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Renewable Energy Perspectives for Canada

Part 1: Historical/Technical Overview

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Preface

This paper is a working document of the Office of Energy Research and Development, prepared for information and discussion purposes for the Task 4 Interdepartmental Renewable Energy R&D Committee of PERD.

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Table of Contents

List of Tables

Page

List of Figures

Page

RENEWABLE ENERGY PERSPECTIVE FOR CANADA

1. Introduction

Energy concerns have gone beyond the issue of secure petroleum reserves and now touch on issues of energy mix, long term environmental appropriateness and sustainable economic development. These issues are, in part, due to an increased recognition of depleting world resources of readily accessible and "inexpensive" fossil fuels, and the growing apprehension that continued widespread use of these fuels could result in major and possible irreversible climatic changes in our lifetime (ie. the problem of increasing CO_2, NO_x and other emissions from the combustion of fossil fuels).

In this context, renewable energy technologies are becoming more attractive. Not only do they appear to be more environmentally acceptable when managed properly than most existing technologies, but also the energy potential of these sources is enormous.

Through research and development, we are learning how to extract and concentrate these renewable energy resources so that they can be used to supplement our existing energy mix in an environmentally responsible fashion.

In Canada, efforts to develop and commercialize renewable energy technologies (RETs) have been underway for about 15 years. The focus for this effort has been through the research and development activities of the Panel on Energy R&D (PERD), supplementary R&D efforts through federal department A-base budgets, provincial R&D and promotional programs and an initial federal attempt to stimulate industrial activity by the use of grant programs.

Canadian efforts to date have produced a fragile and fragmented renewable energy industry which requires nurturing at the most basic levels. It is now time to appraise what we have accomplished in renewables, assess what is required to maintain this option and protect past investments, and examine what the opportunities might be for renewable energy in Canada's future energy supply and demand picture.

2. Scope

The purpose of this paper (Part 1) is to pull together historical and current resource material to produce a concise and accurate reflection of the efforts undertaken to develop renewable energy technologies in Canada. It is expected to provide background information and be the anchor to a following discussion paper (Part 2) whose purpose is to provide a **credible and objective** view regarding the future prospects for renewable energy technologies in Canada. In one sentence, this discussion paper (Part 2) will attempt to address the question:

> "what role can RETs play in addressing national (federal policy) objectives over the course of the next twenty years and what should the federal (R&D) role be in preparing for the future"?

It is hoped that together, these papers will provide a basis for debate and deliberation on the future directions Canada might take with renewable energy technologies and policies.

3. Objective

This paper, (Part 1: Historical/Technical Overview), will encompass renewable energy technologies developed and applied in Canada, and will:

- review the historical development and current "state of the art" of renewable energy technologies domestically and internationally;
- review past Canadian government activities and initiatives to develop and commercialize these technologies; and
- identify key technical successes and achievements leading to the development of world class technologies in Canada.

4. Historical Background

4.1 Characterisation of Renewables

Renewable energy can be derived from natural resources related to the solar cycle which are either inexhaustible or replenishable. Renewable energy sources, including solar, wind, water, geothermal and biomass resources, can be converted into useable energy through a technology "bridge" designed to make energy available to an end user in a convenient form to satisfy a particular energy requirement such as space heat, hot water, motive power, process heat, etc.

At this point in time, characterization of the nature, quantity and distribution of the various renewable energy resources in Canada, such as solar flux, wind intensity, biomass availability, small-hydro sites, geothermal occurrences and peat inventory, is essentially complete.

No Geoth Hydro Bio !!

In certain respects, renewable energy sources and many of the technologies developed to deliver them are environmentally benign in comparison to oil, gas and nuclear energy sources and technologies. This is not to suggest however, that they may not have any environmental impacts.

The renewable energy technology (RET) areas of traditional and/or present interest and support in Canada include: hydraulics, active solar, passive solar, photovoltaics, bioenergy, wind and geothermal.

EE or AE? Here, in my view, but EAETB

4.2 Historical RETs Evolution in Canada[1]

Renewable energy resources are diffuse by nature. In Canada, a relatively young country, we have a dispersed population on a continental landmass encompassing diverse geographic regions. As a result of this geography, our endowment of these resources is immense in comparison to other countries. Ironically, all these "positive" factors tend only to handicap Canada's ability to develop and use these special resources. In comparison to many, if not most of the western economies, we have too many choices to make (as to which resource area to focus on), we do not have a large enough domestic market base in which to develop these technologies and hence must rely on export markets, and finally, our small, dispersed population has not, nor perhaps can afford, the larger well developed energy infrastructure into which RETs could be integrated. However, this has not always been the case.

wood

Renewable resources (almost entirely biomass) have historically played a prominent energy supply role, satisfying almost all of Canada's energy needs during the 1800's. Beginning in the late 1800's wood was gradually replaced by coal, until the 1920's when the contribution from wood had fallen to 15 percent of total primary energy demand (TPED). Over the 1930-1970 period, the contribution from wood continued to fall, reaching the 4 percent level in 1975 as low cost supplies of oil, and later natural gas, became available.

This decline in the wood component of renewable energy was partially offset as hydroelectricity in centrally planned electricity systems began to gain prominence, rising from about 1 percent in the early 1900's to the current 12 percent of total primary energy demand. By the early 1970's, renewable energy (other than large scale hydroelectricity) had lapsed into almost complete disuse, except for a small amount of biomass derived fuel used by the pulp and paper industry and that used for residential heating. At the same time, petroleum products accounted for more than 50 percent of TPED. An abundance of low cost conventional energy was the norm then and essentially continues to prevail today.

Public and political awareness of the problems associated with increased dependence on non-renewable petroleum resources was dramatically heightened with the OPEC oil embargo in late 1973. This oil "price shock" clearly demonstrated the adverse effects of inflexible energy system planning and precipitated major changes in the energy policies of Western industrialized countries. These countries, including Canada, responded by collaborating in the International Energy Agency (IEA) and shifting their energy policies to include a broader range of technical options which could enhance their energy security. These options included (and still do) investing in energy R&D to find and develop alternative sources of energy, and developing programs aimed at achieving efficiencies in the use of energy.

Effort on renewable energy technologies was initiated during the mid-1970's with considerable expectations for the potential role of renewable sources. In Canada, the complete lack of available technology and necessary support infrastructure dictated an initial focus on technology R&D, followed by infrastructure and market development efforts.

Over the last decade and a half, the federal government implemented some fifteen separate programs, including R&D initiatives, in the renewable energy area. Some of these programs have involved joint federal/provincial delivery or have been carried out in concert with energy conservation programs. In the main, however, most programs have been targeted to specific renewable energy technologies. The development of new technology, stimulation of industrial infrastructure and capability, and market development have been and remain dominant themes in the current overall program strategy.

In 1975, federal support for renewables R&D was initiated through a broad energy program, managed by the interdepartmental Panel on Energy R&D, with the National Research Council (NRC) playing the role of lead agency for the R&D work. Then, in 1977, Energy, Mines and Resources (EMR) created a formal renewable energy policy function which led to the 1978 announcement of a major five year program initiative with funds of $380 million allocated to the PASEM (Program of Assistance to Solar Equipment Manufacturers), PUSH (Purchase and Use of Solar Heating), FIRE (Forestry Industry Renewable Energy), and CREDA (Conservation and Renewable Energy Demonstration Agreements) programs. The focus of these programs was to stimulate industrial and product development and demonstration to assist the commercialization of conservation and renewable energy equipment and systems.

In 1980, the National Energy Program (NEP) was announced. The NEP provided major incentive programs (e.g. COSP - Canada Oil Substitution Program) designed to reduce Canada's dependence on oil products, but including initiatives in other areas (e.g. RCDP - Remote Communities Demonstration Program, SDHW - Solar Domestic Hot Water program) as well. At the same time in the early 1980s, the Government of Canada's Energy R&D Program had evolved to include the four principal objectives of:

a) using energy efficiently;
b) developing indigenous resources;
c) diversifying the energy economy to be less reliant on oil;
d) developing long-term alternate energy sources.

As part of the NEP, federal funding for energy R&D (including renewable energy) was increased substantially. Also in 1980, an accelerated capital cost allowance became available to certain renewable energy equipment through the Class 34 provisions in Schedule II of the Income Tax Act. This accelerated capital cost allowance can substantially increase project returns.

