although a "state-of-the-art" review of the technology to reduce atmospheric pollution is beyond the scope of this Report, because of the importance of CO_2 pollution, selected references in this field are included.[10]

Structure of Demonstration Program for Land Reclamation

The techniques of land reclamation after coal is strip-mined have advanced satisfactorily during recent decades. These techniques, however, can and should be further improved to enhance overall land management and especially to preserve the increasingly scarce factors of production in agriculture.

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*At an international conference on future sources of organic raw materials, Toronto, 10-13 July 1978, M. King Hubbert indicated that the peak in "the rate" of world coal production will probably occur between the years 2100 and 2200.

One of the key problems is the uncertainty which remains in connection with income loss in cases in which strip-mining encroaches on agricultural land. A series of demonstrations could reduce much of this uncertainty. The following task structure is recommended for demonstrations for land reclamation after coal is strip-mined.

A first task, prior to any demonstration project, would be to develop a realistic conceptual framework. The functions required of the technology assessment and other analytical techniques must be carefully specified. The main methodology lines and alternatives must be determined. Parameters, which are critical to acceptable levels of accuracy in interpretation, must be identified. The initial data base required to perform the first year's activities should be specified in advance.

A second task, to be performed in parallel with Task 1, would be the creation of a project file to store and retrieve all information with respect to the demonstration program. All engineering, economic, physical, chemical, biological, social and other data, together with the relevant forecasts and analytical tools identified in Task 1, should be collected. Correspondingly, research and development objectives of the demonstration program should become part of the information base.

In Task 3, the adequacy of the data base would be assessed by comparing the data collected in Task 2 with the data requirements specified in Task 1. Task 4 would address the development of a detailed work plan for an integrated technology assessment.

Data must be finalized and integrated in order to provide the decision maker with improved possibilities for identification of appropriate technologies for land reclamation. Moreover, the decision maker would require an effective, if not optimal, strategy for dealing with the selected technology or scenario. This strategy must consider and interact with the institutional framework involving all levels of government but more particularly the provincial authority. Thus an enlightened situation may arise wherein government control is exercised possibly using a variety of policy tools — land reclamation standards, taxation of coal produced,[11] tax credits for quality achievement, rights of way and safety regulations, advance payments for land reclamation into special funds, and insurance of crops or any other land revenues in and from adjacent areas.

A successful land reclamation demonstration program should be able to produce:

(1) a determination of economic damage functions by which losses caused by strip-mining can be monetized;
(2) an evaluation of identifiable attributes for facilitating the description and summation of unquantifiable damages; and
(3) a confirmation that the total monetary and non-monetary damages are finite and controllable with appropriate and affordable land reclamation technology and management.

The objectives and the level of costs for each reclamation program must be clarified. On the one hand, the possibility that some strip-mines may be located on agricultural land or near population centres accentuate the need for judicious development of land reclamation programs. On the other hand, if coal is to compete in distant markets, either in Canada or abroad, it is important to minimize or preferably eliminate altogether, any negative aspects of land reclamation programs.

Although additional research is needed to improve the handling of overburdens which are stripped and then replaced, it was already possible in several cases to nearly duplicate the original landscape and sequence of soils during the reclamation process. For illustration of on-going industry-provincial programs and demonstrations in Canada, see notes 12-14.

Level of Effort

1. Reference Points

(a) Relevant information may be found in:

- *A Coal Development Policy for Alberta*, Government of Alberta, 15 June 1976 37 p.; A7 p.

- L.J. Carter, "Strip Mining: Congress Moves Toward 'Tough' Regulations," *Science*, 9 August 1974, pp. 513-514.

- "An Environmental Vote for Stripping," *Technology Review*, May 1975, p. 62.

- Carl E. Bagge, "The Emerging Partnership of Coal and Agriculture," *Vital Speeches of the Day*, September 1975, pp. 724-728.

- G. Atwood, "The Strip-mining of Western Coal," *Scientific American*, December 1975, pp. 23-29.

- E.A. Imhoff, "Planners Can Improve Responsiveness to Surface Mining Reclamation Issues," *Practicing Planner*, September 1976, pp. 20-22.

- Strict Law Challenges Strip Mine Operators, *Chemical and Engineering News*, 22 August 1977, pp. 18-19.

(b) C. Holden, "Curbs on Strippers Celebrated," *Science*, August 1977, p. 743:

"In the U.S. the Surface Mining Control and Reclamation Act of 1977 was signed by the President on August 2nd, after a colourful history. The bill, remotely resembling the first strip-mine bill introduced 37 years ago, establishes national standards for leasing, mining and reclaiming strip-mined land."

(c) "Report of NAS for Ford Foundation," *Scientific American*, December 1975, p. 27:

"Average cost of reclamation is $1650 per acre. Cost estimates made by mining companies range from $500 to $5,000 per acre."

(d) Strip-mining of lignite in the Coronach area of Saskatchewan:

"Authorities have committed Saskatchewan Power Corporation to spend $1 000 - $1 500 per acre to reclaim the worked out coal pits for recreational and wildlife preserves after the coal is mined."

2. Exploratory Calculations

(a) *Assumptions:*

- *"Model" Reclamation Cost*
  $2100 per acre.
- Several demonstrations are needed for different types of land and conditions: initially 7 experimental plots.
- The size of each plot should be about 1 per cent of the actual acreages disturbed at this time by coal mining in western Canada: say approximately 10 acres.

(b) *Cost of Actual Land Reclamation Phase*

70 acres at $2100 per acre equals: $147 000

(c) *Tentative Approach:*
- First Task
  $95 000

- Second Task
  $185 000

- Third Task
  $37 000

- Fourth Task
  $95 000

- Fifth Task: Reclamation
  $147 000

- Monitoring and Dissemination of Information
  $185 000

  Grand Total: $744 000

The magnitude of costs for preparatory work and dissemination of information in relation to the cost of the actual physical land reclamation effort would indicate that this "pilot" demonstration must have ulterior widespread application in order to be cost-effective (e.g., development and publication of model reclamation projects). Similarly, it follows that the government subsidy for particular industry projects should be substantial.

Time Frame

An illustrative profile of expenses required for an initial demonstration of agricultural land reclamation after coal is strip-mined, may take the following form:

1979	$ 95 000	– Tasks 1 and 2
1980	145 000	– Tasks 1 and 2
1981	169 000	– Tasks 2, 3 and 4
1982	150 000	– Tasks 4 and 5
1983	100 000	– Monitoring and Dissemination of
1984	85 000	Information
Total	$744 000	

Notes

Environmental Context

1. Garnet T. Page, "Coal and Canada's Industrial Strategy," *Journal of Canadian Petroleum Technology*, Montreal, October-December 1977, pp. 31-33.
2. Gregg Marland and Ralph M. Rotty, "The Question Mark Over Coal: Pollution, politics and CO_2," *Futures*, February 1978, pp. 21-30.
3. G.T. Page, *op. cit.*
4. T. Alexander, "A Promising Try at Environmental Detente for Coal," *Fortune*, 13 February 1978, pp. 94-102; R.T. Marshall, "Environmentalists add to coal mining headaches," Meeting of the Canadian Institute of Mining and Metallurgy, Calgary, April 1978, Summary 1 p.
5. T. Alexander, *ibid.*; Luther J. Carter, "Sweetness and Light from Industry and Environmentalists on Coal," *Science*, 3 March 1978, pp. 958-959.

6. Wallace S. Broecker, "Will the Coal Economy Overcook the Earth?," *Business and Society Review*, Winter 1977-1978, pp. 4-9; G.M. Woodwell, *et al.*, "The Biota and the World Carbon Budget," *Science*, 13 January 1978, pp. 141-146; Minze Stuiver, "Atmospheric Carbon Dioxide and Carbon Reservoir Changes," *Science*, 20 January 1978, pp. 253-258; G.M. Woodwell, "The Carbon Dioxide Question," *Scientific American*, January 1978, pp. 34-43; William W. Kellogg, "Is Mankind Warming the Earth?," *Bulletin of the Atomic Scientists*, February 1978, pp. 10-19.

7. "CO_2 pollution may Change the Fuel Mix," *Business Week*, 8 August 1977, p. 25.

8. Thomas W. Mason and Thad D. Smith, "An Approach to Policy Formulation: Sulfur Oxide Emissions in Indiana," *Journal of the International Society for Technology Assessment*, Winter 1976-1977, pp. 43-47.

9. R.D. Winship and P.W. Brodeur, Controlling NOx Emission in Pulverized Coal-Fired Units, *Engineering Digest*, September 1973, pp. 31-34.

10. Colin Norman, "Assessing the 'Greenhouse Effect'," *Nature*, 28 July 1977, pp. 289-290; G.M. Woodwell, *et al.*, "The Biota and the World Carbon Budget," *Science*, 13 January 1978, pp. 141-146; Minze Stuiver, "Atmospheric Carbon Dioxide and Carbon Reservoir Changes," *Science*, 20 January 1978, pp. 253-258; U. Siegenthaler and H. Oeschger, "Predicting Future Atmospheric Carbon Dioxide Levels," *Science*, 27 January 1978, pp. 388-395; "Increased use of coal deemed safe through 1985," *Chemical and Engineering News*, 30 January 1978, pp. 22-23; G.M. Woodwell, "The Carbon Dioxide Question," *Scientific American*, January 1978, pp. 34-43; William W. Kellogg, "Is Mankind Warming the Earth?," *Bulletin of the Atomic Scientists*, February 1978, pp. 10-19.

Also

Luther J. Carter, "Sweetness and Light from Industry and Environmentalists on Coal," *Science*, 3 March 1978, pp. 958-959.

OECD, *Energy Production and Environment*, Organisation for Economic Cooperation and Development, OECD, Paris, 1977, pp. 74-88.

Land Reclamation

11. Symposium on Coal Economics and Taxation, Regina, Saskatchewan, 7-9 May 1978.

12. (Ken Barron), "Coal research program planned," *Oilweek*, 10 October 1977, p. 14.

13. Charles R. Pearse, "Coal Comes Back: Its Promise and Challenge," *Canadian Geographical Journal*, April-May 1978, pp. 70-75.

14. "Environment," *Coal in Canada*, Coal Association of Canada, Calgary, 1978, pp. 37-42.

Also

F.S. Matter *et al.*, *A Balanced Approach to Resource Extraction and Creative Land Development*, University of Arizona, Tucson, 1974, 85 p.

Technological Innovation and Forces for Change in the Mineral Industry, Committee on Mineral Technology, Board on Mineral and Energy Resources, Commission on Natural Resources, National Research Council, National Academy of Sciences, Washington, D.C., 1978, 74 p.

M. Waldrop, "Strict Law Challenges Strip Mine Operators," *Chemical and Engineering News*, 22 August 1977, pp. 18-19.

Nuclear Energy

1. The Demonstration of an Acceptable Irradiated Fuel Management and Disposal System

Management of Radioactive Wastes

Concepts and Objectives

Waste management in a broad sense comprises the collection, sorting, treatment, conditioning, transportation, storage and disposal of radioactive wastes. Radioactive waste is "any material containing or contaminated with radionuclides at concentrations greater than the values that the competent authorities would consider acceptable in materials suitable for uncontrolled use or release and for which there is no foreseen use."[1]

Irradiated or spent fuel, which is dealt with in this demonstration, is no longer immediately useful in the reactor because of the build-up of neutron absorbing fission products and depletion of fissionable material. Reprocessing conducted for the purpose of extraction of plutonium and/or uranium for further use, is an operation which also results in the separation of radioactive waste products. Since reprocessing is a future possibility, the design and demonstration of an acceptable irradiated fuel management and disposal system must consider all aspects of reprocessing.

The management of radioactive wastes produced in uranium mining and milling operations,[2] and fuel fabrication and decommissioning of nuclear reactors are excluded;[3] as are low level radioactive wastes.[4]

The objective of waste management is to protect human health and the environment.[5] According to the NEA Group of Experts Study, radioactive waste management should have the following objectives.[6]

"(a) comply with radiological protection principles for present and future generations;
(b) preserve the quality of the natural environment;
(c) avoid pre-empting present or future exploitation of natural resources;
(d) minimize any impact on future generations to the extent practicable."

Ideally, one could determine by a broad cost-benefit analysis whether the total detriment associated with any development is appropriately small in relation to the benefit resulting from a certain route or course of action. Fundamentally, there are only two courses of action available;[7]

(a) dispersion, dilution and discharge of radioactive wastes to the environment under controlled conditions; e.g., gaseous or liquid radioactive effluents;
(b) containment of radionuclides by suitable storage or disposal methods in order to achieve the required degree of isolation from the human environment.

As the title indicates, the proposed demonstration concentrates on the second course of action, and more specifically, on disposal methods. Storage means the emplacement of waste materials with the intent that the material can be retrieved, whereas disposal generally connotes the emplacement of waste materials without intention of retrieval.[8]

A Framework for Management Strategies

The long-term storage of wastes with high radiotoxicity or very slow decay rates poses a challenging technical and administrative problem. The Royal Commission on Environment Pollution in the UK recommended with subsequent government acceptance that responsibility for the management of nuclear wastes should be moved from the Department of Energy to the Department of the Environment. The government, however, was not disposed to act on the further recommendation that a nuclear waste disposal corporation should be set up with specific responsibility for the acceptable disposal of atomic wastes from nuclear station sites.

Due to significant present and future implications, one can easily envisage separate permanent institutions for nuclear development and nuclear waste management. An institution charged with the management of radioactive wastes would be an attempt to transcend short-term political and social influences.

In respect to regulatory aspects of nuclear power development in Canada, the Atomic Energy Control Board is the federal agency responsible for the orderly development and use of atomic energy. The agency, through its Research and Coordination Directorate is supposed to prepare research proposals, initiate and administer contracts, and evaluate results of research in the development of criteria for radioactive waste management; included in this activity are systems of disposal of radioactive wastes in geologic formations.

The Geological Survey and Atomic Energy of Canada work according to scientifically developed criteria and have recently intensified their experimental investigations of potential underground disposal.

A far-reaching agreement on the management of radioactive wastes was concluded in 1978 between the federal and Ontario governments.

Options and Technical Directions

What is possible and what is desirable are important questions.* A cursory examination of the options available show various approaches: some seemingly exotic (e.g., shooting wastes into space, preferably the sun;[9] burying wastes inside the Antarctic ice cap) and some apparently more realistic (e.g., storage above ground in specially constructed buildings, such as engineered storage facilities, concrete mausoleums); either storage or disposal underground in abandoned mines or man-made cavities, and placing wastes strategically on tectonic plates[10] or pushing wastes deep into the bottom of marine trenches. Additional methods are: (a) dilution and dispersion, and (b) transmutation.

Reference to information on a taxonomy of options may be found in note 11 and on selection criteria in note 12.