In 1983, the Solar Demonstration Program was announced as a replacement for the PUSH program. The program design included the use of declining grants to drive down system costs and focused on developing private sector markets. In the same year ENERDEMO was announced as a federal energy technology demonstration program to replace the CREDAs.

In 1984, as part of a federal deficit reduction plan, NRC's Division of Energy, the lead federal renewables R&D agency, was eliminated. The lead role was then picked up by EMR where, in 1985, the National Conservation and Alternative Energy Initiative (NCAEI) was announced. NCAEI was the transition from the high cost NEP granting programs to less costly but more integrated research, development, and demonstration efforts. It had a termination date and was wound up in March 1990.

Just prior the NCAEI wind-down, the Energy, Efficiency and Diversity initiative was instituted in April 1989, which completed the transition from the NEP program to a more market based approach to technology development. As a result of the wind-down of certain NCAEI programs, demonstration activities and the regional office structure were terminated.

The remaining renewables effort has been recently reorganized (Fall 1989) into the Canada Centre for Mineral and Energy Technology (CANMET) of EMR. A greater emphasis on partnership efforts with industrial partners is part of the new philosophy, with specific cost-sharing and cost-recovery objectives. About the same time, the Energy Diversification Research Laboratory (EDRL) in Varennes, Québec, a laboratory of CANMET, was announced. It will undertake, initially, some effort in photovoltaics R&D.

The federal renewable energy R&D effort is now primarily funded through PERD with some "in-kind" contribution (principally O&M, salaries and person-years (PYs)) from the remaining departmental participants (EMR, Forestry Canada (FC) and Environment Canada (EC)).

From the onset of the federal government's interest in this area, the principal method of undertaking R&D has been through contracting out. Though the work has been directed by scientists from federal laboratories, in fact, only a small percentage of R&D has ever been actually undertaken in government laboratories. This reflects both the lack of human resources available to be dedicated to this task (with the exception of the fiscal years 1981-86, see Tables 7 and 10) as well as the lack (initially) of expertise in these respective technology fields.

Over the course of the years, other participants have been involved in the RETs area, principally the provincial governments, many of which, in the earlier years, undertook modest R&D efforts in those technology areas felt most appropriate to their regional/economic concerns. Their greatest contributions though, have been through demonstration and encouragement programs many of which were in partnership with federal demonstration activities. Their present activity level in this area is very low, if not non-existent. However, many provincial energy boards and utilities are now re-examining their policy support for these technologies and some have even instituted buy-back policies and rates for independent power producers for which the renewable energy technologies can compete.

During the late 70's and early 80's, energy R&D was considered a priority area for the Natural Sciences and Engineering Research Council (NSERC). It undertook to support some of the more fundamental renewables R&D through its Strategic Grants program to the universities. Today, energy R&D is not a priority; hence, it must compete with all the other R&D demands received by NSERC.

Many Canadian universities have been involved in the RETs areas in the past and many still are today though their roles have evolved. In earlier years, they provided some of the "horsepower" to pursue the fundamental R&D needed to develop these technologies. Their funding came from NSERC and from the federal/provincial governments.

Today, there are fewer university participants[2] and those who remain are mostly supported as centres of expertise in special areas of fundamental work for RETs by the federal government. As well, their role is now more of a catalyst in helping a fledgling industry develop their products and services on a sound scientific footing.

4.3 Current Federal Renewable Energy Program[3]

As the situation stands presently, Task 4 of PERD is the sole federal program with the specific goal of supporting efforts in renewables. The principal objective of this renewable energy R&D program is:

> *to encourage the development of science and technology to exploit biomass, solar, wind and other renewable energy resources.*

Currently and more specifically, each technology program's formal objectives are:

Hydraulics:	To develop design methods and guidelines for advancing hydraulic technologies, particularly low head/small scale hydro;
Active Solar:	To develop active solar energy technologies to the point where they are commercially competitive with other, more traditional energy forms;

Passive Solar: To increase and optimize the passive solar energy contribution to the energy load of buildings;

Photovoltaics: To develop photovoltaics technology to the point where it is commercially competitive with other, more traditional energy forms, particularly for applications where other feasible energy sources are economically or environmentally expensive;

Bioenergy: To develop bioenergy technologies (in production, combustion, anaerobic digestion, preparation, handling, pretreatment and conversion) which are capable of providing a growing and sustainable contribution to an environmentally acceptable renewable energy supply;

Wind: To establish a technology base for cost effective wind energy technologies as an energy supply alternative;

Geothermal: To assess the technical and economic feasibility of this resource in various regions of Canada and provide support for ground source energy extraction systems and technology/engineering development. (**Note:** It has been recently decided to stop efforts in this area of work)

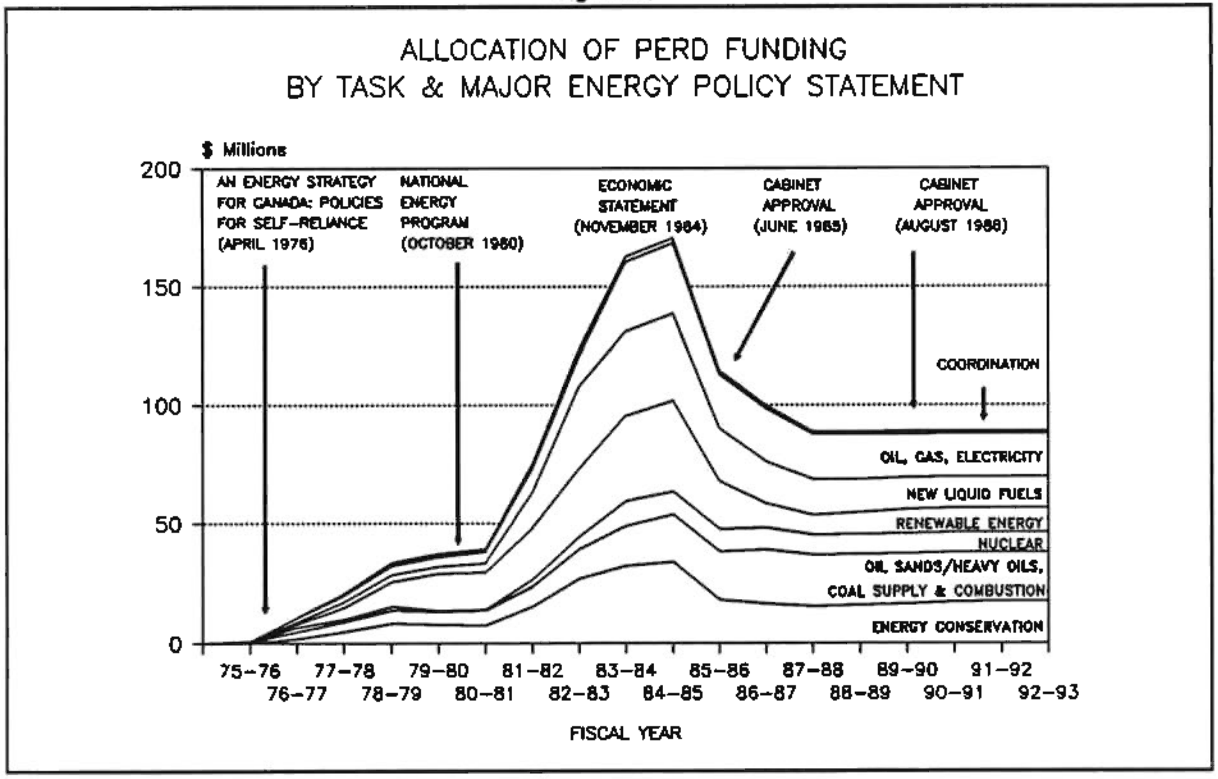
That portion of the Task directed to the short term emphasises efforts with Canadian companies in technology transfer and the encouragement of developing and undertaking industrial opportunities, be they in domestic or international markets. The Program encourages the development and export of technologies and products to buyers in countries that are burdened with more expensive energy than Canada. In the course of this activity, Canadian firms can develop their technologies and lower their production costs. This should have the desirable result of narrowing the cost disadvantage that renewable energy suffers when compared with its conventional competition in Canada.

About 75% of the Task's R&D is contracted out to private industry and universities, the latter having a longer-term R&D orientation.

4.4 Expenditures

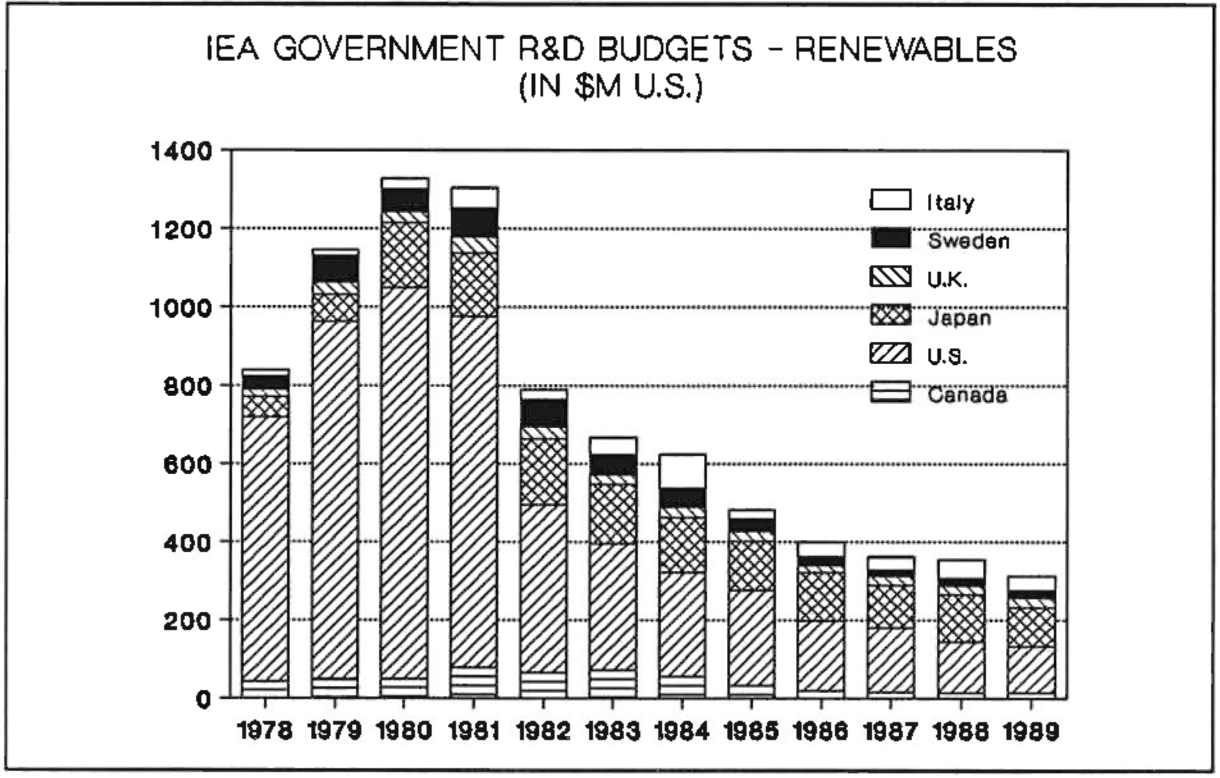
The Interdepartmental Panel on Energy Research and Development came into existence in 1975/76 in response to a recognition that energy R&D could play an important role in addressing the need to reduce Canadian dependence on fossil fuels, particularly oil, and improving national energy security (in response to disruptions in international oil markets). The Program has supported a coordinated federal R&D effort in all energy technologies with the exception of nuclear fission. Figure 1 graphically describes historical program expenditures.

Figure 1



In the international context, support for renewables R,D&D in Canada was notable eight to ten years ago in comparison to other IEA member countries, being roughly comparable to the respective efforts of Sweden, the United Kingdom and Italy. All IEA countries R,D&D budgets were on the increase as a result of uncertainties regarding the price and supply of oil. However, the 1982 budget cuts in the U.S. signalled a downturn in support which was followed in later years by other countries, Canada making significant reductions in 1984. Figure 2 comparatively outlines the funding support of Canada and five other IEA member countries. In recent years, some IEA members (but not Canada) have begun to re-emphasize their efforts and increase their funding support for RETs.

Figure 2[5]



Prior to the PERD Program allocating funds to pursue renewable energy R&D in 1976/77, a small effort was being undertaken through the A-base budgets of a few federal departments. Following the initiation of PERD support to 1980, this A-base effort became a diminishing percentage of the total monies spent. The A-base resources shown in Figure 3 for the years 1986-90 are from the NCAEI and EED Programs of EMR frequently referred to as "topping up" funds in support of the PERD effort. With the continual erosion of renewable energy funding, the PERD allocations to renewables are essentially the "last foothold" the federal government has in this area.

Figure 3 outlines total funds initially allocated to Task 4 of the Program (Renewable Energy) and do not necessarily reflect the actual dollars spent. Frequently, priorities shifted within the overall energy R&D program in mid-year for various reasons (eg. cuts for deficit reduction, support for the Space Program, Neilson Task Force recommendations, etc.).

The federal totals must be seen as reasonable estimates as the sources of information for earlier years of the demonstration programs are "soft". Most of these numbers were disaggregated from more highly funded demonstration programs of conservation and alternative transportation fuels.

Figure 3[6]

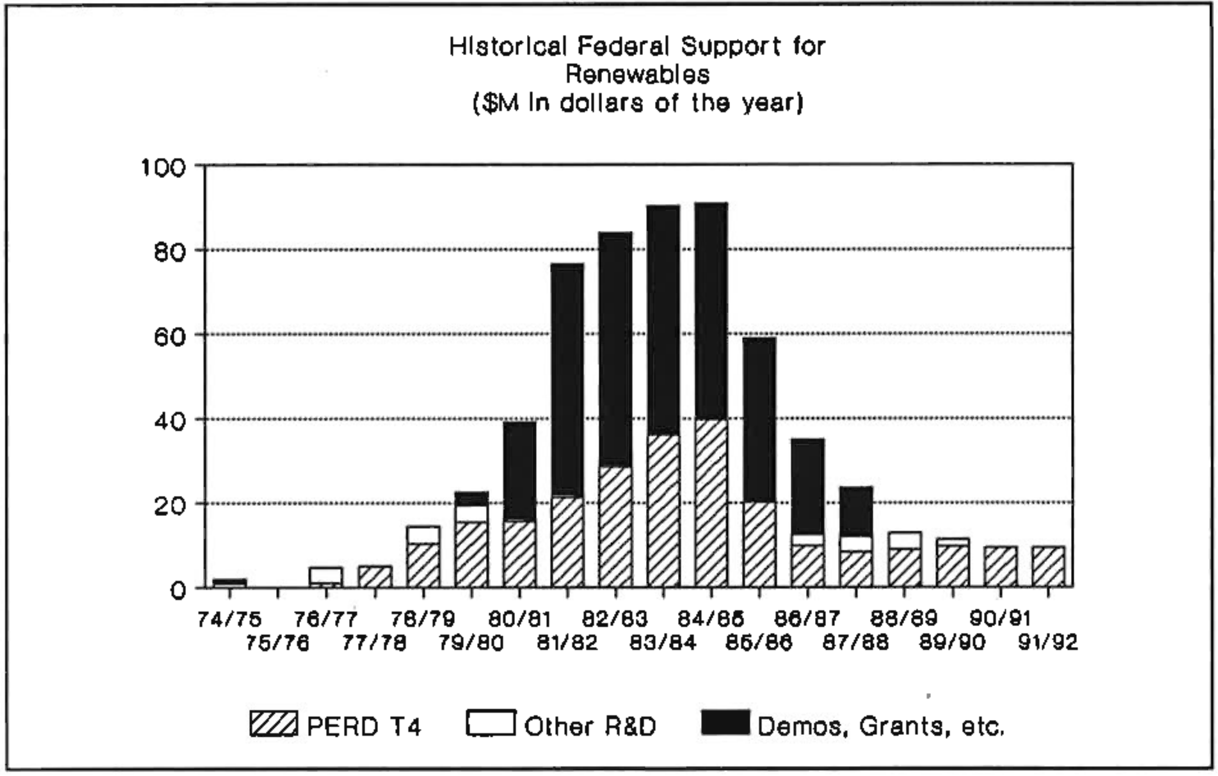


Figure 4 provides the information necessary to put the renewable energy R&D effort into the overall energy R&D picture of PERD as well as of the country.

As a percentage of the overall PERD effort, renewable energy R&D funding has been at a very high level (reflecting original objectives of energy security and reduced oil dependence). This changed in 1984 with the dismantling of the NEP and the policy objectives it supported. Funding support has levelled off at around ten percent of the overall budget.