The US government has decided to dispose of high-energy radioactive wastes from nuclear power plants by storing them in stable geologic formations, such as salt domes, under the continental land mass.[13] Reference to information on safe burial in deep geological formations is found in note 14, and on the role of geology in note 15.

Due to the variety of possible technical directions, it is beyond Canada's means to actually develop all of the options.[16] Within the framework of extensive international collaboration, all relevant national programs are discussed and evaluated. A successful demonstration program would assist rational decision making toward the development and proving of an acceptable fuel management and disposal system.

Assumptions Respecting the Articulation of a Radioactive Waste Management R, D & D Policy

Several assumptions which apply specifically to Canada are presented to provide a framework for the design and performance of the proposed demonstration.

- If all the irradiated fuel accumulated by the year 2005 were to be placed on a

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*Another important consideration is the separation of fact from fiction.

regulation football field 100 m long and 60 m wide, the height of the storage will not exceed 8 feet or 2.5 metres.

- Large disposal facilities to accommodate this volume, therefore, might not be needed until the beginning of the next century.
- Most radioactive wastes will be stored in the interim in a way that will facilitate safe retrieval.
- The first phase of storage, as in the past, would constitute storage of irradiated fuels bundles in special bays at the nuclear reactor site for the first 5-10 years.
- Engineered surface storage facilities away from reactor sites will last 50-100 years; possibly they would be needed for only 20-30 years.
- Conceptual development and preliminary engineering work for disposal systems can be completed over a period of two decades.
- A sufficient amount of time will be provided for the appraisal of the selected disposal systems before it is used on a large scale.
- The problems of radioactive wastes are as much sociological-environmental-economic-political as they are technical-scientific.[17]
- Sufficient but not excessive time is available for the careful articulation of a long-term nuclear waste disposal policy (e.g., 3 years).
- Certain frameworks for developing a public policy have already been proposed in this and related fields.[18] The study of relevant socio-political and scientific processes and frameworks will prove useful.[19]
- A sufficient effort will be sustained in order to maintain and enlarge knowledge of "state-of-the-art" on an international scale.
- Allowances will specifically be made for the fact that the storage and disposal strategies and costs in spent fuel management are dependent upon adopted fuel cycles and types of reactors.
- Any implementation of multinational or regional fuel cycle centres, or similar arrangements, may determine the optimal type of irradiated fuel management, depending on reprocessing methods.
- The influence of reprocessing schemes on waste conditioning and disposal strategies and economics will be given special consideration.
- Plutonium recycling is a future possibility for Canada.
- No permanent disposal will generally take place until a long-term policy concerning the possibility of reprocessing of spent fuel and re-use of plutonium is formulated in its main directions.[20]
- Considerable weight will be attached to R, D & D before operational facilities are commissioned in Canada.
- Demonstrations are meaningful and will prove or validate certain important aspects of an acceptable irradiated fuel management and disposal system, provided that the whole system is designed rationally and credibly.

Level of Effort

In the area of irradiated fuel management and disposal using deep formations on land, among others, R, D & D is needed to:

1. Ascertain types of geologic formations and strata sequences suitable for the permanent disposal of long-life wastes. This evaluation activity will require a high quality level of effort. Geologic systems must offer effective barriers within the critical time frames and meet several necessary criteria, e.g., low seismic activity, poorly interconnected cracks and faults, very slow moving groundwater along lengthy non-vertical paths, presence of absorbing materials, etc. They must effect isolation from the biosphere for a very long time. Yet to be answered are questions concerning (a) the possible need for testing several types of formations (e.g., igneous and metamorphic rocks, volcanic rocks, shales, clay, salt and ocean bed) to provide redundancy as a hedge against conceptual error and uncertainty, and (b) whether or not the finality of disposal procedures should render wastes totally irretrievable (e.g., use of very deep drilling which may be "reamed" to accommodate larger volumes).

2. Conduct safety measures through testing and pathways analysis using realistic digital and experimental models based on careful measurements of material properties (e.g., physical, chemical and electrical interactions). The principal objectives of this preparatory phase is to verify all relevant concepts of the disposal systems selected for scaling-up.

3. Develop and demonstrate materials and processes which will incorporate the fission products and associated wastes into an insoluble matrix (glass or ceramic) before disposal in a practical and economic manner.

4. Maintain and monitor current programs for the interim storage necessary for spent fuel fission products and actinides before disposal. During this period cooling, shielding and isolation must all be provided. The use of water-filled bays is standard retrievable storage of irradiated natural uranium; air-cooled concrete canisters are being investigated. Fuel storage convection vaults are also considered. The water-cooled pool concept has been recently extrapolated to a large-scale interim fuel storage facility.

5. Develop and demonstrate materials and processes that are necessary to store the medium- and low-level activity wastes.

6. Continue R, D & D on safe and efficient methods of handling and transporting nuclear wastes. Special equipment must be developed and demonstrated. Conceivably but unlikely, some of the equipment involved may become quite exotic (e.g., tracked and remote-controlled vehicles to handle radioactive waste). Also, it has been proposed that it may be advisable to locate interim spent fuel storage, fuel reprocessing and refabrication, and ultimate disposal all at the same site. This practice would improve safeguards, offer the potential of economic savings, and facilitate coordination and reduction in transportation requirements.

7. As with other aspects of the nuclear cycle, it is essential to monitor, evaluate, and be actively involved in developments in waste management on the international front. Such developments could encompass investigations of the possibilities of deep-sea disposal of spent fuels or eventually transmutation of radioactive substances. A basic R, D & D capability is required within Canada to assess international developments.

The discussion which follows, based on indicated relevance, concentrates specifically on a disposal system using deep formations on land.

The full scope of the proposed demonstration for an adequate irradiated fuel management and disposal system may be summarized as follows.[21]

(a) Technology for handling and disposal
- irradiated fuel
- separated waste products.

(b) Repositories; permanent or retrievable
- siting problems;
- possibilities or risks of further recovery;
- institutional environmental and safety aspects including repository integrity problems, and geologic and organizational protection against possible dissemination of fission products;
- costs
- legal matters.

1. Reference Points

(a) Useful references are:
- NEA Third Activity Report, 1974, OECD Nuclear Energy Agency, pp. 25-29.
- Luther J. Carter, "Radioactive Wastes: Some Urgent Unfinished Business," *Science*, 18 February 1977, pp. 661-666, 704.
- M. Gauvenet, "Les résidus radioactifs," *Revue de l'Energie*, January 1977, pp. 7-14; March 1977, pp. 152-159, and April 1977, pp. 213-227.

(b) EMR News Release, 11 February 1977:
Total Federal Nuclear Budgets (1976-78)

1976-77	
$M	(%)
93.7	(73.3)

1977-78	
$M	(%)
93.7	(68.0)

AECL will expend 7.4 million per year for, "Environmental protection and radioactive waste management."

(c) Contract 11SQ; 87055-6-0135; (OSQ76-00153); on behalf of Atomic Energy Control Board:
"Investigation of the parameters necessary for the regulatory assessment of the suitability of Canadian rock formations, for the disposal of radioactive waste":
$54 707

(d) "ERDA Foresees Huge Costs for Nuclear Waste Disposal," *Science and Technology*, 15 December 1976, p. 3:
"The cost of construction and operating disposal facilities for commercial wastes will be about $2 billion between now and the end of the century."

(e) S.R. Hatcher, Communications of 6 and 22 December 1977, and 26 July 1978, various paging.
Experts expect that the fuel cycle waste management program will cost about $370 million (1978) up to 1987. This would provide material from pilot plants suitable for disposal, construction of four shafts and initial

development of a deep underground repository in hard rock. Monitoring and subsequent longer term expenditures would depend upon directions taken in the fuel program, e.g., demonstration of irradiated fuel disposal or thorium fuel recycle.

2. Exploratory Calculations

A demonstration program using "deep geological formations on land", inclusive of testing of the relative acceptability of rock salts, argillaceous formations (e.g., clays) or hardrocks (e.g., granite, limestone, metamorphic rocks), would require, tentatively, the following level of funding effort:

(a) *Additional Interdisciplinary Analysis**

This activity comprises logical testing of alternative disposal systems with a view to developing an adequate generic, non-site specific, conceptual base:

3 years; several teams at $2 500 000 per year equal $7 500 000

(b) *Continued Monitoring and Integration of International Developments*

This activity, extending over the demonstration period, involves international cooperation in respect to evaluation of relevant information, obtaining detailed data on specific projects and referring foreign studies and test conclusions to specific Canadian conditions:

19 years; one systems coordination team at $400 000 per year equal $7 600 000

(c) *Continuing R & D*

This activity must address various aspects of intervening processes and determine design parameters (e.g., effect of elevated temperature and pressure on rocks):

5 years; several teams at $1 400 000 per year equal $7 000 000

(d) *Construction of Pilot Facilities: Capital*

This activity requires building of pilot plants to prove conceptual designs or parts thereof and confirm technical solutions before scaling-up:

First Stage: several partial pilots	$12 500 000
Second Stage: 1-2 integrated pilots	$25 000 000
Total	$37 500 000

(e) *Evaluation of Pilot Systems and Re-Design*

This activity is intended to experimentally determine or confirm the design parameters for the full-scale disposal system:

5 years; one team at $750 000 per year equal $3 750 000

(f) *Exploration for Underground Storage*

This program comprises the search for, and testing of, geologic formations in accordance with all identified parameters and safe disposal requirements:

Drilling and evaluation testing at several sites $10 500 000

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*Among disciplines involved are economics, policy analysis, operations research, geophysics, special geology, hydrogeology, geochemistry, rock mechanics, radiation-chemistry, thermodynamics, materials sciences, mining, drilling, and civil engineering.

(g) *Completion of Full Scale Disposal System*
This phase may involve driving of several access shafts, construction of emplacement galleries and development of underground facilities in 1-2 geologic formation sequences:

$367 750 000

(h) *Evaluation of Demonstration and Dissemination of Results*
This phase includes integration of all demonstration results in respect to the demonstrated disposal system(s), and adequate public information:
$3 000 000

Grand Total $444 600 000

Time Frame

Simultaneous consideration of pros and cons of an evolutionary, as contrasted to a rapid development of a radioactive waste disposal system, and an identification of the intervening trade-offs, would point out the following decisive aspects:

1. Relevant Key Activities and Periods

(a) *Public Participation*
To facilitate public participation, a period of 3 years would be required immediately preceding the firm articulation of government medium- to long-term R, D & D policies in this area. This activity, e.g., focussing in the period 1979-1981, would cost in excess of $1 500 000. In view of the educational scope of this public information effort, however, the costs are not considered part of the proposed demonstration.

(b) *International Cooperation*
Canada is already a participant in the working party addressing radioactive waste within IEA's Cooperative Program in Energy Research, Development and Demonstration. It may be assumed that this is a continuing effort extending at least until the completion of the demonstration.

(c) *Preliminary R & D Period*
In a world context, we make the broad and flexible assumption that it would be necessary to conduct additional R & D addressed to specific Canadian conditions over a period of some 5 years.

(d) *Pilot Tests*
In the process of development of emplacement dispositives and control systems, we assume that a scaled-up effort would be required involving digital and analog computer simulations, physical experiments and pilot tests.

(e) *Completion of Demonstration Disposal System*
A further consideration is the completion of the demonstration disposal facility proper. We assume that it can be constructed over a period of five years or less.

2. Time Table of Demonstration Stages

The previous and additional minor assumptions lead to the following illustrative time table:

1979-1981	Additional Interdisciplinary Analysis
1979-1991	Continued Monitoring and Integration of International Developments

1980-1984	Continuing Mission-Oriented Research and Development Program
1981-1984	Construction of Main Pilot Facilities
1981-1985	Evaluation of Pilots Systems and Re-Design
1982-1984	Exploration for Underground Storage
1985-1991	Completion of Full-Scale Disposal System
1989-1991	Main Evaluation of Demonstration and Dissemination of Results

"Mile" posts of a possible demonstration program and follow-up are as follows:

- 1985 – Selection of disposal sites finalized.
- 1991 – Depository completed.*
- 1997 – Depository demonstrated.
- 2005 – Substantial reprocessing begins.
- 2010 – Final plans for model repository completely worked out.

3. Funding Distribution

A consistent but still illustrative time-distribution of funds required for the demonstration of an acceptable irradiated fuel management and dis[illegible]l system is as follows:

Year	Current	Cumulative
1979	$ 3 000 000	
1980	4 000 000	$ 7 000 000
1981	12 000 000	19 000 000
1982	15 000 000	34 000 000
1983	18 000 000	52 000 000
1984	30 000 000	82 000 000
1985	45 000 000	127 000 000
1986	60 000 000	187 000 000
1987	70 000 000	257 000 000
1988	60 000 000	317 000 000
1989	45 000 000	362 000 000
1990	30 000 000	392 000 000
1991	20 000 000	412 000 000
1992	13 000 000	425 000 000
1993	7 000 000	432 000 000
1994	5 500 000	437 500 000
1995	3 500 000	441 000 000
1996	2 100 000	443 100 000
1997	1 500 000	444 600 000
Total:	$444 600 000	

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2. The Demonstration of the Feasibility of the Thorium Cycle

Evolutionary Development of the CANDU Reactors

Report No. 23, *Canada's Energy Opportunities* recommended among other proposals for future development of fission energy:[1]

- "Increased attention to the development of new technologies for the processing of uranium ores of decreasing quality;
- "increasing emphasis on the introduction of thorium into the CANDU fuel cycle, as a means of dramatically increasing the resource base of our nuclear fuel;
- "continuing evaluation as to the desirability of re-cycling the plutonium generated in current CANDU plants."

The Report notes, however, that:

> "The expectation of improvements in fuel cycle economics must be carefully balanced against the undesirable features of the reprocessing system which would of necessity be involved."

The recommendations in Report No. 23 are, in essence, valid today and provide an incremental technical development of the CANDU very much as expected.[2] More recently, several researchers and officials addressed the further evolution of the CANDU reactor and the development of the thorium cycle.[3] Theoretically, the feasibility and success of the CANDU thorium cycle is expected with a high degree of certainty.[4] The CANDU reactor can indeed be modified to convert thorium by neutron capture into the fissionable isotope uranium 233.

Contrary to expressions of optimism, however, there appears to be serious opposition to the further development of fission energy as expressed by some groups.[5] Few detractors of nuclear energy have specifically taken issue with the thorium cycle; however, by continuing to point out associated externalities and perceived dangers such as thermal pollution, health hazards (e.g., radiation and radon inhalation), reactor accidents (e.g., loss of coolant; meltdown), and acts of terrorism and proliferation, the implications are quite clear. More recently, interest has focussed on the dangers related to the handling of irradiated fuel wastes.[6]

On the international scene, considerations concerning widespread diffusion of nuclear power and proliferation of nuclear weapons require political solutions (e.g., Treaty on the Non-Proliferation of Nuclear Weapons (NPT)) and international institutions for effective control (e.g., International Atomic Energy Agency, (IAEA)).[7] Both NPT and IAEA attempt to limit proliferation without interference with the peaceful use of nuclear power.