In comparison, all Canadian renewable energy R&D as a percentage of the total energy R&D effort in Canada (including fission) is lower by about fifty percent but follows basically the same pattern. This pattern is slightly delayed in time when support was increasing and slightly ahead of PERD funding levels when they were being reduced.

As a percent of overall national effort, renewable energy R&D has not been very high, perhaps because of the long term nature of this technology option.

Figure 4[7]

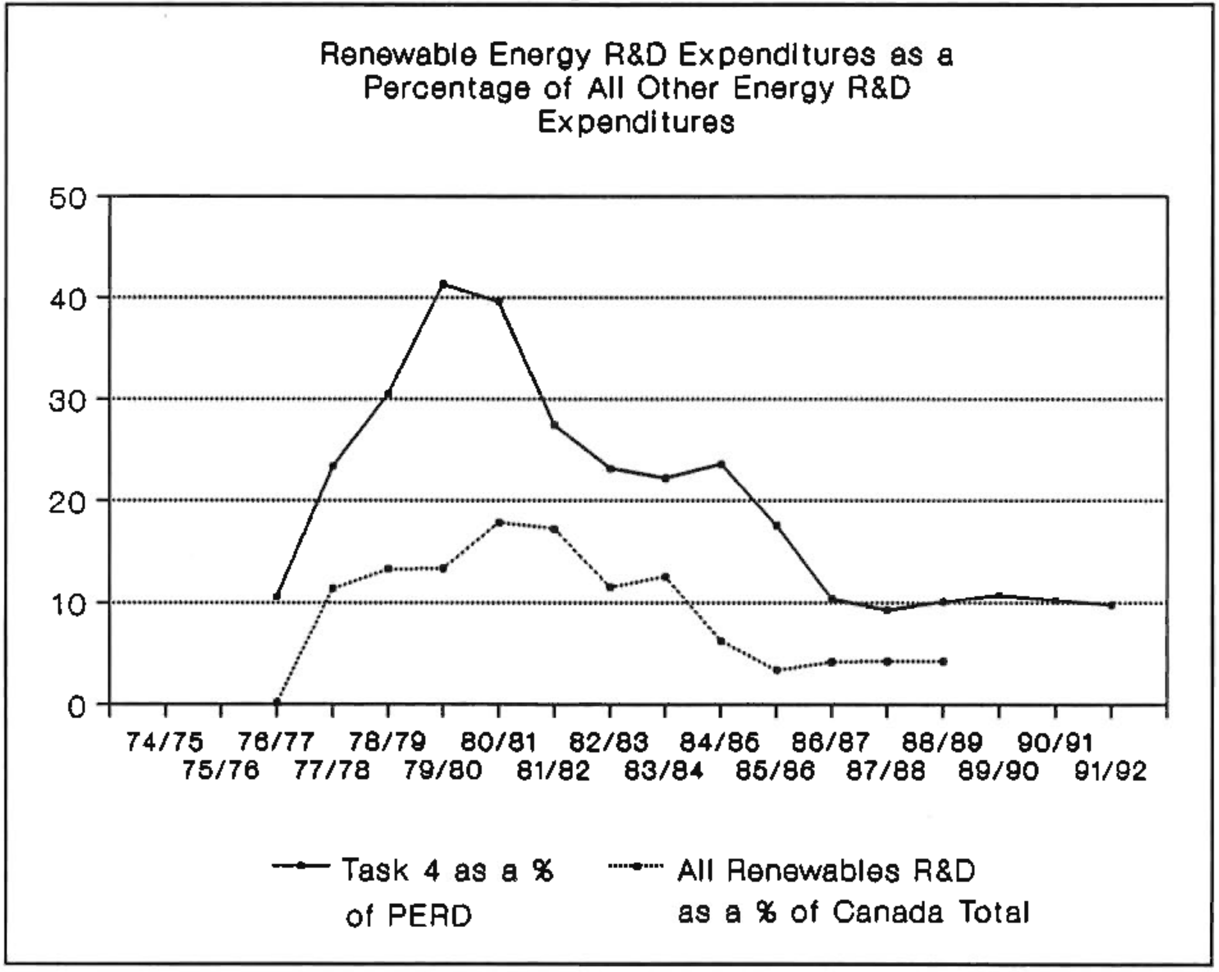
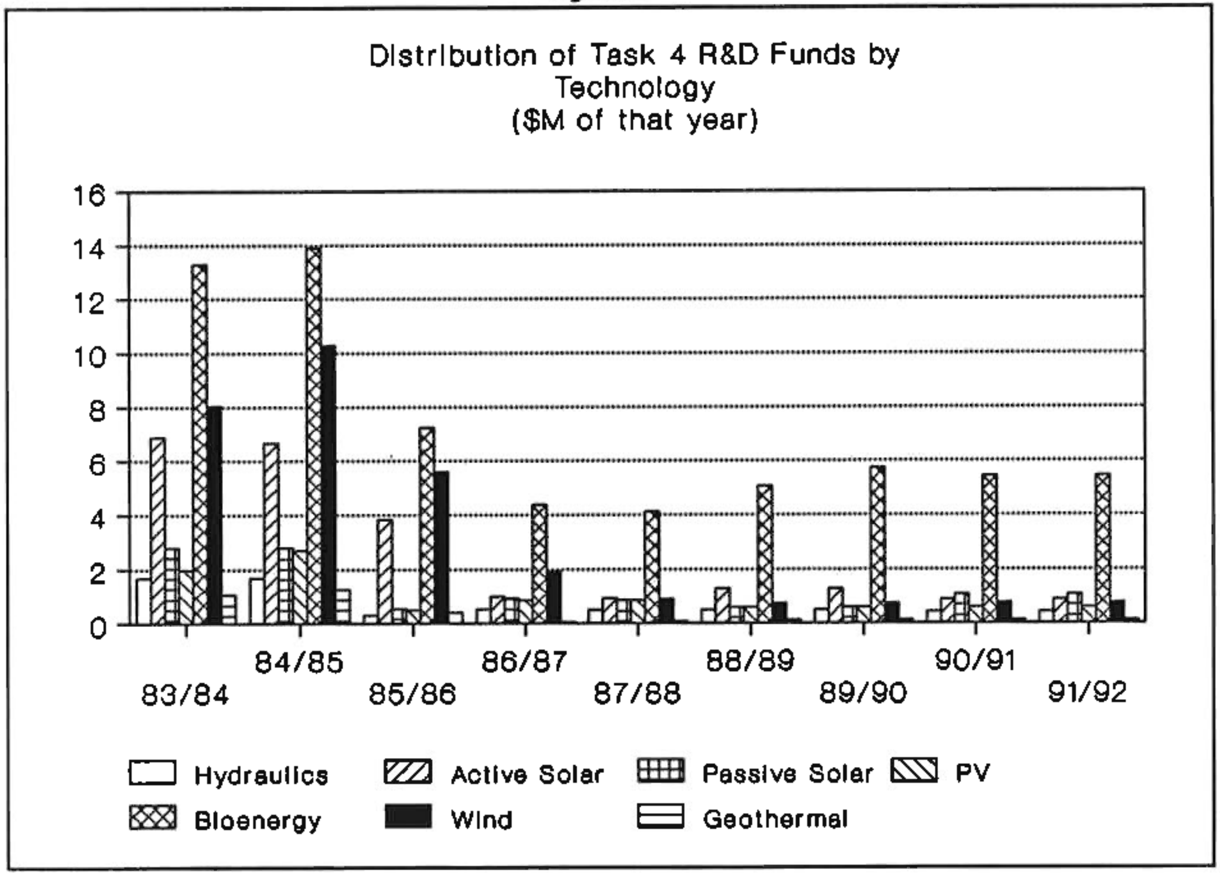


Figure 5 shows the PERD allocations broken out by the seven principal renewable energy R&D areas of interest in Canada. In the early years, it is known that a small effort was being undertaken through the A-base budgets of a few federal departments with the principal interest being in active solar.

Once again, the data shown reflects funds initially allocated to the technologies within Task 4 of the Program (Renewable Energy) and do not necessarily reflect the actual dollars spent. Overall energy R&D program priority shifts and R&D priority shifts from within the Task have affected the allocations to specific technology areas.

Figure 5[8]



5. Technical Background

The following sections identify and define the current renewable energy technologies presently receiving federal government R&D support in Canada. As well, a status report which attempts to cover the technical and economic/industrial activity is presented along with the current thinking on the potential for each area. Geothermal energy R&D is included in this chapter although it was decided recently (PERD interdepartmental Renewable Energy R&D committee meeting of 1990/91) to discontinue these efforts federally.

5.1 Hydraulics[1]

Definition

The technologies represented in this area transform the potential and kinetic energy in water to electricity. They include everything from run-of-the river devices to traditional, but small, hydraulic turbines to tidal power. Very limited activities (R&D or private sector) in Canada are known to be pursued in wave energy or ocean energy.

Small-hydro is generally considered to include power capacities up to 15 MW. The range is divided into micro (up to 100 kW), mini (100 to 1000 kW), and small (1 MW to 15 MW). Low-head hydro defines plants with a head of less than 40 metres and includes tidal power.

Status

In Canada:

There are about 400 hydro electric stations in Canada and total hydroelectric capacity now exceeds 60,000 MW. Half of these stations are small-hydro stations and have a capacity of less than 10 MW. There are 10 small-hydro manufacturers and many consulting companies involved in this business. Annual business is between $40-60 million. R&D activities are oriented to developing competitive products for international and domestic markets.

A 20 MW (rated capacity) tidal power generating plant was installed in the Annapolis Basin (Nova Scotia) in 1984 as a demonstration. There have been no significant operational difficulties since its commissioning. However, some environmental impacts need to be assessed and monitored. Larger scale environmental impacts (felt internationally) could be expected depending on the size of future installations. Environmentally related studies are presently the only activity supported by PERD for this technology.

Efforts within the R&D program in this technology area are focussed on development and commercialization of more cost-effective turbines, generators and control systems as well as techniques for site selection and analysis, plant design and construction. Activities encompass the development of prototypes for field trials or models for laboratory testing including axial flow turbine packages, ultra-low head turbines, submersible packages, variable speed or induction generators and automatic controls, development and application of innovative intake and dam structure, technology transfer of CAD software, stream flow modelling and information dissemination particularly on site development.

Worldwide:

Small hydro for off-grid supplies about 10 000 MW worldwide. Many developing countries particularly in South America and South East Asia are opting for small scale hydro for rural applications. In developed countries such as Germany, there already exists 10,000 small hydro plants. The Commission of the European Communities has a small hydro technology demonstration program. As well, the United States has had a significant small hydro program for the last 5 years.

Two recent (1990) surveys, as outlined in Table 1, of the current status of small-hydro (Water Power and Dam Construction) and micro-hydro (World Energy Conference) give an indication of the current potential market for equipment.

Table 1

Worldwide Small and Micro-Hydro Capacity in MW

	Small-Hydro	Micro-Hydro
Built	16 100	9200
Under Construction	500[a]	4340[b]

[a] represents unit capacities of 2000 kW or less.
[b] represents unit capacities of 1000 kW or less.

Based on these statistics, the world wide market for small-hydro (less than 10 MW capacity) is in the region of 2000 MW/annum.

However, over one-half of this market is in China, where 2800 MW of micro-hydro capacity is currently being installed. Not including China, the probable market is in the region of 1000 MW/annum.

Canadian Strengths/Weaknesses - Barriers/Problems:

The Canadian small hydro industry is reasonably strong given the current levels of support through provincial and federal programs and the limited interest by utilities. Canadian consultants are well known and respected internationally. There are a few Canadian turbines and generator control products exported overseas. The principal barrier facing the industry domestically is the difficult regulatory and legislative process involved in developing small hydro sites on private and public lands. Canadian utility buy-back rates are not known to be generous either, although recently, interest is starting to grow for independently produced power.

R&D activities presently focus on developing innovative civil works components design, ultra low-head turbine packages, generators and controllers.

Although R&D activity during the past few years has produced low cost turbines, generators and control systems for small-scale development, lack of demonstration funding prohibits the field testing or trials and monitoring of these innovative designs. This naturally restricts technology development since such trials are key steps in the development process.

Small hydro technology has a low environmental impact in comparison to large scale hydro installations or stand alone diesel systems. As well, through application of this alternative, a fossil fuel power generation credit could theoretically be realized through reduced CO_2 and acid rain pollution. An additional advantage is that reliability of a utility's power system operation could be increased by decentralization at local load centres.

Potential

The installed capacity of small hydro in Canada has been increasing by about 20 MW per year. This is equivalent to about 100 million kWh of energy saving per year. There is potential for an increase to more than 40 MW per year at the full penetration level. The economic impact of this activity is estimated to be between 740 to 2160 person-years/annum of employment.

Surveys of the Canadian small-hydro resource (sponsored by EMR) have identified about 2800 sites with a total capacity of about 5200 MW as outlined in the following table. There are about 20 000 MW of low-head potential, principally tidal power.

Energy purchase rates determine economically viable potential. Generally speaking, at rates of less than 4¢/kWh, only some of the potential outlined in Table 2 is presently economically viable. As might be expected, there are many factors which influence economic viability, from site specific conditions at each installation to the power buy-back rates offered by purchasing utilities.

Table 2

Canadian Small Hydro Resource in MW

Province	Resource Potential By size			Total
	Micro-hydro	Mini-hydro	Small-hydro	
Newfoundland	0.8	30.0	1062.6	1093.4
Nova Scotia		9.6	133.5	143.1
New Brunswick			251.7	251.7
Québec	0.5	13.1	855.0	868.6
Ontario	25.9	252.0	1247.5	1525.4
Manitoba			236.0	236.0
Saskatchewan			91.0	91.0
Alberta	0.1	2.7	53.3	56.1
B.C.		21.4	893.0	914.4
TOTAL	27.3	328.0	4823.6	5179.4

5.2 Active Solar[2]

Definition

The technologies represented in this area involve the direct conversion of solar radiation into thermal energy which can then be used to heat a fluid (usually water or air) or provide cooling through a thermodynamic process.

Currently in Canada, the focus of R&D activities is on devices for residential hot water heating and pre-heating industrial ventilation air with the goal of improving these products and enabling them to further develop their markets.

Status

In Canada:

The Canadian active solar industry consists of 18 relatively small companies employing in total about 100 people. A product evaluation and rating program is administered by the Canadian Solar Industry Association (CSIA). Products from nine companies are currently listed in the CSIA approved product directory. Products not listed are either in the prototype development stage or have not been tested to CSIA requirements. The CSIA approved product list includes plastic swimming pool collectors, water and air based flat plate collectors, high temperature evacuated tube type collectors and solar domestic water heating systems.

Of the nine companies listed there are four main players (Conserval, Thermo Dynamics, Fournelle, and Sunglo), two of which are located in Ontario, one in Quebec, and one in Nova Scotia. Each of these companies is marketing a distinctly different product.

Conserval owns the patent rights to the Solarwall concept for preheating ventilation air and is currently marketing its product in commercial/industrial markets in Canada, the United States and Europe.

Thermo Dynamics owns the Micro Flo DHW technology and the Sunstrip manufacturing equipment and is currently marketing a new Micro-Flow solar appliance in Canada and the United States. It is selling Sunstrip product in Europe. Recent marketing ventures include Mexico and Russia.

Fournelle owns the technology and manufacturing facilities for the evacuated tube collector formerly owned by Philips of the

Netherlands. This type of collector can produce relatively high temperatures (ie. greater than 100°C). Fournelle is concentrating on the European market.

Sunglo exports about 50% of its product, plastic pool panels, to the United States, principally California, Florida, and Arizona.[3]

Total sales of active solar products in 1988 including exports amounted to approximately $5 million.

Total solar collectors installed in Canada amount to about 600 000 square metres for residential DHW, commercial/industrial, and residential pool applications (12%, 20%, and 68% respectively) resulting in annual energy savings of 170 million kWh (0.6 PJ) (16%, 20%, and 64% respectively).

Outdoor pool heating technology is well developed and available with good performances and is competitive in certain market areas with other forms of heating including gas, propane, electricity, and heat pumps. While there is some potential for lower costs from larger production volumes, it is unlikely that there will be a major change in the price of these systems. However, with an estimated half million residential and 10 000 commercial/institutional outdoor pools in Canada alone and another 12-15 000 new pools added each year and with the trend towards increased heating of pools, there is a significant potential for market growth in solar pool heaters.