Clearly, it is beyond the scope of this report to discuss arms control, safeguards, attitudes and expectations or acts of nuclear terrorism.[8] At best, we can only note that we have and will continue to have proliferation even without nuclear power development and that, more critically, widespread nuclear power would probably increase the possibility of proliferation.[9] Notwithstanding a difficult situation, positive steps are now being taken in the area of safeguards and proliferation, with Canada playing a very important role.[10]

The reaction of Canadians to the nuclear policy of US President Carter was that of sensing an opportunity for the further development of the CANDU system. Rippon reports:

> ". . . and not to be outdone, Bennett Lewis, the father of CANDU recalled his 'value breeder' concept using an organic cooled heavy water reactor with a mixture of low enrichment uranium amd thorium fuel."[11]

President Carter's policy of renunciation of the existing breeder construction program and the immediate commercial reprocessing of irradiated fuels, associated with a postulated move to zero electrical energy growth, may be viewed with skepticism; however, it cannot be ignored since it has influenced world energy policy.

Perhaps at this point it will be useful to review the evolution of the CANDU reactor. The Canadian nuclear power program was launched 25 years ago using natural uranium fuel in the CANDU heavy water moderated reactor. At that time the associated R & D program included work on fuel reprocessing and radioactive waste immobilization. By 1958 AECL had concluded that fuel reprocessing was not economically necessary in the first generation of CANDU reactors. They also concluded that radioactive wastes, such as arise in reprocessing, could be safely immobilized, or made insoluble, for permanent disposal. On these assumptions, the major effort was applied to the development of the CANDU reactor system and the once-through fuel cycle. The decision was made to store irradiated fuel in a retrievable manner in suitably designed interim storage facilities, e.g., water-filled pools, until the need arises to treat it further. Meanwhile most other countries using enriched uranium reactors had based their fuel cycle programs on the immediate benefit to be obtained from reprocessing. The recovered plutonium and U-235 were intended for recycling in existing reactors and the plutonium for use in the developing fast breeder reactors for extending uranium resources.[12]

Recently in the United States, there has been a review of the economic and other implications of reprocessing.[13] President Carter's nuclear policy has been widely misunderstood by many who have not followed the US program in detail.[14] He has, according to one interpretation, announced a policy that now parallels the Canadian position; that is, not to reprocess fuel commercially in the near future, but to store irradiated fuel and continue R & D on fuel cycle options, while pressing ahead with work on radioactive waste disposal. The US policy advocates continued R & D on fast breeder reactors but contends that specific design of the Clinch River demonstration reactor is obsolete and that the project should be abandoned.[15] This is, of course, one possible interpretation of Carter's proposed policy. The impacts of this policy on the global nuclear energy development — and in fact on long-term US energy policy — are by no means clear at this point.[16] Much would depend on information programs and public acceptance of nuclear energy.[17]

In summary, in respect to the political feasibility of the thorium cycle in Canada, the situation is as follows. In view of decisions taken at the May 1977 summit meeting in London, the Canadian government adopted the policy that fuel cycle research will go on but it will remain confined at the laboratory level until the international situation is clarified. This research will be continued until completion of the International Nuclear Fuel Cycle Evaluation (INFCE), which involves participation of some 40 countries. Thus in Canada, the program of fuel cycle evaluation, as it existed in 1977, will be extended over the next 2 years or so. In the meantime, Canada is in a uniquely favourable position: it has both (i) large quantities of uranium and (ii) flexible reactors.

In closing this section, yet another option must be referred to – in fact an optimum for the once-through fuel cycle which can be implemented with CANDU – use of 1.2 per cent enriched uranium.

A Framework for Thorium Cycle R, D & D Policy

Assumptions Relevant to the Development of the Thorium Cycle

In this section reference will be made to certain aspects which will play strategically significant roles.

(a) Energy requirements early in the next century will still be considerably higher than at present, even assuming a rigorous conservation policy. By 2020, the most which can be expected with respect to the decoupling of energy requirements from the GNP is a 50 per cent "emancipation" from the present rigidly established relationship; yet even with this extraordinary, socioeconomic and technical "achievement" a large energy supply would still be needed.

Specific supplies for these needs are by no means assured. It is fairly clear, therefore, that Canada will have to develop new and adequate technology eventually. Due to large resources, utilization of coal comes to mind first.

(b) Direct utilization of coal for heat and electricity, however important in the short and medium terms, may well prove to be a transitory technology. The carbon dioxide produced in coal (and other fossil fuels) combustion appears to pose a long-term threat by heating the atmosphere via the greenhouse effect. There is no practical control of this environmental problem, yet to be scientifically demonstrated. Although the heating of the earth's surface as a result of particulates and other pollutants such as sulphur dioxide and nitrous oxides is very uncertain, some researchers place the occurrence of incipient critical global climatic effects sometime early in the next century.

Our present understanding of the planetary carbon cycle is very weak because of insufficient or incomplete data, but long-term decisions still must be made. "The best assumption would appear to be that CO_2 will continue accumulating in the atmosphere as it has in the recent past."[18]

By 2025-2050 there may be global problems with the CO_2 build-up in the atmosphere and control of the direct utilization of coal for heat and electricity may be required. It will, therefore, not be surprising if by 2030, regional and urban pollution would resolve the socio-ecological crisis in favour of a more ecologically sustainable form of energy production.

The controversy surrounding the accumulation of CO_2 in the atmosphere, with possibly catastrophic effects on the climate, "is one aspect of the debate on the long-term reliance of coal versus energy sources producing no new CO_2, such as nuclear, solar, and biomass sources."[19]

(c) Considerable time is required to develop alternatives such as wind, geothermal, tidal and solar-direct conversion to electricity.[20] In addition, their contribution will be relatively small initially.

(d) Canadians cannot wait until some "delayed breeder or alternative" appears on the scene; a development assumed to occur about 2020 by near-official US sources.[21] In recommending a strategy, we cannot simply assume that some as yet unknown technology will miraculously fill the gap between already trimmed down requirements and an unsatisfactory supply of energy in Canada.

(e) Fusion, even if successful, cannot play an important role in Canada by 2025-2050. Probably the first commercial reactor in the world will not be built earlier than 2015. There appears to be only a very small chance that fusion will supply electricity on a competitive basis before 2030.

(f) Solar-electric, as a longer-term technology — especially in Canada relative to the US — would have an impact only in the post-2025 era, if ever.

(g) According to NEA and IAEA,[22] uranium production rates in the principal supply countries are assumed to be:

Year	Quantities in Tonnes	Growth in Percentage
1976	18 000	—
1980	50 000	29
1985	100 000	15

Some 1 750 000 tonnes are assured reserves at a rather economically acceptable cost (say $110 per kg of uranium oxide: according to more recent information, the world's reasonably assured resources of uranium, exploitable at costs less than $130/kg U, amount to 2.2 million tonnes).[23] To establish certain relationships the above reserves equal 17.5 times the 1985 rate of 100 000 tonnes per year. This does not mean that the uranium reserves will be exhausted by 1995 or so. Indeed, contrary to concerns expressed elsewhere in the world (e.g., OECD), in respect to shortages of uranium expected to occur before the end of this century, Canada has reasonably assured uranium resources for its domestic use and good prospects for increasing uranium supplies through investments. Therefore, the equation between demand and supply of uranium, not immediately but in the long term, shows the need for a broadening of the resource base, as the supply of reasonably priced uranium begins to diminish.

(h) Globally, the proposed thermal reactor installation programs will exercise considerable pressure on established uranium reserves. The CANDU program, like other thermal reactor programs, without plutonium recycling and utilization of thorium, could well require an exponentially increasing annual supply of uranium if fission energy is to supply a significant part of Canada's future energy needs.[24] Among other considerations are exports and assistance programs for developing countries. Clearly, uranium requirements on a world scale will be increasing. In this context, and assuming continued resource conservation practices, Canada's energy policy would be inconsistent in taking the posture of conserving every finite resource, except uranium.

Moreover, it is inconceivable that indication of oil and gas resources near the shore (e.g., Sable Island) should be ignored before proceeding further offshore with drilling in deep waters. Forging ahead with advanced nuclear reactors without investigating the potential contribution of abundant thorium resources would not be reasonable. Indeed, it seems paradoxical to attempt to find substitutions for oil, and eventually gas, because they are ultimately finite, and at the same time to neglect extension of the nuclear fuel supply by using thorium.

(i) All expanding nuclear systems, be they thermal or fast reactors, will require continuing uranium supplies for long periods of time. However, in the absence of the implementation of the thorium cycle, a nuclear program comprising exclusively thermal reactors — even the more efficient CANDU reactors — will have to rely on an increasingly larger uranium supply and therefore will be exposed to significantly increased prices.

(j) The assurance of an economic and safe thorium cycle will create the incentives "to go into marginal resources of uranium" for export, concomitant with the search for the associated thorium deposits. This will eliminate "high grading" and increase the ultimate uranium resources.

(k) A clear distinction must be made between (a) "continuing evaluation as to the desirability of recyling the plutonium generated in current CANDU plants" through R, D & D and (b) actually producing energy by using thorium and recycled fuels. The difference between (a) and (b) is a long-term program of applied research, development and commercialization of the thorium cycle.

(l) Probably it would take 25 years to develop and demonstrate the technology required for the thorium cycle and related processes.

(m) If the fuel cycle is extended to include reprocessing and recycling, new potential health risks are introduced. The impacts of the new proposed operations must be identified and evaluated, both in absolute and relative terms. The credibility of any required solutions must be demonstrated. Not all impacts, however, are expected to be detrimental. Utilization of thorium, together with reprocessing and recycling, would reduce the need for some uranium mining and milling, and thus potentially reduce the health consequences of these operations.

(n) Throughout this discussion of a framework for a "Thorium Cycle R, D & D Policy", it must be assumed that such a long-term commitment is consistent with Canada's industrial strategy, in general, and a viable structure of a national nuclear industry in particular.

In summary, new and adequate technology will be difficult to develop and implement and there will be advantages to proceed with what we know and can achieve as our needs dictate, i.e., the thorium cycle.

Level of Effort

Present experience, in Canada and abroad, is sufficient to give confidence in the technical feasibility of the proposed thorium cycle. However, a great deal of work remains before the thorium reactor system represents a proven option on which to base a decision on commercial fuel reprocessing and recycling. Further experiments are needed to define the critical details and hence the potential of each process involved. In addition, the thorium cycle requires laboratory pilot-plant work on both chemical reprocessing of spent fuel, and active fabrication of fuel for recycling to provide reliable cost estimates for these processes, and to obtain the experience necessary to design larger plants if required.

Since fuel recycling involves handling, among other materials, plutonium or uranium-233, which are toxic and fissile, an essential part of the demonstration program must show that recycling fuel in CANDU reactors would not result in unacceptable risk of accidental releases and thus hazard to the health of employees and the public.

1. Reference Points

(a) Useful references are

- Heinrich Mandel, "Construction costs of nuclear power stations," *Energy Policy*, March 1976, pp. 12-24.
- J.S. Foster, "Financial Resources Required for the Future Nuclear Power Program," Paper CNA-73-502, presented at the Canadian Nuclear Association Meeting, 17-20 June 1973, 20 p.; also Proceedings of Standing Committee on National Resources and Public Works, House of Commons, 15 March 1977.
- Atomic Energy of Canada Limited, *Annual Report 1976-1977*, Ottawa, 15 p., F 13 p., and T 33 p.
- J.A.L. Robertson, *Research and Development for Canadian Nuclear Power*, AECL-5314, Ottawa, Ontario, January 1976, 17 p.

(b) EMR News Release, 11 February 1977; Total Federal Energy R & D Budgets (1976-78):
Nuclear fuel cycle = $15 900 000 per year.

(c) *Inventory of Energy R & D*, EMR, February 1977; Federal Funding of Energy R & D 1976-77:

"3. Nuclear Energy	$93 739 000
3.1 R & D in support of the Regulatory Function	$ 2 026 000
3.2 Securing the Fuel Base: Uranium and Thorium	$ 5 217 000
3.3 Nuclear Energy Utilization and Support	$84 713 000
3.4 Nuclear Fusion	$ 1 783 000"

(d) "A possible reprieve for the fast breeder,"* *Business Week*, 20 June 1977, p. 31:
- The proposed 350-megawatt demonstration breeder at Clinch River, Tennessee, has already cost about $102 million.
- US Energy Secretary Schlesinger estimated that the Clinch River plant would ultimately cost $1.5 billion.
- A half-built reprocessing facility has already cost $250 million.

(e) S.R. Hatcher, Communications of 6 and 22 December 1977 and 26 July 1978, various paging.

Experts expect that the thorium fuel R, D & D program will cost a total of $1.5 to 2 billion and will extend over a 25 year period commencing in 1980. About 10 per cent of this amount might be spent in the first five years with a peak rate of expenditure occurring in the second five-year period as major capital demonstration facilities would be built.

2. Exploratory Calculations

A demonstration program would require the following level of funding effort:

(a) *Complementary R & D*
- 3 years; 3 teams at $375 000 per year equal: $3 375 000

(b) *Continued Research and Development*
- 3 years; 3 teams at $750 000 per year equal: $6 750 000
- 16 years; 1 systems coordination team at $375 000 per year equal: $6 000 000

Sub-Total: $12 750 000

(c) *Laboratory Experimental and/or Pilot Plants*
- Thorium Cycle Reactor or Modification of Existing CANDU Reactor
- Chemical Processing of Spent Fuel
- Active Fabrication of Fuel for Recycling

Sub-Total: $15 000 000

(d) *Evaluation of Pilot Plants, Selection of Prototypes and Engineering Design of Entire Scaled-Up Demonstration System*

At some 15 per cent of total estimated costs: $262 500 000

(e) *Demonstration Thorium Cycle System and Upgrading*
- Thorium Cycle Sub-System. A most probable figure according to information reviewed would be: $725 000 000
- Separation Facility Sub-System
  Say plant reprocessing capacity of 1000 tons of irradiated fuel per year: $231 375 000

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*The proposed thorium cycle reactor, however, is still a thermal reactor or convertor, not a fast breeder.