The next best residential application is the provision of hot water for dishwashing, showers, laundry, etc. offering paybacks from 7 to 10 years. The cost of solar domestic hot water systems has fallen by 60% since 1981 due to innovative components and systems, improvements in production methods, and simplification of installation. System reliability has improved dramatically, although controller and pump failures remain a minor problem. In Canada about 12 000 hot water systems have been installed.

The most cost effective commercial industrial application in Canada is the preheating of ventilation air, offering paybacks of 3 to 5 years when combined as a package with other building energy conservation features such as added insulation and destratification. Approximately 28 000 square metres (about 2.8 hectares) of solar wall collectors have been installed in Canada and the United States since 1984.

Solar thermal power to produce electricity is not presently being pursued in Canada.

Worldwide:

It is estimated that more than 25 million square metres of solar collectors have been installed within the IEA countries providing more than 10 TWh of annual energy savings. The United States and Japan have the largest installed base at over 10 million and 8 million square metres respectively. Israel is third with almost 2 million square metres while Australia is fourth with about 1.5 million. On a per capita basis, Israel is the leader with more than 450 square metres installed per 1000 inhabitants, ahead of Australia (80 m^2) and Japan (70 m^2) followed by Greece and the United States (43 m^2).

In Japan, over 200 000 thermosyphon solar water heaters were installed in 1987/88, representing the major solar collector market in that country. In Australia in 1987/88, over 30 000 solar water heaters were produced. In excess of 300 000 (6%) of Australian households have a solar water heating system.

In the United States, there are five main companies representing 75% of the sales. In 1987, 380 000 square metres of solar collectors were produced with pool heating as the major application. Thermosyphon and integral collector storage systems were estimated to account for approximately 35% of solar water heater sales nationally with the major market in California, Florida, and Arizona.

In California, 135 MW of solar thermal power has been installed (Luz Corporation) and another 200 MW are planned by 1992.

Although very much country and system dependant, the following general statements can been made with respect to the penetration of active solar in IEA member countries:

a) Swimming pool heating applications, as well as hay drying and hot water preparation in the agricultural sector, are cost competitive or almost competitive in all countries even against the cheapest conventional energy source;

b) Solar DHW appears not to be competitive against heat from oil or gas in most countries by a factor of 2 to 4 in some cases, and 1 to 2 against electricity. In sunny climates (non-freezing) or when displacing electricity, simple solar DHW installations are currently cost-effective (Israel, Australia, Greece);

c) Space heating solar systems show similar or slightly less favourable results. Industrial solar heat, except for the Solarwall concept described earlier, is still too expensive by a factor of 2 to 5;

d) Finally, central solar heating plants with seasonal storage seem a promising way to compete with conventional heating plants in countries where there is a need for seasonal storage, but are presently still not cost competitive by a factor of 2.

These conclusions are valid for an evaluation of the penetration of active solar on a broad open market. Special considerations (in remote areas or in very sunny locations, or tax incentives) can change the conditions of comparison making solar competitive especially for low temperature applications.

Canadian Strengths/Weaknesses - Barriers/Problems:

The Canadian solar industry is well developed with a high level of commitment to R&D assisted over the past ten years with provincial and federal government support. The industry has rationalized over these years and products have matured in both the research lab and the market place. However, the industry is having some difficulty in establishing a strong domestic market.

The emphasis in earlier government incentive programs on improving cost/performance has permitted Canadian products to become competitive internationally. Canada has unique manufacturing facilities for Sunstrip and evacuated tubes and produces innovative products such as the Micro-Flo DHW solar appliance and the Solarwall.

Our strengths are the scientific skills and initiative and entrepreneurial spirit of these key research and industry players.

The current barriers to greater sales of solar appliances include high capital costs, a lack of awareness of solar, perceived technical problems and unfavourable siting (i.e. orientation, shading, slope).

For solar DHW systems, with the exception possibly of Eastern Canada and remote communities, cost performance needs to be reduced by 50% in order for these systems to make a significant contribution in the Canadian marketplace at current energy prices and conditions - without government subsidy. In the near term, cost reductions and performance improvements in the order of 25% can be expected through R&D activities related to a) the reduction in the material content of collectors b) improved performance and c) refinements to the micro flow systems such as the development of low power pumps and better integration of the system with the auxiliary tank.

Most of the commercial/industrial systems are still 3 to 4 times too expensive to penetrate the Canadian market with the exception of low temperature preheating applications, especially air systems (Solarwall). Current R&D efforts focus on the near term with the Solarwall technology. Improvements of 40% in cost performance of Solarwalls is expected in the near term.

The use of active solar technologies instead of fossil fuel based ones can have a positive environmental impact. There is however, no financial credit for this environmental advantage. The type of fuel displaced depends on the location in Canada and the application. Solarwalls for preheating ventilation air for industrial plants typically replace gas-fired heating units. Solar pool heating systems are used in place of gas or oil fired heaters or electric heat pumps. New markets for residential water heaters are expected to develop in the East Coast and remote areas. A large percentage of East Coast electricity is coal based.

Potential

Current installed active solar technologies save about 0.6 PJ of energy per year. More aggressive marketing and an increased commitment to research and new product development could double this figure to 1 PJ in the near term and to 14 PJ in the longer term (twenty years) with 10% market penetration in several application areas. The majority of these savings (over 90%) are expected to come from domestic hot water heating, industrial ventilation air heating and residential outdoor pool heating.

Current sales of active solar products is about $5 million per year and can be expected to grow to about $50 million per year by the year 2010. Resulting from this estimate, active solar heating is expected to provide annual benefits of $180 million (in 1989 dollars) in reduced conventional energy consumption.

5.3 Passive Solar[4]

Definition

These technologies, usually incorporated into building structures, collect, control, store and distribute solar energy (heat and light), for use in space heating/cooling and lighting. Window technology is the principal focus in this area in Canada although it also includes sunspaces, atria, direct-gain systems and computer design tools.

Passive solar technology integrates the collection, distribution and storage of energy into the design of the building itself and is therefore inherent in good building design.

Status

In Canada:

The glass manufacturing industry is dominated by a small number of large international firms headquartered outside Canada. They are generally cooperative and knowledgeable concerning advances in technology. The window and insulating glazing unit manufacturing industry is, however, characterized by a relatively large number of small firms. They are in part represented by the Insulating Glass Manufacturers Association of Canada (IGMAC) and the Canadian Window and Door Manufacturers Association (CWDMA).[5] Only the larger firms and some specialty manufacturers are aggressive in implementing advanced technology. These firms are Canadian owned and a few sell some products in the U.S.A. The number of firms presently selling windows incorporating the limit of present technology is less than five.

In Canada, the new house market is very competitive and builders opt for selecting products on the basis of lowest first cost. However, the retrofit market is much more amenable to quality products featuring energy efficient performance characteristics.

The earliest Canadian venture into passive solar technologies was the Saskatchewan Conservation House in 1977, which demonstrated all the first-generation passive solar technologies still in use today:

- low-energy construction;
- increased south-facing glazing, reduced north glazing;
- overhangs for summer shading to avoid overheating; and
- high performance windows.

The most significant Canadian research on passive solar technologies was carried out by the NRC's Solar Energy Program from 1978 to 1985. Initial research focussed on: calculating and quantifying solar gains, and qualitative performance analysis, including Level A and Level B monitoring.[6]

The key to enhancing passive solar in cold climates is windows that transmit solar energy while providing better thermal resistance to losses. In combination with improved mechanical systems which include thermal storage, high-performance windows will allow increased window areas to provide increased net solar gains and will offer new and exciting architectural possibilities without the energy penalty of conventional windows.

The energy efficiency of a window should take into account its resistance to heat flow (ie. RSI value), resistance to air flow (ie. infiltration) and its ability to admit solar energy. Hence, the RSI value is not the only criterion of a high performance window. EMR has established as a performance target, windows that are net energy gainers, that is, windows that collect more energy than they lose over the entire heating season, even on the north side of buildings. Significant side benefits are greater comfort and less condensation.

Fundamental research into heat-transfer mechanisms in windows has increased our understanding of the physics involved, and has led to the development of analytical algorithms and now computer design tools. Two computer programs, VISION and FRAME, have been developed to help design more energy efficient windows and are being supplied to industry at a nominal cost.[7]

Basic research is also continuing on electrochromic coatings and involves efforts in different avenues. The Canadian endeavour at the Institut national de recherche scientifique (INRS) using organic materials is unique in this field. Laboratory scale working devices of up to 30 cm^2 have been produced.