- Active Fabrication Facility
  Plutonium preparation plant plus associated temporary and medium-term storage sub-systems:

	$365 000 000
Sub-Total:	$1 321 375 000
Grand Total:	$1 750 000 000

Time Frame

Nuclear programs are very long term and impinge in an important way on policies for the entire energy sector of the economy. By way of an introduction to time frames, we note that in a very general fashion, the perceived energy scarcity of the next century — as illustrated by difficulties with oil and perhaps gas supplies, as well as lack of ample rich uranium ores — is notionally correlated in the area of fission processes with "global" transition from thermal reactors to fast breeder reactors from the present into the 21st century.

Clearly, the thorium option if exercised will not be ready for commercialization by 1985. The thorium cycle "total system", however, could be in operation on a large scale by 2015-2020. Contrary to views in other countries that similar programs can be useful in terms of large impacts before the end of this century, we expect that the CANDU Thorium Cycle, if fully commercialized, will have an impact only beginning sometime during the first part of the next century.

Perceived Critical Energy Periods
The gap between energy requirements and supply will become critical around 1985, and again toward 2025 when supplies of oil and gas would be increasingly difficult to obtain.[25]

The demonstration of feasibility of the thorium cycle must generate information for the commercial development of all support facilities for thorium fuel manufacture, reprocessing of irradiated fuel and waste management, necessary to establish integrated system performance on a full scale in the early 2000s. Only in this time framework can the thorium reactors be really beneficial and justify the high costs of R, D & D. But if they can help in this most critical period, the trade-offs between benefits and risks, referred to in *Canada's Energy Opportunities*, can be more readily evaluated and accepted by the great majority of Canadians.

On this assumption, working backward from the year 2025, we may proceed as follows:

(a) *Thorium Cycle Commercialization and Uranium Fuel Conservation*
Considering that the thorium cycle would still require significant quantities of uranium for 25-35 years after its introduction, we recommend that this introduction be targeted on the year 1990, or the earliest practical date following 1990. This sustained pace is required since otherwise the uranium requirements for CANDU reactors would be very large for a very long time.

(b) *Construction of the Demonstration Plants*
Several plants — possibly three plants, co-located, but covering different processes — may have to be completed within the entire thorium cycle demonstration complex. Assuming that the construction and testing net period requires 10 years, then preparations for the construction of the demonstration plants must begin in 1980.

(c) *R and D Period*
Assuming that evolutionary development research would require some 20 years for a proto-type thorium system, it follows that this phase should have

commenced in 1960. Indeed, the 1976-1977 Annual Report of AECL in addressing advanced fuel cycles, states that a study of the conversion of the WR-1 reactor to thorium-plutonium oxide fuel was made and fabrication techniques for Uranium 233 explored. The annual report further indicates that a proposal is under consideration for the conversion of a research reactor to the use of thorium oxide fuel. A study completed at WNRE has shown that an experimental program, based on the conversion of the WR-1 reactor to thorium oxide fertile material and extensive pre-irradiation experiments in ZED-2, is feasible and possibly will provide most of the required information in the form of: (i) reactor physics data; (ii) design and analysis methods, and (iii) nuclear characteristics of thorium-fuelled CANDU reactors. The report concludes that these activities would have to be complemented subsequently by experiments using Uranium-233 extracted from irradiated fuel.

In this framework, we can assume therefore that it would be quite possible to develop the thorium cycle and its sub-systems by no later than 2005, using an evolutionary process, to the same degree of perfection that the natural uranium CANDU has reached today. Alternatively, one could start with the present and assess whether a demonstration program initiated immediately following the INFCE completion would result in the introduction of the thorium cycle at an appropriate time.

Illustrative Funding Distribution

The timing of the demonstration of the feasibility of the thorium cycle is surrounded by some uncertainty, partly dependent upon complex international developments. Moreover, although the illustrative funding distribution is based on different stages of the R, D & D program, these are not indicated explicitly since the spending pattern is affected by long lead times to a very considerable extent. A purely notional distribution or time-profile for illustrative purposes only, of funds requires to complete the demonstration for the feasibility of the thorium cycle system, could take the following form:

Year	Current	Cumulative
1979	$ 7 000 000	$ 7 000 000
1980	10 000 000	17 000 000
1981	15 000 000	32 000 000
1982	23 000 000	55 000 000
1983	40 000 000	95 000 000
1984	80 000 000	175 000 000
1985	140 000 000	315 000 000
1986	210 000 000	525 000 000
1987	280 000 000	805 000 000
1988	270 000 000	1 075 000 000
1989	237 500 000	1 312 500 000
1990	126 000 000	1 438 500 000
1991	87 500 000	1 526 000 000
1992	60 000 000	1 586 000 000
1993	38 000 000	1 620 000 000
1994	28 000 000	1 652 000 000
1995	22 000 000	1 674 000 000
1996	18 000 000	1 692 000 000
1997	14 000 000	1 706 000 000
1998	10 000 000	1 716 000 000
1999	8 000 000	1 724 000 000

2000	7 000 000	1 731 000 000
2001	6 000 000	1 737 000 000
2002	5 000 000	1 742 000 000
2003	4 000 000	1 746 000 000
2004	4 000 000	1 750 000 000
Total	$1 750 000 000	

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Renewable Energy

1. The Demonstration of The Feasibility of Generating Gaseous and Liquid Fuels from Forest and Agricultural Residues

Dimensions of Uncertainty

There are few authoritative and specialized studies regarding feasibility and cost of either: (a) energy input, labour, collection, preparation, transportation and storage of crop and forest residues, and on outlets where they might be converted to and consumed as liquid or gaseous fuels, or; (b) animal waste digester systems for the production of a gaseous energy product usually referred to as "biogas". Thus, with very few exceptions there is presently much uncertainty about the advisability and feasibility of generating "biofuels" from forestry and agricultural residues for either direct utilization in these industries or as supplement for gasoline in transportation. Moreover, there is much uncertainty with respect to the ecological impact of large-scale biomass schemes.

Perceptions of an Adequate R, D & D Program

The characteristics of an adequate program which could reduce uncertainty include the following elements:

(a) Research, development and demonstration activities in the area of renewable biomass energy are strongly interrelated. Thus, any program must be accompanied by, or include, R & D on forest management, breeding programs, harvesting, collection and packing techniques, returning nutrient matter to soil systems, and research on ecological effects of proposed biomass programs.

(b) Demonstrations must be carefully designed and planned. Preliminary studies appear to indicate that it is useless to spend "further money" on either obsolete or premature demonstration plants.

(c) Projects of any size, therefore, will require advance and back-up R & D. Most "instant demonstration" installations would be disastrous and would erode the credibility of the whole enterprise. A long-term commitment is required for a systematic national effort in R & D. Funding must be matched with availability of good ideas and competent people to carry out the work.

(d) A "balanced" R, D & D program must be developed by both theoretical design and information based on experience. As an illustration, focusing on alcohol (e.g., methanol and ethanol) has special theoretical importance because it is a transportable liquid, concentrated and easily adaptable energy form that could eventually, if practical, substitute for products of expensive and "insecure" imported crude oil. As mentioned previously, however, there may be clear advantages in many circumstances to provide transportable fuels from coal, at least for several decades. Notwithstanding this direction, it must be recognized that by expanding the R & D program for the "generation of gaseous and liquid fuels from forest and agricultural residues", an opportunity is simultaneously created to build on the versatility of the natural system.[1] The same basic chemical process (thermal treatment in this case) can be used to produce a variety of materials, combustible gases and liquids, including alcohol. This diversity is important. Restricting the effort to alcohol would severely — and unnecessarily — limit the potential of the future demonstration program, and indeed, the very scope of the current scientific inquiry. Conceivably, a demonstration program completed at an appropriate time will show how to husband the resources effectively and provide more than one product in an optimized fashion.

(e) A management structure must be developed, which would reflect the need for an integrated approach across the entire spectrum of biomass sciences and technologies. At the earliest possible stage, existing and potential producers of "hardware" must be effectively involved to assure satisfactory economic benefits.

(f) Once having initiated an appropriate decision and control framework, it is possible to focus on specific modular projects and plants as their relative and individual values become manifest. The need for some of these "component projects" will become abundantly evident and would require only a limited amount of research and evaluation before proceeding. Thus, an excellent opportunity exists for the demonstration, modification, testing and commercialization of a Canadian designed wood gasifier with the flexibility to produce several forms of energy, or, indeed, chemical feedstocks.

Moreover, there is a consensus that with regard to plant and animal wastes, the most likely biotic process to have significant practical importance is the production of methane gas. To develop systems that can operate effectively under Canadian climatic conditions, heat exchange, storage, safety and other aspects of "biogas" technology must be developed beyond the simple anaerobic digestion process of producing gas. A continuing demonstration project of practical unit sizes to convert wastes from 200-400 cattle (or their equivalent)* is being already initiated by EMR.[2] Preparatory R & D would be mandatory, however, in order to plan and perform other "component" demonstrations meaningfully. Some potential candidates are:

- Efficient generation of heat and electricity from wood residues by the pulp and paper industry.
- Electricity generation in systems driven by diesel engines using a feed delivered by wood gasifiers.
- Gas production from fibrous materials.

(g) Finally, the demonstration projects, which will be identified by the preparatory program, should be carried out at geographical locations most appropriate to the undertaking (e.g., resource availability, end-use location and existing talent).

Resource Base, Potential and Relevant Processes

Numerous publications address questions of resources and their availability on a sustainable basis.[3] For references on resources related to wood products and residues, see notes 4-8. Agricultural resources and their wastes are referenced in note 9; waste yield estimates of western Canadian grain crops, note 10; primary productivity, note 11; possible directions, notes 12-19; the roles of biology and chemistry, notes 20-25; and comparisons of "biomass fuels" with fossils (from technical, economic and environmental points of view), notes 26-47.

Possible Directions and Constraints

Several observations and practicable directions are presented in order to provide background for the overall thrust of the proposed demonstration program.

(a) The economics of the generation of liquid and gaseous fuels from forest and agricultural residues will be determined more by the cost of collection equipment

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*The technology is not easily transformed from using hog waste to processing cattle manure as feedstock. Moreover, certain animal and plant wastes have potential "high grade" applications as livestock feeds, and thus undergo an additional loop within the system, prior to their use as an energy source and eventual return to the land.

and labour, and the distance the wood wastes must be transported, than by the capital cost of fuel generation equipment.

(b) Many lumber companies, although realizing that substantial amounts of waste occur, consider it unprofitable to harvest the fuel wood that is left behind in their operations. Consequently, thousands of cords of usable wood lie rotting in many forests since the high cost of salvage precludes their contribution to energy supply programs.

(c) In the area of waste collection, many situations require ingenuity and better management, not R, D & D.[48] Utilization of slash and other residue presently left in forests, however, may require new technology for collecting and handling.[49] Fuller utilization of the forests and agricultural yields through better management and new harvesting systems on the other hand, will reduce the amount of wastes. The handling of transportation of wood and agricultural wastes may be improved particularly by compaction, gasification and liquefaction.[50]

(d) Because of increased fossil energy bulk prices and substantial transportation costs there is a need and a sense of urgency in certain communities to intensify efforts in developing technical and economically feasible systems, on a local or regional basis, less dependent on fossil energy. Thus, in many favourable situations — but not in all cases — energy self-sufficiency may be approached economically through ingenious site-specific husbanding of resources, inclusive of human resources.

(e) Increased rehabilitation of degraded forests and utilization of agricultural residues in low-income regions would have significant social benefits. The continued viability of these systems must, at least in part, be based on sound comparative economic advantages.

(f) Moreover, all expectations of future success in this area must rest on advanced scientific progress in more intimate cooperation with "mother nature". R, D & D and economic studies of appropriate technologies must help reduce the required capital investments at the local level (e.g., biogas installation).

(g) Of special importance are: (a) research on biological processes; (b) enzymic fermentation, and (c) direct use of microbial systems for specified fuel production.

(h) Due to significant international developments, it is important for Canada to improve its technical ability to evaluate, filter and support successful results of national significance.[51] It is to be hoped that Canada will continue to monitor international research and remain an active participant in the Biomass Energy Working Paper of IEA. A sustained evolutionary process of education and training is required at home to acquire the necessary understanding and skills.

(i) The potential exists for use of inhouse residues to provide energy for a plant. Bark and wood are not contributing significantly to the energy requirements within the pulp and lumber industries.[52] As an illustration of the order of magnitude of projects involved, the *Daily News Bulletin* of 26 August 1976, reported as follows:

> "British Columbia Forest Products Limited of Vancouver plans to spend $11 million to add a major waste wood burning boiler at its Crofton pulp and paper mill on Vancouver Island. The project will be completed in about 2.5 years."

(j) There is considerable uncertainty in respect to the ultimate or dominant utilization of forest and agricultural residues. In competition with the use of forest and agricultural "wastes" for generating liquid and gaseous fuels are: (a) potential use of wood and tree foliage for supplementary cattle feed on a large scale (e.g., poplar trees) and (b) possible use of wood, bark and foliage as a source of chemicals for pharmaceuticals and industry. Moreover, because of reduced feedstock transportation costs, most mill residues may be sold for fibre uses for woody material such as pulp and paper, and other products, or utilized on site in the production of heat energy rather than used in the generation of fuels. Even high transportation costs in general will not prevent wood and agricultural wastes from being utilized as chemical feedstocks in markets commanding high prices (e.g., pharmaceuticals). If the generation of fuels proves successful, it is probable that – not unlike low Btu gas – they will be utilized in or near the area in which they are produced. Even the medium Btu fuels produced by gasification cannot, because of economics, be transported to distant markets.

(k) For reasons of simplicity and available markets, residues may be used to produce electricity.[53] Thus, wood residues could replace oil and natural gas by producing process steam through the use of fluidized-bed combustors.[54] Moreover, other types of combustion systems should not be downplayed. Many experts would first prefer the development and commercialization of a simple, robust, economic, "all-purpose" Canadian system. The practicability and economic feasibility of many engineering aspects of direct conversion technology require continued attention. Clearly, wastes may be used to produce both heat and electricity.[55]

(l) The collection and utilization of forest residues for fuelling large central power plants, however, does not appear attractive in present socioeconomic conditions.

(m) The production of liquid fuels from wood wastes is technologically possible and requires continued economic scrutiny.

(n) Currently, the production of a synthetic automotive fuel by the pyrolysis of wood is technically feasible but economically prohibitive.[56]

(o) The ecological consequences of any continued and more complete utilization of wastes need to be better understood. A related factor is the long-term effect on atmospheric carbon dioxide levels of an expanded and intensive activity related to growing and utilizing biomass. The balance and interchange of carbon dioxide between the atmosphere and the various global reservoirs are very complex phenomena, involving any fuels except hydrogen.[57]

(p) A broad base of knowledge and capability should be encouraged as an energy supply insurance policy to maintain an adequate "alcohol" plan of action for effective execution if and when needed.

(q) Since the competitive industry may oppose development of such fuels, the federal government should encourage timely research and development, and fund necessary pilot plants for synthetic fuels.