High performance windows and an integrated mechanical system are being demonstrated at the Advanced House in Brampton. It is a showcase to builders and the public that demonstrates that the latest passive technologies and conservation techniques reduce energy consumption by one-half that of an R-2000 home and one quarter of its conventionally built neighbour.

Worldwide:

Because Canada's climate is similar to that of northern Europe, Canadian passive technology is developing along similar lines. So far, R&D emphasis into passive solar in northern Europe, Canada and the U.S. has focussed on four major areas:

- sunspaces and atria;
- direct-gain systems;
- computer design tools; and
- better windows.

Canada's climatic conditions vary from mild maritime to extreme Arctic cold. The typical European approach of aiming for zero purchased energy levels does not work in our harsher environment. All countries have learned the lesson that passive solar strategies offer a greater percentage energy contribution once heating and cooling loads have been reduced through conservation strategies.

In most countries the current R&D emphasis is now on major improvements to windows. Relative to other building components, windows have not undergone a significant improvement in energy efficiency since sealed double glazing was commercialized in the 1950's-1960's. High performance windows occupy less than 10% of the Canadian market while in the U.S. and Europe, the market share is approximately 30% and 50% respectively.

Window R&D generally falls into two areas, improvements to existing window technologies (heat-reflective coatings, gas fills, multi-glazings, improved spacers and frames) and basic research into innovative technologies (such as transparent insulation, electrochromics, aerogels, and evacuated glazings).

The technology offers significant HVAC equipment savings also. For example, baseboard heating or fan coil units needed under windows to combat the cooling effect of the lower window surface temperatures may not be required. In future, inside window temperatures for advanced windows may be 5°C warmer. This leads to greater occupant comfort and may enable the thermostat setting to be reduced, while maintaining comfort.

Canadian Strengths/Weaknesses - Barriers/Problems:

Of all the renewable energy technologies, those represented by passive solar offer the greatest opportunity for near-term market penetration and energy displacement due to its closeness in nature to cost effective conservation technologies (usually the first to be implemented) and the nature of the market - ie. well established and large in size. The Canadian window market alone is valued at about $5 billion annually.

A present problem is the lack of energy labelling of windows to indicate their energy efficiency and no accepted procedure to produce such a label. This deficiency has obstructed efforts to promote advanced windows by utilities and provincial authorities. It is a high priority of current R&D efforts.[8] Installing techniques also need to be improved (ie. better training), documented and conveyed to the industry - poor installation will negate window performance.

Another significant barrier is that design and construction professionals are still unaware of the full potential of existing technologies.

Potential

Passive solar has a significant environmental benefit directly related to the reduced use of conventional fuels and reduced need for new generating capacity. As well, a major benefit could be achieved through electrical peak load reduction. In a typical house, the peak reduction savings to an electrical utility from advanced windows would be one kW. This saving is approximately equivalent to the cost of the windows in a typical new house (the incremental cost of new generating capacity is $ 3 000 to $ 4 000 per kW).

Table 3, from a recent passive solar potential study, indicates that by using current and clearly emerging passive solar technologies, the technically feasible potential for solar utilization/energy conservation is about 363 PJ/year by the year 2010.

Table 4, from the same study, indicates that a reasonably achievable market potential in four building sectors using the same clearly emerging passive solar technologies is about 131 PJ/year in 2010.

Table 3
Summary of Passive Solar Potential in Buildings in the Year 2010

	Ultimate Passive Solar Potential (PJ/Year)	Technically Feasible Potential (PJ/Year)	Reasonably Achievable Market Potential (PJ/Year)
Existing Residential Retrofit Potential (to 1988)	296	136	36
New Residential (1989-2010)	151	53	25
Existing Commercial Retrofit Potential (to 1988)	172	100	26
New Commercial (1989-2010)	108	74	44
TOTAL	**727**	**363**	**131**

Table 4
Estimates of Reasonably Achievable Passive Solar Potential in the Year 2010

Unit

Emerging Technology	Residential		Commercial		Total
	Existing	New	Existing	New	
High Performance Windows	36	14	23	11	84
Daylighting	-	-	3	31	34
Integrated Mechanical Systems	-	10	-	-	10
Thermal Storage	-	1	-	2	3
TOTAL	**36**	**25**	**26**	**44**	**131**

5.4 Photovoltaics[9]

Definition

Photovoltaic energy technology involves the direct conversion of light into electricity by means of a solid-state device, the photovoltaic cell. The cell is composed of thin layers of semiconductor materials that produce electricity when exposed to light. When electrical contacts are attached to the layers and the circuit is completed, an electrical current will flow, generating energy. To protect them from the environment, cells are linked together and encapsulated in modules, which are used in various applications.

PV cells can be made from a number of materials and fabricated in a number of designs. The prevalent semi-conducting materials used include single-crystal silicon (most often used), amorphous silicon (growing in use), polycrystalline silicon (growing in use), copper indium diselenide and gallium arsenide.

Status

In Canada:

In Canada, research first done under the NRC program followed the world-wide trend and concentrated on developing cheaper and more efficient PV cells and modules. In parallel, government bodies such as the Coast Guard, Environment Canada and the Department of National Defence made their own assessment of the technology and started using it in remote applications. In 1985, EMR took over the R&D program from NRC. While continuing some basic cell research, efforts have focussed more on systems development and promotion of the use of PV technology.

While PV power is still very expensive, in the 30-50¢/kWh (installed) range in Canada, it has special economic interest for remote applications and in developing countries. Because the technology still shows considerable promise for cost reduction, these niche markets are being pursued and enlarged as these reductions occur.

Emphasis is on development of systems that can use photovoltaics as an energy source rather than the development of the PV cells themselves. The technology is developed to the point were it is considered reliable and durable, and cost-effective in certain remote applications. About 3200 PV-powered systems have been installed in Canada for navigational aids and remote sensing applications. In Canada PV has considerable potential for northern applications where fuel costs are high and the environment is especially sensitive. Canada has one company which manufactures PV cells and modules using raw cell material from the U.S. There are also several companies selling U.S. PV products in Canada. The annual sales of PV systems in Canada is around \$6M and about another \$7M in export sales.[10] The total energy currently produced in Canada from PV is not significant as a percentage of energy demand (probably less than .01%).

Current R&D efforts in Canada focus on the development of PV/diesel hybrid systems capable of supplying power to loads ranging in size from single residences to small villages or scientific/industrial outposts.

Ongoing support for product testing, design and simulation software development, field monitoring and system performance analyses, and thin film PV cell fabrication is also included in the current R&D program.

Worldwide:

The U.S. has historically been the major world player in PV development having spent some \$750M federally over the past 10 years. Several European countries (notably Germany) and Japan have recently increased their efforts in this technology area and the U.S. no longer dominates this field by itself. Several large oil and electronics companies have PV development underway and industrial R&D is probably out spending federally-funded R&D in many countries.

The world market is growing each year; in 1988 about 35 MW_p of PV modules were sold worth over \$100M (U.S.). The U.S. and Japan each had about 1/3 of that market. Work continues internationally to reduce the price of PV modules to a price of \$1 per watt peak. Work also continues to develop higher efficiency cells (current commercial cells have an efficiency of 5% for amorphous silicon cells and about 14% for monocrystaline silicon, laboratory cells have efficiencies up to 30%). Multilayered thin film cells are approaching the 40% efficiency level in the lab. SERI's observation about efficiencies is that lab efficiencies become market efficiencies within ten years. Annual sales of PV cells are forecast to reach 100 MW_p by 1995 (Frost and Sullivan).

Canadian Strengths/Weaknesses - Barriers/Problems:

Solar energy can be an intermittent source of energy and is site sensitive. However, intermittency is not an impediment for well matched applications. As well, PV modules have the advantage of modularity when a utility wishes to install additional capacity. In Canada the best locations are in much of the North and in the southern prairies of Alberta and Saskatchewan.

Canada's strengths are in system development for remote power applications used in conjunction with diesel powered generators. Canada does little in cell development and has little cell manufacturing capability. The Canadian market is dominated by U.S. PV systems. The barriers to PV development in Canada are:

- the Canadian PV industry is small and under-capitalized;
- lack of R&D funding by private or government;
- high cost of PV power compared to grid power; and
- lack of knowledge and appreciation of technology.