(r) All biomass technologies will initially require a coordinated program of astute review, advanced research, and target oriented leadership. A "priority research program" designed along the directions of *Schwerpunkt* programs, as are widespread in West Germany, might be appropriate. This concept requires the financing and supra-regional coordination of the work of several researchers on a certain topic or project, as a rule for a period of up to 5 years.

(s) The demonstration program proposed in this section is not concerned with growing trees or building plants on a large scale for the express purpose of mass generation of fuels.

(t) In this proposal therefore, we do not concentrate on large scale operations (e.g., large scale methanol fuel production) using energy farms or plantations but — as the title indicates — we focus intentionally on forest and agricultural wastes or residues (e.g., excess growth and residuals of naturally established stands of timber; surplus agricultural straw and manure).

(u) The R & D and tests proposed herein represent two different scales of magnitude: (1) very small scale which would be matched with and respond to local materials, labour supply and energy requirements, e.g., rural and isolated communities, and (2) medium scale which should have a substantial impact on the energy requirements of potentially self-reliant energy intensive industries, e.g., forestry and lumber company systems.

(v) Independent of technological success, a sound core of activity must be established before proceeding with commercial fuel production, e.g.: (1) on-farm fuel production; (2) pulp and paper energy self-generation; and (3) energy self-sufficiency of the entire forest products industry.

Energy plantations and fuel farming — often pictured optimistically in scenarios — are not yet the answer to national energy problems. As energy prices increase, however, the feasibility of generating fuels from wood and perhaps agricultural wastes will be the first to improve because of a shared or joint cost situation. As an illustration – if and when practical in Canada – methanol may be used "straight" or in blends with gasoline.

Recommended Directions of R, D & D

In summary, the following directions should be emphasized:

- The small size of incipient energy supplies based on biomass technologies should not be construed as a limitation: these supplies are important because they replace hydrocarbons, can be sustainable, and can lead to energy self-sufficiency of certain communities and industries.
- Biomass energy, particularly in cases where appropriate technology is applied, can often find a "niche" wherever there is isolation because the cost of interregional transport of conventional energy forms acts as an important negative economic factor.
- Proceeding in accordance with the generally accepted direction "wood gasification for energy, not for methanol", would require focussing on the priority: "gasification first; methanol by far next only."
- Selection of pyrolysis from among several processes, that can convert organic wastes into high-quality fuels (e.g., biogas productions, fermentation, hydrogasification, hydrogenation). In other words, by giving priority to the decomposition of biomass by heating in an inert atmosphere as in the case of town gas or charcoal manufacturing, it is expected to facilitate a more natural and evolutionary development of biomass energy.

In order of perceived importance, by way of comparison, we list and briefly discuss technological aspects associated with the following processes:

1. Gasification of wood and residues.
2. Testing methanol technologies.
3. Evaluation of ethanol potential.
4. Generation of biogas.

1. Gasification of wood and residues: Conversion of wood to gas is an old technique which opens a wide range of opportunities. The organic development and successful demonstration of technology for the generation of gaseous and liquid fuels from agricultural and more specifically forest residues will require the test facilities and demonstrations to be "organically" embedded in a supportive R & D activity focussing on aspects of forest management, breeding and growing programs, harvesting, collection and compacting techniques, ecological evaluations, returning nutrients to the soil and so forth. The research activity must be orchestrated nationally in a coherent manner but the particular tests must take into consideration regional conditions.

Since utilization of waste wood products can render saw mills self-sufficient, and the use of wood gas could become locally or regionally price competitive - even in small-scale operations - say in 10 years or so, funding for the development and demonstration of a wood gasifier under realistic conditions appears justified. With a comprehensive assessment and dissemination of results completed early in the 1990s, depending upon prices of oil and gas, it should be possible to proceed with marketing without significant subsidies.

2. *Testing methanol technologies:* Methanol can be made by combining hydrogen and carbon monoxide. This alcohol may be produced from several primary materials such as natural gas, coal, crude oil, peat, and biomass. Currently, there are plans to use some of the wasted natural gas in the prolific oil fields of the Middle East to produce methanol for shipment by marine mode to industrial countries. Methanol, in the long term, could become an accepted energy carrier for the transport sector, except of course for electrified railways and electric vehicles. At least theoretically, it is relatively easy to convert the above mentioned primary materials (e.g., gas) to methanol on the spot, and introduce methanol into the market using the existing car-stock. Moreover, because methanol can be obtained from a broad spectrum of energy sources, it would be possible to introduce this new fuel gradually.[58] A mixture of gasoline and methanol can, with small modifications, fuel existing cars. Pure methanol can fire Otto-cycle engines following somewhat more extensive changes. Nevertheless, any program for methanol utilization must include a demonstration of the practicality of its end-use in vehicles under Canadian conditions.

From an environmental point of view, methanol appears to be a preferred fuel. By using methanol as an additive to gasoline, the tetraethyl lead could be dispensed with and other emissions from cars could be considerably reduced. Eventually, in the very long term, by using fuel cells, which are very clean, powered by methanol, low overall levels of emissions could be achieved.

In addition, methanol could play a role in the storage and the important linkages of the energy systems of the future. Thus, since storage of hydrogen produced during periods of low electricity use would be relatively expensive, the hydrogen and oxygen derived from water electrolysis could be directed to methanol production. Consequently, at least conceptually, hydro, wind and perhaps solar energy could be connected to the energy system in the form of methanol.

An important consideration is the high loss of conversion from primary sources to methanol. Primarily because of the large losses which occur in the conversion from biomass to methanol, firewood, where appropriate, has advantages.*

So far, methanol has been produced in practical quantities, only from natural gas and coal. The conversion efficiencies are of the order of 55 and 45 per cent, respectively. By more efficient recovery of heat, 65-68 per cent levels could be achieved realistically. Methanol has not been produced from wood and organic

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*Apparently, lack of installed, small-scale equipment for burning wood "directly" instead of gas and oil is a principal barrier to an important natural substitution.

residues in any consequential quantities; however, since these primary materials can be gasified (as discussed briefly in the previous section) no unsurmountable problems are expected. In relative terms, because of very low sulphur content, the catalysts used in methanol conversion from biomass should be more effective. The conversion efficiency, however, on the average is a low 35 per cent and it is particularly sensitive to the size of the plant and the degree of heat recovery. Unlike the gasification of wood and residues which may remain effective on a smaller scale, the production of methanol would have to rely on advantages of a larger scale conversion which in turn would require a longer radius of gathering and transportation of wood and residues. This latter aspect could be defeating in terms of both costs and net energy. (An alternative for bypassing the losses in converting wood to methanol, advanced more recently, would be the direct use of wood powder in diesel engines.)

The need for the introduction of a new energy fuel, as a substitute for gasoline in the transportation sector, has been emphasized throughout this Report. Although there are no absolute transport restrictions for biomass, the cost of transportation is higher than for oil, and probably most hydrocarbons, and will therefore determine to a large extent the pattern of biomass distribution.[59] Because of relatively large quantities of conventional oil, heavy oils, and oil sands in Canada, gasoline from these feedstocks will be preferred for some time. Moreover, Canada's large resources of natural gas would indicate an increased distribution and use of natural gas liquids. Synthetic liquids from coal would further postpone the use of methanol. Liquefaction of wood by a process similar to liquefaction of coal, is a far more efficient process but is not yet ready for commercial development.

Yet, in the long-term, several factors appear to favour methanol: it is liquid, it can be introduced in an evolutionary manner into the existing transport system, and it can be stored. When methanol's time will come and exactly how is difficult to visualize. Very probably, if methanol's adoption is to be realized, it will precede hydrogen which would demand a net departure from the existing technology and therefore would result in a less gradual and easier changeover. Hydrogen, however, being a high quality fuel, results in lighter losses in transformations from electricity to storage and again to either electricity or fuels via electrolysis of water and utilization of fuel cells. Thus, it is premature to write-off hydrogen's long-term future. In fact, ERDA has already programmed the demonstration of relatively large, first and second generation fuel cells before the end of the 1990s.

Why, then, not proceed immediately with the introduction of methanol? A preliminary overview of methanol in Ontario concluded that it may have a role to play as a transportation fuel; however, the timing, raw materials availability, and economics, as well as specific production technology – although the hydrogenation process was singled out with some optimism more recently – remain unclear.[60]

The Advisory Group on Synthetic Liquid Fuels of the Ontario Ministry of Energy examined the opportunities available for alternative liquid fuels and, in a comprehensive seven volume report made important recommendations for Ontario which may be interpreted briefly as follows:[61]

(a) Economics will not justify the use of wood and municipal garbage as a resource for liquid fuel production, possibly for many years; say until crude oil reached about $45 per barrel.[62]
(b) The most efficient means of producing energy from wood and municipal waste is to burn them directly in thermal power plants, and not to convert them to alternative liquid fuels.
(c) The significant R, D & D program required for the production of methanol from biomass cannot be recommended at this time because of the significantly lower cost availability of other fuel sources.

(d) Because of the necessary long lead times for resource and technology development, liquid fuels from renewable feedstocks would not be a reasonable substitute in Ontario if a crude oil shortage were to occur in the 1980s.
(e) It would be more cost-effective in Canada to develop fully conventional crude oil, heavy oils and oil sands to their potential, rather than make major investments in the production of synthetic liquid fuels from biomass.
(f) On the basis of relative costs of production, distribution and automotive utilization, and efficiency, straight methanol appears to offer the best potential for synthetic liquid fuels; followed by gasoline produced from methanol, methanol blended with gasoline and ethanol.
(g) The study concluded that it is premature at the present time to select which synthetic liquid fuel will ultimately be the most economical choice beginning several decades from now.

Although there are differences in current evaluations (e.g., Ontario's Advisory Group on Synthetic Liquid Fuels vs. InterGroup Consulting Economists Limited of Winnipeg)[63] it is possible that in the presence of a differential cost increase of crude oil of 5-10 per cent, the difference in years between the times at which methanol would become price-competitive is less than 3-5 years. Assuming a substantial increase in the price of oil in the future (which is possible if not probable) production of methanol from biomass could become a realistic proposition in the period 1990-2005, at least on a regional basis (i.e., based on the concept of "niche" for straight methanol harboured by high gasoline transportation costs into the region).

Undoubtedly the topic of biomass is highly controversial and methanol seems to be at the centre.

In addition to price, there is the question of size of resources. Some experts see in biomass, at least a partial solution for energy and chemical supply problems; others point to potential competition and conflict with essential applications, and tend to favour the use of biomass to produce construction materials, fibres, chemicals and food, rather than energy. Independent of this concern, the emphasis seems to be placed on forest products and residues rather than on agricultural products and wastes. More specifically, the potential for biomass energy conversion from energy farming and residues, is perceived as limited because of constraints of land and possibly water resources. Comparatively, somewhat greater contributions are possible through agriculture and especially forestry. On a net energy basis, however, the situation appears more complex and less hopeful.

On the basis of these rather sobering observations, the demonstrations for generating liquid fuels from forest products require special formulation:
(a) Canada cannot ignore the potential of "methanol-from-any-source" and the amount of research being conducted internationally on production and use of methanol - and ethanol - fuels. Any related technological breakthroughs and engineering programs which may be mounted abroad and could bring the prospects nearer to practicality should be followed closely. Indeed, Canada has already signed a first IEA cooperative research and development agreement in the biomass area which includes the joint planning of national programs of participation countries in forestry energy, i.e., the use of short-rotation forestry biomass and forestry residues to produce clean fuels, petrochemical substitutes and other energy-intensive products. Centres of gravity established regionally would enhance the integration of these and other international developments into domestic conditions.

(b) In Canada, a broadly-based, extensive R & D program is recommended as being both desirable and necessary because of the long-term role which an energy system based on domestic renewable resources could play, and because of the uncertainty surrounding specific preferred paths of development. A comprehensive feasibility study of generating liquid fuels from forest and agricultural residues and products is required first.

(c) R & D into biomass yields, gathering, production and transportation is needed to provide a sound data base for decisions, inclusive of a better definition and determination of costs. Elements of this phase of the program would be:

1. Forest and agricultural resources evaluation.
2. Establishment of maximum transportation distances based on zero net energy (e.g., radius of potential operations).
3. Survey of existing forest and agricultural biomass energy conversion techniques.
4. Energy analysis of inputs for growing, gathering, harvesting, and processing forest and agricultural biomass, and of outputs of potential energy, e.g., conversion efficiencies and useable energy.
5. Considerations of conversion plant sizes and sites.
6. Economic analysis of the integrated generation operations necessary for delivery of useable liquid fuels.
7. Identification of major energy consuming and cost deteriorating operations necessary for obtaining energy from biomass in the form of liquid fuels.

(d) Any demonstrations of production or utilization of liquid fuels should be programmed on the basis of feed-back obtained from intervening R & D. In any case, but mainly dependent upon regional circumstances, major demonstrations beyond the pilot plant stage should not be undertaken lightly in order to avoid sinking large funds in a technology which might not be commercialized upon completion of such demonstrations because of economic reasons.

(e) An expanded "liquids-from-biomass" base R & D program should be conducted to support a conceptual conversion effort and eventually to provide information needed to proceed with a commercial methanol-from-biomass demonstration in the period 1900-2005. This phase may include:

1. Conduct of R & D culminating in a design formulation for improved and region-sensitive pilot-plant projects with a re-evaluation of the state-of-the-art and action recommendations report before the end of 1983.
2. Testing and completion of components and activities which are necessary to support a pilot-size program beginning in 1985.

Moreover, the proposed program would not be complete unless a comprehensive economic evaluation and commercial assessment is produced early in the 1990s. This evaluation, however, must consider applicable policies for exploitation of domestic resources, security of supply and broadening Canada's energy options, employment opportunities, and regional development.

3. *Evaluation of ethanol potential:* Ethanol in the long term could perhaps become a credible alternative to methanol. For some time now, countries such as Brazil have produced ethanol for fuel from sugar-cane, manioc, babassu, sorghum, and other raw materials. Ethanol offers a significantly greater overall efficiency and, of course, higher specific fuel value than methanol. Cars and trucks appear to run "zippily" without substantial engine modifications when ethanol is mixed 20:80 with gasoline and 50:50 with diesel. Moreover, ethanol appears to present fewer difficulties when used in retrofitted diesel engines. Ethanol is derived from plants by the fermentation of sugar which in turn can be obtained either directly from a source such as sugar cane and molasses, or indirectly – and for Canada more importantly – by the hydrolysis of starch and cellulose. Alternative crops would

require careful evaluation in Canada's climate to establish their technological and economic viability as feedstocks. In terms of priorities, we wish to identify: (a) development of harvesting methods and (b) adaptation of continuous fermentation process to specific Canadian conditions. Even if competitive, the potential of ethanol in Canada is expected to represent rather a small fraction of requirements. Studies, assessments and, possibly, pilot tests will require several years of planned government and industry activities.

4. Generation of biogas: A continuing demonstration program must focus on the timely development of innovative, flexible, full-scale, "northern country" plant and animal wastes digester systems. A state-of-the-art survey of biogas generation should be undertaken to define the relevant process parameters in a cold climate, and success stories – identifying advantages, problems and solutions for each case – should be disseminated among potential users. Some critical design parameters are: dilution requirements, loading rates, retention times and associated digester volumes. Before expanding the hardware demonstration program, however, the effort should be focussed on several areas of pressing need for more fundamental preparatory studies, including: (1) determination of heat balances surrounding the biological reactions, particularly the anaerobic processes which are heat sensitive; (2) micro-biological work to breed productive bacterial strains, and (3) system studies on heat conservation by integrating waste heat recovery with biomass digestion. The research at the University of Manitoba on pig manure should be refocussed and extended accordingly.

Level of Effort

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"The Pulp and Paper Research Institute of Canada (PPRIC) has conducted a detailed analysis of the cost of producing methanol as a bulk chemical from wood and bark wastes in various locations across Canada. Their production costs estimates (including raw material, marketing, transportation and tariffs) ranged from a low of $115 per ton for a 1004 ton per day plant in Thunder Bay at a capital cost of $65 million to a high of $145 per ton for a 398 tons per day plant in Kamloops at a capital cost of $35 million."

2. Exploratory Calculations

(a) *Resource Evaluation and Feasibility Studies*

Forestry:

8 studies at $245 000 each, equal: $1 960 000

Agriculture:
8 studies at $185 000 each, equal: $1 480 000

Total: $3 440 000

(b) *Pilot Tests or Upgrading of Existing Plant and Equipment*
Forestry:
4 projects at $265 000 each, equal: $1 060 000

Agriculture:
4 projects at $105 000 each, equal: $420 000

Total: $1 480 000

(c) *Demonstrations*
Forestry:
2 demonstrations at $50 000 000 each, equal: $100 000 000

Assuming grants at the 35 per cent level, the demonstration applicable cost is:
$35 000 000

Agriculture:
8 demonstrations at $300 000 each, equal: $2 400 000

Assuming grants at the 50 per cent level, the demonstration applicable cost is :
$1 200 000

Total: $36 200 000

(d) *Utilization Activity and Marketing*
$1 225 000

Grand Total: $37 425 000

Time Frame

An illustrative envelope over all funding anticipated for the feasibility study and evaluation of the "pros" and "cons" of generating gaseous and eventually liquid fuels from wood and agricultural wastes is as follows:

1979	$ 615 000	—	Continued resource evaluation and broad
1980	850 000		feasibility studies involving R & D
1981	1 250 000		
1982	735 000	—	Continued R & D, modification of existing
1983	500 000		systems, testing of new components and
1984	1 650 000		design of pilot tests
1985	4 000 000	—	Pilot test program inclusive of evaluation
1986	7 450 000		of several conversion processes
1987	8 500 000		
1988	6 800 000		
1989	3 225 000		
1990	1 400 000	—	Appraisal of pilot tests and dissemination
1991	450 000		of results to industry.
Total:	$37 425 000		

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2. The Demonstration of Solar Water and Space Heating Systems

Many issues and questions remain unresolved concerning the industrial, economic, legal and social *feasibility*, and the consequences for the *large-scale implementation* of "active" solar heating technology. A demonstration program is proposed for both solar domestic water heating and solar space heating. Solar cooling is not specifically addressed, but is not ignored. Moreover, the fact that we concentrate in this Report on "active" solar systems should not be construed as a negation in any way of "passive" solar technology. Quite the contrary, passive solar energy designs, together with effective energy conservation measures, do precede and supplement "active" systems naturally and to a point improve their economics significantly.*

Characteristics of Demonstrations

Only "demonstrations" performed under realistic conditions, and of a sufficient magnitude, will be able to truly dispel the many uncertainties concerning solar heating. Proof is required to show how rows of buildings can be heated by solar energy. A realistic demonstration should contain at least one entire housing development equipped with solar space and water heating, and heat storage (e.g., several apartment blocks including ordinary dwellings and high rises; a typical neighbourhood; a "quarter" of a city).

Within the overall framework of an effective group of demonstrations, it is proposed that: (a) individual demonstration projects be undertaken on the scale of hundreds — if not thousands — of homes and buildings; (b) up to three full-scale "coherent" demonstrations be undertaken sequentially in representative human habitats and city environments. These demonstrations might be carried out in conjunction with the development of new boroughs or townships and the redevelopment of city cores. Early tests should be designed to evaluate concepts of centralized heating plants and neighbourhood systems which would supply warm water and heat to some 50-100 households or homes. Solar energy for remote communities and village developments should also be considered and appraised.

The "final" approach, avenue, or path to solar heating and cooling is by no means determined at this time. Demonstrations must be phased out properly to incorporate feedback information and improve the learning curve. Substantial modifications to both size and type of demonstration are highly probable. Thus, a 50-100 household unit may well demonstrate uneconomic solar heating while a 500-1000 household project could prove economical under 1980 conditions. Even mutations in the overall approach are not unthinkable.

In urban physical environments, land use control regulations become critically important in connection with the introduction of solar heating technology.** Some retrofitting of older homes and buildings should be incorporated into such a demonstrations program to obtain more definite information on this controversial aspect.

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*Reference is made to the excellent presentations at the UN, ECE, Seminar on the Impact of Energy Considerations on the Planning and Development of Human Settlements, Ottawa, 3-14 October 1977; see (i) C.I. Jackson, *Canada Human Settlements and Energy*, 62 p. (ii) *Habitat and Energy in Canada*, National monography prepared by the Canadian delegation, 101 p.

**School of Urban and Regional Planning, University of Waterloo, Solar Energy Research Project 1977, Preliminary Statement of Research Intentions.

Solar heating implemented on the scale proposed will provide the opportunity to compare competitive systems. Eventually, solar heating may be evaluated side-by-side with a city sector using mainly electric resistance heating and heat pumps, or a sector utilizing natural gas, and if possible in the future, a sector using co-generated heat. Alternatively, solar heating may be tested in groups of buildings interspersed almost at random throughout a city using a checkerboard plan for the distribution of oil, gas, or electric resistance heating.

Likewise, there should be an opportunity provided in the planning of demonstrations, to test heat pumps* in conjunction with solar systems for cooling.

The large scale of the demonstrations is crucial to a proper evaluation of the contribution of solar heating to the country's energy requirements. Because heating is vital to survival in Canada's cold climate, a solar heating system has to be assessed under rigorous conditions. Moreover, the complex network of required services, institutional policies (e.g., mortgaging, taxation and zoning), legal and social policies and issues, involved in such an endeavour will have to be monitored and assessed along with the technological performance.

Long-range planning of phased-in demonstrations will have to be accomplished interactively by a highly cooperative effort by many parties. University researchers would have to work together in a multidisciplinary environment with specialist architects, mechanical engineers, energy experts, and developers. City administrators and planners would have to work effectively with the construction industry, the manufacturing industry, and "specialist" lawyers. Representatives from all the trades involved could be invited to contribute and learn. It may be an opportunity to develop a uniquely Canadian showcase of technological and managerial cooperation.**

The Expected Contribution of Demonstrations

In brief, the reasons for comprehensive, multi-stage demonstrations are as follows:

- (a) To increase the level of knowledge of the application of solar heating technology and arrive at an understanding of the implications of technical and economic realities.
- (b) To set the necessary and exacting conditions for a valid evaluation of the problems of durability and reliability over a long period of time.
- (c) To ascertain the level of peak load demand from, and its cost to, any required supplementary utility.
- (d) To evaluate the economics of solar heating in the "real world."
- (e) To determine to what extent the desired rate of implementation of solar heating need be subsidized to maintain it as a reliable energy option.
- (f) To test various modules and associated systems in controlled conditions and recommend improved performance standards.

The matter of appropriate performance standards requires special attention both prior to and during the proposed program, since demonstrations may

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*The role of heat pumps in the Canadian context has yet to be determined although the technology is well known.

**John G. Douglas, *Strategy for the Development of a Canadian Solar Energy Industry*, A study prepared for the Science Council of Canada, October 1977, 47 p.

be viewed as a potential for developing useful standards. Standards are required both for materials and equipment, and servicing, in order to represent the minimum level of performance needed for commercial solar energy systems that are considered for purchase or lease. These standards must be set at levels which the "would-be users" consider necessary to accept and, eventually, promote further acquisition of solar installations. The standards must be determined and proved by actual measurements to be feasible. Both equipment and standards must be offered for public viewing and comment. Perhaps contractors, designated by EMR, should work with government agencies in an effort to muster the expertise necessary in developing the standards. The initial standards should be used and tested in all government-assisted demonstration projects. But they may have to be updated at frequent intervals during the overall multiphase demonstration program. Following the demonstrations, performance standards may become guidelines for combined industry-government requirements for solar "off the shelf" installations.

Test conditions and methods together with safety regulations must be carefully established for all categories of projects before each proposed demonstration phase, and periodically reviewed during the program. Since standards specify only minimum levels of performance, they do not represent the sole basis of acceptability of solar heating technology. Hence, it should be possible to specify various priorities for increased performance levels and additional considerations within and among the identified and designated categories of solar equipment to provide a sufficiently broad spectrum of options. Performance evaluation criteria may include user needs and preferences, reliability, maintainability, safety, capacity, warranties, costs, and other qualitative factors which may determine success and which, in addition, may be expected to be practicable.

In a technological sense, demonstrations can be instrumental in contributing to (i) improvement of solar system concepts; (ii) evaluation of the performance and aging of materials in actual operational solar energy systems; (iii) identification of technologies which are adequate or even specific to Canadian conditions; (iv) assessment of current adaptation capability of materials and equipment industry; (v) sizing-up of the additional industrial and structural capability required; (vi) identification and testing of initial standards in connection with planned "field" inspections; and, (vii) establishment of fabrication and installation standards and norms for both materials and components of solar energy systems.

Moreover, demonstrations are expected to greatly reduce the uncertainty related to the various cost estimates, economic evaluations, and financing formulae.

Solar energy is generally considered environmentally sound, however, demonstrations could find solutions to any undesirable impacts. Thus, solar heating technology as conceived today, raises serious questions of net energy, materials, and risks. Solar heating — as differentiated from passive solar — is now "parasitically" dependent on the mature and aging fossil fuels technology; requires vast amounts of materials for both energy capture and storage — which in turn require large quantities of high grade energy — and seems to utilize equipment and installations of a relatively short useful life. In addition, aesthetics or amenities of solar energy are a matter of some disagreement.

A well designed demonstration program should lead to the identification and evaluation of net social benefits of solar water and space heating in conjunction with the assessment of technical, economic, and environmental viability and sustainability.

In terms of institutional aspects, demonstrations are expected to identify and examine barriers, and clarify the role of the various systems and organizations (e.g., definition of reference systems such as electrical power grids and gas distribution networks; limits of jurisdictions of federal, provincial, and municipal governments; roles of existing designated instruments such as public utilities).

Finally, and most importantly, demonstrations should assist not only in the determination of potential energy supply but also in the forward assessment of the competitive environment and available markets.

Both *experimental demonstration projects* and *full-scale demonstrations* must expand research and development activities aimed at converting solar energy to actual practical use. Although solar energy technology might already be fairly well developed, there is still a great deal to do. The industrialization of solar energy is a challenge and opportunity for Canadian technologies and firms. Thus:

(a) Experimental demonstration projects, judiciously selected on an individual merit basis, should complete the test for feasibility of solar heating under diverse, but not adverse, Canadian conditions.
(b) Full-scale demonstration programs should evaluate the potential of solar heating nationwide under realistic conditions and ascertain the effects of widespread use on the financial structure of existing utilities.

Finally, it must be emphasized that only the full participation of interested developers can ensure success.

Role of Governments

Cooperation is required between governments and administrations at all levels; federal, provincial and municipal.

The federal government must orchestrate new legislation, regulations and standards that would create a favourable climate for *timely implementation* of solar energy. More specifically, governments must first determine their priorities in terms of desired solar energy contributions, adopt appropriate deployment rates and use disposable instruments, mechanisms and processes to encourage identified or designated Canadian firms (preferably small, dynamic, entrepreneurial companies) to develop solar technologies for northern conditions. Canada needs an industry which would place solar collectors and storage units on the market at an affordable price.

Moreover, other components of solar heating systems represent significant costs which must be also reduced. A strong government commitment would probably be needed initially to develop solar energy. This very commitment, if properly phased and communicated, should generate an equally strong commitment and investment of time and money from the manufacturing sector and the financial community.

Level of Effort

Reference Points

(a) Useful references are:
- K.G.T. Hollands and J.F. Orgill, *Potential for Solar Heating in Canada,* Report No. 77-1, University of Waterloo, Ontario, February 1977, 102 p.; source used in cost evaluations for solar space heating.

- K.G.T. Hollands and J.F. Orgill, *Continuation Study of the Potential for Solar Heating of Buildings in Canada,* Report No. 77-2, University of Waterloo Research Institute, Waterloo, Ontario, August 1977, 41 p.

- Roger M.R. Higgin, *Solar Heating for Buildings in Ontario,* Ontario Ministry of Energy, August 1976, 16 p.

- Thomas E. Lenchek, "Energy Expenditures in a Solar Heating System," *Alternative Sources of Energy,* June 1976, pp. 13-18.

- *Catalogue on Solar Energy Heating and Cooling Products,* Division of Solar Energy, ERDA in cooperation with the Department of Housing & Urban Development, Oak Ridge, Tennessee, October 1975, various paging.

- Robert Argue, *Catalogue of Solar Heating Products and Services in Canada,* Research Report 12, Office of Energy Conservation and Renewable Energy Resources Branch, EMR, Ottawa, February 1977, 112 p.

- F.C. Hooper, Communication of 28 November 1977, 2 p.; Source and in cost evaluations for solar water heating, distributions of projects among type of dwellings and levels of funding.

(b) "Inventory of Energy R & D; EMR, February 1977

Federal funding of solar energy R & D 1976-77: $1 641 000

(c) Total Federal Energy R & D Budgets 1976-78

Renewable 1976-77		Renewable 1977-78	
$M	%	$M	%
4.7	(3.5)	9.1	(6.6)

(d) Parliamentary Standing Committee on Natural Resources
In a session of the Parliamentary Standing Committee on Natural Resources (30-3-1977: p. 15:23) it was stated that in the 1978 federal government energy R & D program, some $1 million will be spent by the National Research Council for a program to assist Canadian industry to develop solar heating equipment.

(e) NRC Recent Annual Reports and Research News
NRC awarded 14 contracts totalling $229 000 for the design and installation of solar heating systems.

2. Exploratory Calculations

(a) *Research and Evaluation of Existing Techniques*
Before proceeding with demonstrations on a larger scale, several preparatory studies would be required, e.g.,:

- Multidisciplinary study of the possibility of solar heating in city cores. An important component would be to assess the feasibility of "retro-fitted" solar heating.

- A study of all parameters determining the cost-effectiveness of annual storage at the scale of a single family home. Both this storage technology[1] and type of habitation is important to Canada as a base-line reference.

- A study of liquid annual storage and designs being pioneered in Canada (e.g., utilization of anti-freeze and collector drainage systems).

- A study of the Canadian climate (e.g., extreme temperatures or humidity) on useful life of collectors.

- Continued study for the improvement of design methods in all cases but specifically pertaining to annual storage under favourable conditions.

- Study of the environmental cost of extracting and processing the metals, glass, and other materials used in the manufacture of solar collectors.

- Analysis of the energy required to produce the materials and to construct the plant and equipment necessary for implementation of solar heating. This study should assess the net dependence of solar heating technology on hydrocarbon and nuclear resources.[2]

Some 6-12 in-depth studies supported by laboratory research and pilot tests, as needed, each averaging about \$300 000 would require about:
\$3 000 000

(b) *Solar Heating Demonstration Projects*
Proposed individual solar heating demonstration projects are of two kinds:
(1) Solar water heating, and (2) Solar space heating.

At this point it is again emphasized that the scope of well disseminated individual demonstration projects is to appraise solar energy prospects in general, determine favourable conditions, and identify, define, and evaluate all geographic, seasonal and climatic factors pertinent to valid evaluation.

Solar Water Heating Demonstration Projects: Providing domestic hot water may be considered one of the most promising solar applications for early broad scale implementation in Canada. Both direct and indirect solar heating of water is considered. Domestic hot water systems are suitable for either retrofit or new installations. They exhibit high load factors and reflect good economics mainly because they are employed year round.

Consequently, the following program is proposed:

1. 1200 domestic hot water single family systems at \$1 500: \$1 800 000
40 per cent

2. 2300 domestic hot water, multi-family and commercial systems at \$800 per "family" served: \$1 840 000
40 per cent

3. 8 industrial facilities for process hot water generation, at \$115 000: \$920 000
20 per cent

In summary:
Total solar water heating demonstration projects:
3500 units*

*Rounded

Total costs for solar water heating systems:
$4 560 000
Unit cost: $1 300

Assuming a subsidy of 33 per cent of total costs of water heating systems, we arrive at a funding requirement of:
0.33 × 4 560 000 = $1 504 800
i.e., approximately $1 500 000*

Solar Space Heating Demonstration Projects: Since many parameters relevant to the realization of solar space heating systems are still subject to uncertainty, the current selective program of individual — and isolated — demonstration projects must be continued. As an illustration, assuming 6 types of buildings, 3 solar system designs, 2 designs of collectors of 3 fabrications, and some required redundancy for control purposes, it appears that a range of 200-300 projects is a minimum requirement. Assuming further that the average solar heating system costs $40 000 inclusive of monitoring, and that the demonstration applicable fraction is 33 per cent — since most units would be useful habitations — it follows that a minimum funding level for solar space heating demonstration projects would be approximately $4 000 000.

The following distribution over the various solar heating systems is proposed, together with total costs inclusive of maintenance and monitoring, as well as funding levels:

1. 50 single family space heating systems with liquid annual storage at $31 500: $1 575 000 (6 per cent)

2. 300 single family space heating systems with short-term storage at $13 500: $4 050 000 (16 per cent)

3. 295 single family space heating air systems with rock storage at $12 000:* $3 580 000 (14 per cent)

4. 120 multiple family units, apartments and town houses at $38 000: $4 560 000 (17 per cent)*

5. 25 hospital, school and public building space heating systems at $245 000: $6 125 000 (24 per cent)

6. 20 heating systems for commercial spaces, offices, stores, warehouses, factories, and agricultural applications at $300 000: $6 000 000 (23 per cent)

In summary:
Total solar space heating demonstration projects:
810 units
Total costs for solar space heating systems:
$25 890 000
Unit cost:
$31 963 or approximately $32 000*

*Rounded

Assuming a subsidy of 33 per cent of total costs of space heating systems, we obtain a funding requirement of:

0.33 × 25 890 000 =	$8 543 700
i.e., approximately	$8 500 000*

By way of summing up in respect to demonstration projects for both solar water heating and solar space heating, we note that the proposed program has the following key parameters:

- Total Systems: 4 320 units*
- Total Costs: $30 450 000
- Total Funding: $10 000 000
- Funding for water heating projects, percentage of total: 15 per cent
- Funding for space heating projects, percentage of total: 85 per cent

Finally, it is suggested that a significant portion of the funding for this demonstration scheme be fully committed by 1980 or 1981.

(c) *Solar Heating Full Scale Demonstrations*

A three-phase program of water and space heating demonstrations is envisaged, ultimately involving some 1800 units. Questions of both supply and demand must be addressed. Due to very high costs of demonstrations on one hand and expected substantial benefits from the associated learning process on the other, the program should be organized in 3 phases based on feedback obtained from the preceding phase. Consequently, only the first phase is considered and delineated at this time.

For illustrative purposes, the following unit and total costs, inclusive of maintenance and monitoring as well as representative mix or distribution, are assumed for the first phase of the full-scale demonstration program:

1. 1 shopping centre at $100 000 for service water heating and $1 600 000 for space heating: $1 700 000 (3.5 per cent)*

2. 4 hospitals, schools with living quarters or public buildings at $40 000 for service water heating and $420 000 for space heating: $460 000 (1 per cent)

3. 3 industrial facilities for process hot water generation at $230 000: $690 000 (1.5 per cent)

4. 10 warehouses or storehouses at $20 000 for service water heating and $3800 for space heating: $580 000 (1 per cent)

5. 35 single family dwellings at $1500 for domestic water heating and $12 900 for space heating using liquid collectors: $504 000 (1 per cent)

*Rounded

6. 50 single family dwellings at $1 500 for domestic water heating and $11 100 for space heating utilizing air collectors: $630 000; (1.5 per cent)

7. 100 single family dwellings at $1 500 for domestic water heating and $13 500 for space heating employing short-term storage: $1 500 000; (3 per cent)

8. 150 single family dwellings at $1 500 for domestic water heating and $31 500 for space heating with annual storage: $4 950 000; (10.5 per cent)

9. 250 multiplex dwellings and individual stores at $6400 for service water heating and $140 000 for space heating: $36 600 000; (77 per cent)

In summary:
Total units of first phase of full-scale demonstration program:
603 or approximately 600*

Total costs for solar heating systems and monitoring:
$47 614 000

Unit cost:
$78 962**

In respect to funding it must be realized that this is an area of development and demonstration on which much dependence may have to be placed when establishing important future energy policies. Assuming that funds requested for the full-scale demonstration represent 50 per cent of total costs of heating systems, we obtain:
0.5 × 47 614 000 = $23 807 000
i.e., approximately $24 000 000*

(d) *Assessment, Dissemination of Results, and Commercialization*
Assuming that the assessment and dissemination of results cost some 5 per cent of total, we obtain:
0.05 × 47 614 000 = $2 380 700
i.e., approximately $2 400 000*

Additionally, a sum of $1 000 000 is provided for the initial steps toward commercialization of successful solar heating techniques and proven equipment.
Total: $3 400 000
Grand Total: $40 400 000

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*Rounded
**Solar heating, as noted previously is a preferred technology for large buildings but the first costs of solar heating systems are higher than for alternative fossil fuel-fired systems even though they are fully amortized over the system lifetime — which may prove to be generous.

Time Frame

An illustrative profile of the funding distribution of a possible adequate *first phase* of an evolutionary demonstration of solar heating systems is as follows:

1979	$1 000 000	– Research and Evaluation of Existing Techniques
1980	3 250 000	– Demonstration Projects
1981	4 485 000	
1982	4 265 000	
1983	2 150 000	– Full-Scale Demonstration
1984	2 650 000	– First Phase
1985	3 850 000	
1986	7 670 000	
1987	5 760 000	
1988	1 920 000	
1989	900 000	– Assessment
1990	1 000 000	– Dissemination of Results and Commercialization
1991	1 000 000	
1992	500 000	
Total:	$40 400 000	

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Exploratory Calculations

1. Annual storage systems are suited for large installations rather than individual homes; Ref. Frank Hooper, "Large Scale Thermal Storage," *op. cit.*
2. Heinrich Mandel, "Construction costs of nuclear power stations, *Energy Policy*, March 1976, pp. 12-24.

3. The Demonstration of Energy Generation from Solid Wastes

This program deals with schemes for energy recovery from municipal solid waste (MSW). A notable illustration is the Ontario Government "watts from waste" project.* As the name implies, the energy generated is electricity. A different approach is taken for generating fuels. The fuel produced by the conversion of solid wastes and which can be utilized with some flexibility by industry, an electric utility, or also by groups of residential and commercial users, is referred to as refuse derived fuel (RDF).

Strategies for Economical Energy Generation

A set of observations and assumptions will provide the information needed to design demonstrations for generating energy from solid wastes.

Economic Directions and Difficulties

(a) As energy costs and "garbage" disposal costs rise, the trade-off might swing gradually in favour of energy recovery from solid wastes. Recent developments seem to confirm that solid wastes' contribution is not a major energy source but energy recovery from solid wastes as a by-product helps aleviate the primary problem – "getting rid of the garbage."

(b) As in the case of similar resource recovery schemes, the energy recovery systems using MSW are impeded by various difficulties such as:

- need to implement large facilities to exploit economies of scale (e.g., handling over 1000 tons per day produced by populations exceeding 500 000 people);
- jurisdictional conflicts in respect to both financing and operating shared facilities;
- marketing of energy products (e.g., steam, fuel) because of difficulties encountered with either (i) integrating heat generated from MSW with central heating and cooling systems undergoing significant seasonal variation, or (ii) matching delivery and quality characteristics of liquid or gaseous fuels presently used in industrial combustion systems.

(c) There appears to be substantial advantages in a decentralized approach to MSW (with a threshold of some 500 tons per day still applicable), in comparison with large regional plants for generating energy from solid waste.

(d) In the decentralized approach, using either an incinerator-boiler or pyrolysis-gasification system, an important constraint appears to be the capacity cost of combustion facilities (e.g., in excess of $30 000 per ton of daily capacity).

(e) The technology for steam generation utilizing solid wastes is well developed (e.g., plants in Montreal, Quebec City, Hamilton). The main thrust of R, D & D in this area must be in the direction of reducing capital costs by optimization of the interrelated sub-systems (e.g., deployment of processing and storage sites).

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*Ontario Ministry of the Environment literature prepared by Case Associates Limited of Toronto.

(f) The technology for producing direct fuel input from solid wastes for industrial process heating requires a more sophisticated system. Storage, handling and combustion facilities needed are not unlike those used for coal. The properties of solid wastes differ from locality-to-locality as well as from day-to-day creating conditions more difficult than in the case of forest residues and certain grades of coal. Separation at source and pre-treatment or benefaction processes would enhance the physical and fuel value parameters of solid wastes. Improved pyrolysis — gasification tecnology and wastes handling would offer significant benefits both in the case of installation of new facilities for generating fuels and modification of existing oil or gas fired units for generating steam.

Technological Directions and Operational Solutions

R, D & D in this area should be along the following lines:

(a) Close scrutiny of ongoing and extant research and development in the US and Europe;

(b) Improvement of separation, collection, transport, and storage systems by appropriate systems technology;

(c) Investigation of the possibility of reducing the use of plastic products; halogen contents in solid waste have a very corrosive effect on surfaces exposed to hot flue gases;

(d) Control of deposition of solids on heat transfer surfaces which is an important aspect; and

(e) Investigation of methods of removing small solid particles from gas streams.

On a broader scale, operations research (OR) and feasibility studies are necessary to assess particular needs and opportunities (e.g., determination of the amount of garbage the regional municipalities can provide). In the short term, incineration* and recovery of heat appears to be a most sensible disposal system. By sustained R, D & D, the entire energy generation system must be rendered economical in the context of sensibly varying conditions. The federal government should encourage the provinces and municipalities to construct demonstrations in the medium and large urban areas where they can best be used and appreciated by the public. Encouragement could be reinforced by technical expertise and partial funding. Rather than concentrating on full-blown large demonstrations initially, several processes and technical systems should be tested on an appropriate scale (e.g., pilot tests).

Level of Effort

1. Reference Points

(a) *Useful References are:*

- Environmental Protection Agency, *Using Solid Waste to Conserve Resources and to Create Energy,* Report released to Congress by the Comptroller General of the United States, 27 February 1975, Washington, DC, 69 p.

- *Pyrolysis (Urban Wastes) in Canada's Renewable Energy Resources: An Assessment of Potential,* Middleton Associates, Toronto, April 1976, pp. 113-117; also Municipal Wastes, pp. 165-166.

- "Fires burn brighter for solid wastes," *Chemical Week,* 26 January, p. 94.

*Among competitors are: on-grate, suspension-burning and fluidized-bed incinerators, and gasifiers using starved-air pyrolysis, pyrolysis by oxygen, or pyrolysis by electric-arc.

- "Garbage Power," *Forbes,* 1 May 1977, pp. 29-30.

(b) Evaluation, and Facility Design and Construction (Ref. NSF:RANN — Program Announcement May 1977)

Research Activity	$100 000
Management and Coordination	34 000
Utilization Activity	21 000
Total	$155 000

(c) Middleton Associates, *op. cit.*
Lifetime Cost of Plant and Operations: Fuel gas by pyrolysis of solid waste; say $43 000 000; Yearly cost: $2 200 000.

Plant to produce methanol from municipal solid wastes in Seattle: $50 000 000 or $3 300 000 per year.

2. Exploratory Calculations

(a) *Resource Evaluation Studies*
Research addressing:

- sources, volumes, types, compositions and characteristics of feed materials, and
- useful contributions toward future energy needs.

Coordination by 3 professionals and their staff over a period of 3 years:
3 × 3 × 3 × 37 000 = $999 000

(b) *Economic Viability Studies*
Statistical and economic efforts in order to determine parameters of economic solutions in defined situations.

Synthesis by 3 professionals over a period of 2 years:
3 × 2 × 37 000 = $222 000

(c) *Operations Research Studies*
Rigorous decision-analysis studies to optimize operations in specific economic cases.
A $65 000 per year program over 2 years:
2 × 65 000 = $130 000

(d) *R & D Program*
A program for the assessment of the development status of applicable technologies, oriented essentially toward adaptations suitable to the socio-political and geographical conditions in Canada. The impacts of the processes involved on the environment, operational linkages and economic spin-offs will be considered:

- Materials Research
- Combustion Research
- Emission Control
- Wastes Management

Total cost over a period of 3 years: $450 000

(e) *Demonstrations*
Development and implementation over a period of 5 years of a program of three demonstrations costing $75 000 000 each. Assuming government grants at the 25 per cent level, the total cost amounts to:
$56 250 000

(f) *Dissemination of Success Stories*

A promotion budget for dissemination of appropriate technology includes recommendations for government and institutional support of continued technological development: $ 430 000*

Grand Total $58 481 000

Time Frame

An illustrative time-table of a possible disbursement of funds necessary for the proposed demonstration of energy generation from solid wastes is as follows:

1979	$ 350 000	– Resource evaluation
1980	350 000	begins
1981	450 000	– Economic studies start
1982	175 000	– OR begins
1983	185 000	– Specific R & D commences
1984	185 000	
1985	10 100 000	– Demonstrations are initiated
1986	12 500 000	
1987	13 756 000	
1988	12 500 000	
1989	7 500 000	
1990	245 000	– Dissemination of results starts
1991	185 000	– Demonstration is completed
Total	$58 481 000	

Notes

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Conversion Technologies

1. The Demonstration of the Co-Generation of Electricity and Heat

Industry and utilities can generate electricity and steam together by — so to speak — raising the temperature and pressure of the "reject" steam from the power cycle to an appropriate condition, to make it useful to industrial processes or to commercial and residential heating systems.

Some technologists tend to assume that since hundreds of "co-generating units" have been supplied and installed without fanfare during the last 20 years, co-generation is "old-hat" technology. They cannot understand any "excitement" about such demonstrations. "If anyone wants co-generation, all he or she has to do is order the equipment," reflects a typical attitude. In accordance with our assessment, this orientation is based on an oversimplification and appears myopic. Consequently, to emphasize economic, entrepreneurial, managerial and institutional aspects we recommend the following direction.

The maximum potential benefit for Canadians from co-generation of electricity and heat could be realized through a concerted national program. Two important aspects to be addressed are: (1) Industrialization of co-generated electricity and heat, (2) Residential and commercial utilization of co-generated heat.

1. Industrial utilization

The first component of the proposed program focusses on industrial applications. The co-generation approach, based on the intelligent combination of existing techniques rather than on new R & D, must reconcile conflicting interests into an integrated and realistic pattern of planned technological complexity and sophisticated industrial economics. The choice of heat, power, and sources of energy must be matched not only to the immediate conditions, but the co-generation plant and equipment must be designed to meet dynamic circumstances.

The rapidly changing energy supply mix must be taken into account and linked with industry's pattern of future demand (e.g., ratio of heat to electricity and geographical long-term deployment of energy load centres). The decisions on co-generation of heat and electricity must tread a delicate path between the public interest and the interests of the various industries and electric utilities.

The problems are vast, multi-faceted and ill defined and we do not underestimate them, but long-term, continuous markets must be found and researched for the different products of the industries involved. The design must "look" at the complete spectrum of processes across industries to be integrated. Initial investments are huge (e.g., entire industrial parks). The compounded regulatory lag could be devastating. The coordination and the engineering management of construction and operations must control unneccessary expenses (e.g., interest costs for delayed plant construction). Financing, ownership, administrative, and operational matters involving co-generation of heat and electricity plants and equipment, and their relationship with existing and new developments must be studied and planned to a relatively high degree of detail. Intervening lead times are dissimilar. All factors involved in the selection of co-generation must be weighted against competitive forms of acquiring energy (e.g., buying electricity from utilities or self-production).

To assess all aspects of industrial co-generation on a realistic scale, we need to proceed with specially designed energy parks as early as possible.* Small-scale co-

*"CEC" Preliminary Study of the Planning Technology and Design for a Combined Energy Centre for the Province of Ontario, Study SD261, Faculty of Engineering, University of Waterloo, Winter 1978; also J.T. Rogers and M.C. Swinton, *Application of CANDU Reactors in Combined Purpose Power Plants, op. cit.*

generation in individual plants and involving specific processes, however, reflects the other extremity of the industrial spectrum and cannot be neglected (e.g., pulp and paper mills).

2. Residential and Commercial Utilization
Combined power and steam generation to provide hot water for district heating represents a "classic" application.

District heating is successful in several European countries with different social fabrics, and only to the extent that Canadian cities exhibit some similar weather and institutional characteristics, this technology might have application here in the future. Of course, this application would be affected by a large number of new policies, inclusive of those for the future development of thermal coal and nuclear power in Canada. District heating policy issues must be resolved and institutional roadblocks eliminated before the technology will find acceptance in Canada. Due to institutional barriers, the central cores of our cities containing large sections of apartment blocks do not have district heating. Mushrooming of district heating in our country, therefore, is improbable. But the stakes are high. The finiteness of Canada's oil and gas resources and the increasing dependence on expensive and unreliable imports make it mandatory for Canada to reduce consumption of oil and gas. Implementation of district heating would be a step in the right direction although it would take time to make a sizeable impact.

Directions in Co-Generation

(a) The concept of availability or energy is recommended for the identification of thermodynamic losses and economic optimization of complex energy processes on a rational basis.[1] For reference to information on illustrative analyses of energy processes and evaluations of the application of availability concepts to energy utilization problems, see note 2; demonstrations of the "use of low-grade waste heat", see note 3; and systematic analysis of energy "degradation" in a CANDU reactor unit, see note 4.

(b) Co-generation creates some difficulties for the electric power industry.[5] The producers, and more specifically the distributors of electrical energy are traditionally cautious about co-production because of required large capital costs and uneven load characteristics (e.g., little if any heating is required in summer).[6] The difficulties, however, to be experienced with the introduction of CANDU reactors for dual-purpose service, (i.e., electricity production and district heating, because of the flexibility characteristics of the extraction-condensing turbines to accelerate the growth of the derived nuclear contribution toward an economic optimum) may not be insurmountable.[7]

(c) Apparently in the US, although the move is toward increased electrification in industry to substitute primarily for natural gas, the trend away from self-generation continues.[8] It is generally assumed that in the US, inplant electric power generation has declined from 15 to 5 per cent of the total electric power generation during the period investigated.

(d) In West Germany, 29 per cent of total electricity is produced by industry. This situation offers enhanced opportunities for the implementation of co-production in integrated plants.

(e) There is considerable experience with co-generation in the USSR.[9] In that country 20 per cent of electrical and 30 per cent of thermal energy are "combined".[10]

(f) In Romania, one third of heat and more than one third of electricity are co-generated. The trend in co-generation is toward utilization of lignite, a marginal resource, which more recently assisted in the broadening of the country's energy supply options.[11]

(g) Implementation of combined production of heat and electricity in a progressive fashion is aided by use of heat storage plants in a building-block approach.[12]

(h) During a period of two decades of strategically planned co-production, the energy savings could amount to 25-27 per cent of a country's specific heating requirements and 10 per cent of its total electricity needs.[13]

(i) The general direction in industry is to implement co-generation together with fuel substitution and modernization of industrial equipment.

(j) Co-generation may be beneficial also in rural environments, but on a much smaller scale.[14] Typical examples of potential applications are grain and lumber driers, poultry farms and greenhouses.

(k) In order to cope with peak loads, the use of inexpensive heating boilers is recommended for about 50 per cent of the maximum thermal load. This arrangement permits steam from the turbines to cover 80-90 per cent of the annual heat consumpton.[15] Also, liquid waste discarded by oil refineries may be used to relieve peaking loads and provide stand-by heat supply.

An important element in the optimization of heating peak coverage, according to other technologists, is the use of electric hot water boilers or warm water accumulators.[16] A further solution to uneven load, albeit conventional is the use of standard electric power stations dedicated for peak load electric power.[17]

(l) A relatively frequent need seems to exist for only moderately large district heating and process steam base loads (e.g., in the range of 50-150 MW). Marginal bituminous materials may be used to fire local dual-purpose plants (e.g., coal, shales, oil sands).

(m) Large nuclear plants are presently considered to be suited to big customers alone.[18] Moreover, it is generally assumed that nuclear plants may be preferentially utilized for process steam requirements that can be fairly constant, and for base load demands in district heating.[19] Due to the flexibility of the extraction-turbines, however, their heat contribution may vary unexpectedly, and still remain economical.[20]

(n) Combined power generation and central heating plants are found only in a few Canadian localities (e.g., Inuvik).

(o) The successful utilization of relatively low-temperature hot water from CANDU nuclear generating stations will depend on the technology necessary to reduce costs of: (i) large-size transmission systems and (ii) large-scale facilities for hot water storage.[21]

(p) Currently, there are serious institutional barriers to co-generation and chances for rapid improvement are limited.[22] On a long-term basis, however, the prospects are encouraging. Institutional aspects are already being addressed by many organizations.[23]

Level of Effort

An analysis needs to be undertaken of the technical, economic, social, and legal aspects of "model district heating systems" for a number of Canadian urban centres. This analysis should indicate the conditions under which district heat service would be attractive to residential and commercial "would-be" consumers. An important consideration, involving both economic and regulatory aspects, is the allocation of costs among electricity and heat customers. It must be emphasized that problems of joint costs are complex and have often received only arbitrary solutions. To develop consumer confidence, 2-3 appropriate demonstrations would be necessary. The demonstrations must focus on several critical aspects:

(a) Development of a Canadian modular approach to "building-up" of district heating systems; design, testing and use of satellite systems in new developments.
(b) Initial use of small transportable units of up to about 10 MW (34 MBTU/hr).
(c) Exploitation of the flexibility characteristics of steam turbines and of early completion of dual-purpose stations to the fullest economically acceptable extent, or depending upon specific conditions, construction of strategically located permanent plants for combined production of electricity and heat when the load distribution system has been sufficiently built up.
(d) Rational growth of a combined generation system (e.g., how new customers are connected and generation capacity is extended).

Demonstrations would be particularly useful in determining the various institutional barriers as well as assessing the various possibilities for primary energy supply: from refuse incineration, industrial exothermic processes, nuclear plants, coal, or from scarce resources such as petroleum and natural gas. Since the capital costs for heat distribution systems are fairly high, demonstrations should be designed to test the feasibility of cost reductions.

More specifically, with respect to R, D & D in the area of district heating, two activities would require urgent attention:

1. Investigation of conversion of existing steam systems to hot water.
2. Amalgamation and rationalization of existing disjointed systems (e.g., seven district heating systems in downtown Toronto).

1. Reference Points

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2. Exploratory Calculations

(a) *Survey and Evaluation*

A "bottom up" approach is proposed to classify opportunities by type, size, and geographical location; package these opportunities; evaluate aggregate potentials; conduct cost-benefit analyses and attach priorities; identify beneficiaries and suggest lead organizations, and recommend level of grants by governments:

say 10 professionals and staff over a period of 3 years:

3 × 3* × 10 × 45 000 = $4 050 000

(b) *Implementation Strategy; Plans*

Studies are required of the means for implementing co-generation, e.g.:

- energy requirements and peak-load management analyses in Canadian industrial and residential environments;
- analyses of institutional barriers and investigation of efficiency of proposed solutions:

Staff:	$1 250 000
Computers:	$ 190 000
Consultants:	$ 760 000
Total:	$2 200 000

(c) *Industrial Applications of Co-Generation*

Say, 2 individual co-generation plants and equipment:

2 × 150 000 000 = $300 000 000

At the 20 per cent funding level, the demonstration applicable cost equals:

0.20 × 300 000 000 = $60 000 000

Say, 1 industrial park, first phase of development containing some 2-3 integrated units:

Total cost: $750 000 000

Using a 25 per cent level the demonstration applicable cost is:

0.25 × 750 000 000 = $187 500 000

Total industrial demonstrations:

$247 500 000

(d) *District Heating Applications of Co-Generation*

Say, 2 district heating systems at 33 per cent level funding:

0.33 × 66 × 300 000 = $21 879 000

(e) *Potential Users Information and Support for Co-Generation*

This activity may require dissemination of news of successful applications, technical assistance and proposals for inducements through costing and pricing practices:

$ 625 000

Grand Total:** $270 000 000

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*"Consultant's multiplier" to account for supporting staff salaries and office expenses.

**Rounded

3. Comments on Required Funding

In order to relate the size of funds with the benefits perceived we offer the following observations: Several assumptions (a) - (c) are made for the year 1985:

(a) *Electricity Contribution*
Electricity contribution will amount to 18.5 per cent of Canada's total secondary energy requirements.*

(b) *Secondary Energy Requirements*
Canada's total secondary energy requirements will be 8.8 quads.†

(c) *Unit Price of Crude Oil and Electricity*
Electricity will be about 2.3 times as costly as crude oil. Crude oil in Canada will approach international price and equal $25 per barrel.

(d) *Oil Equivalent Quantity of Secondary Electricity*
The following conversions for 1985 indicate:
0.185 × 8.8 or 1.628 quads of electricity equal 172 000 00 × 1.628
or
280 016 000 barrels of oil.

(e) *Cost of Secondary Electricity*
The cost of secondary electricity for 1985 calculated on the basis of crude oil unit cost — refinery losses considered for consistency purposes — will amount to:
2.3 × 25 × 280 016 000 = $16 100 920 000 say 16 000 000 000.

(f) Assuming further: that in a first order of approximation hydro's share will be 50 per cent; that two-thirds of the primary energy is wasted as heat in thermal electric plants, i.e., that approximately twice as much energy is wasted as is used; that co-production will save 10 per cent of the "nominal potential" of two-thirds of thermal electricity, and that the 1985 annual saving is representative of the average for the period 1979-1989, then the co-generation benefits equal:
0.50 × 0.10 × 2 × 16 000 000 000 × 10 = $16 000 000 000

(g) By applying a 2 per cent appropriation for R, D & D, to the benefits of co-generation earned solely over a finite period, we obtain a figure far exceeding the level of funding proposed:
0.02 × 16 000 000 = $320 000 000*

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*E.R. Stoian, Science Council, a forthcoming background study.
†Approximate figures.
**Rounded

Time Frame

An illustrative distribution of funds required for a relatively accelerated demonstration program of the co-generation of electricity and heat may take the following form:

Year	Current	Cumulative
1979	$ 900 000	$ 900 000
1980	1 700 000	2 600 000
1981	1 950 000	4 550 000
1982	1 250 000	5 800 000
1983	300 000	6 100 000
1984	87 500 000	93 600 000
1985	130 000 000	223 600 000
1986	45 800 000	269 400 000
1987	300 000	269 700 000
1988	180 000	269 800 000
1989	120 000	270 000 000

Total: $270 000 000

Notes

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