As well, Canada cannot compete with the huge PV energy development plans already in place in several countries.

Currently the market niche in Canada is in remote and northern applications for stand-alone systems and in diesel hybrid systems. Work is needed in power conditioning, design software and some cell and battery research. Progress on developing a simple PV-powered water pump for third world and Canadian remote areas is moving ahead.

The cost of photovoltaic energy generation, although reduced substantially over the past decade, is still higher than the buy-back rates offered by major utilities, except where these are supported by government subsidy or legislation, or in remote regions where the cost of fuel for conventional (usually diesel) power plants is unusually high.

Except for potential chemical pollution during manufacture, a PV system has negligible negative environmental impact during routine operation. This attribute is especially significant in northern regions where that environment is extremely sensitive. For example: a PV/diesel hybrid system can use up to 70% less fuel than a diesel only generator.

Potential

A recent assessment of the technology indicates that photovoltaic applications in Canada are likely to increase to more than 650 MW_p by the year 2010. Applications will include remote stand alone users (350 MW_p), remote community power systems (50 MW_p) and grid connected systems (250 MW_p). As a result of some of these PV applications, there will be a displacement of electricity normally generated by coal and diesel fuel and hence reduced air emissions. Annual sales of PV related equipment are expected to be around $1 billion (by 2010) and the cost of PV electricity is expected to drop to 8.5 cents/kWh (in 1990 $CDN).

The use of PV energy is not so much related to its potential (which is significant) but to the cost of the power being produced by this technology. PV energy prices are foreseen to drop significantly as new breakthroughs occur (e.g. manufacturing, new materials). Concurrently, efficiencies are expected to rise. As present limitations are resolved, applications for photovoltaics are expected to grow.

5.5 Bioenergy

This technology area encompasses the environmentally sustainable growth of biomass (biomass replacement at an equal rate as that of use, through fast growing hybrid trees, grasses, etc.), the collection of biomass residues and the harvesting of woody biomass (not necessarily grown specifically for energy purposes) for conversion to an energy form. Municipal solid waste, although not grown, is also considered a bioenergy feedstock.

The technology required for the extraction of energy from solid biofuels consists of two related but distinct areas: solid fuel processing (e.g. moisture reduction, material preparation, handling) and the thermal conversion (combustion) of the processed biofuel (e.g. furnace, fluidized bed boiler). As well, after the appropriate material processing, thermochemical or biochemical processing can be undertaken. Each of these components is considered in more detail below.

5.5.1 Biomass Production[12]

Definition

Biomass production encompasses many aspects including resource assessment, inventory, growth, harvesting and collection of biofuels as well as the consideration of the environmental consequences these may entail. Currently, it is principally oriented towards woody biomass from forest residues, tree or shrub species unutilized for other purposes, and tree growth resulting from intensive silviculture, including short rotation intensive silviculture. In the early years of the program, agricultural crops such as Jerusalem artichokes, sugar beets and sorghum were considered.

Status

In Canada:

A major effort through the ENFOR (Energy from the Forest) program was undertaken to collect the necessary inventory data, or to convert existing conventional timber inventory data. This information has been published and the database is maintained by the Forest Inventory Program of Forestry Canada at Petawawa National Forestry Institute.

Intensive silviculture, a component of the biomass production R&D activity, is an alternative approach aimed at increasing the concentration and productivity of biomass on selected sites close to where energy is needed.

Work is underway to harness the nitrogen fixing properties of alders with mycorrhizal relationships[13] in order to improve the growth of forest biomass. This work has reached the stage where alders specially inoculated with improved strains of a fungus which forms mycorrhizal relationships are being interplanted with coniferous species in field test plantations.

ENFOR is supporting research on fast-growing woody species raised on short rotations for energy purposes. Species such as hybrid poplars, willows and alders can be grown densely and rapidly as coppice stands which resprout vigorously after repeated harvesting. Efforts in this field have focussed on willows, which can be grown on a wide variety of site conditions.[14]

Prototype machines have been designed and developed, for example, to pick up and comminute slash left on cutovers after logging. However, they rarely proceeded beyond the initial testing stage. A separator-shear system was successfully developed and tested which separates biomass from unusable material in west coast logging sortyards, and divides the large pieces into manageable chunks. The Crabe Combine brush-harvester was successfully developed and field-tested as a biomass harvester for cutting and chipping woody brush and small trees. It can now also serve as a valuable silvicultural tool for preparing brush covered sites for planting, or for clearing utility rights-of-way.

Studies are currently underway to investigate in some detail the potential effects of intensive biomass harvesting on soil physical and chemical properties. This includes effects of equipment and processes on soil disturbance, soil compaction and surface soil erosion. A series of studies over three separate regions in eastern Canada is looking at the effect of total biomass harvesting on soil acidity, nutrient availability and losses.

Considerable emphasis has been given to the development and calibration of FORCYTE, an ecologically-based forest management computer model of considerable complexity and sophistication. FORCYTE permits long-term prediction and evaluation of forest nutrient cycling trends. Its potential applications range far beyond the long-term impact of intensive biomass harvesting to include short-rotation forest planning, agroforestry, climate change and education. Forestry Canada researchers at several locations are calibrating and testing the model for their local forest and site conditions.

Finally, a major new project is being undertaken, to assess at a national level, the impact of Canadian forests and forestry practices (including forest bioenergy use) on the environment in terms of the CO_2 budget.

Worldwide:

Woody biomass is by far the most important source of energy for heating and cooking in two-thirds of the countries of the world. This fuelwood plays an obviously critical role in the developing world. Although fuelwood is not always used in a truly "renewable" fashion, efforts are being made to make it so through aid agencies of the developed world and local agencies in the developing countries. Much of the research is aimed at the conversion end with improved cooking stoves and the like, but there is much work in biomass production through trials of new species, agroforestry trials, tree planting schemes and soil conservation projects.

Forestry Canada is the Canadian signatory to the Bioenergy Agreement of the International Energy Agency. The Agreement involves 14 other countries, primarily in Europe, as well as the United States, Japan and New Zealand, and provides for international collaboration on a series of agreed research and development activities. Specific examples of activities include work on ecophysiology of energy plantations, pest and disease management in energy forestry, integrated harvesting systems, and economics of wood energy supply systems.

Although biomass production R&D is not restricted to member countries of the IEA, the principal countries undertaking biomass production R&D also tend to be the signatories to the above mentioned IEA agreement. As information is shared, the international effort in this area reflects, to some degree, worldwide activities as well.

Research conducted on short-rotation forestry for energy under the IEA has dealt with species selection, evaluation, breeding, and clonal propagation of promising strains. Aspects of production biology, including water use efficiency, nutrients and fertilizers, and the use of root symbionts, have been studied. Management and tending practices, including protection against diseases, insects, and frost damage, have been investigated. Possible ecological consequences of short-rotation cropping have been considered. Considerable work has also been done on designing and testing mechanical equipment for short-rotation forestry.

Harvesting R&D has concentrated on the development of technology and systems to harvest forest residues, residuals and small trees or thinnings for energy, including integrated harvesting systems. The preparation and processing of forest biomass to make it a more efficient and effective fuel have been investigated as well as storage, drying, and internal handling techniques for wood fuel.

Ecological consequences of intensive forest harvesting, both nutritional consequences and possible physical damage to forest soils, are a current subject of concern.

Canadian Strengths/Weaknesses - Barriers/Problems:

The results of this research have application beyond the field of bioenergy. Lumber and pulp and paper industries may, in theory, be considered competitors for a common woody biomass resource but in practice there is no real competition as there is more than enough resource for both. Moreover, the focus of forest bioenergy R&D has always been on parts of the resource which are of no interest for conventional forest products.

Although Canada has extensive forest biomass resources not presently being utilized (so far as components of interest for bioenergy are concerned), most of it is located far from where energy is needed. It also tends to be widely distributed at low densities, presenting economic and technical problems in collection and transportation. The relatively low cost of competing energy sources is a principal barrier.

Good progress has been made in the development of techniques for short-rotation intensive culture and other types of intensive silviculture.

One of the principal problems is a lack of a fully developed, end-to-end forest bioenergy production and conversion system. One tends to think of this in terms of the short rotation intensive culture of hybrid poplars, but it is also lacking in the forest residue end of things. One of the missing elements is a satisfactory, economic harvesting/collection system.

Most of the currently available timber harvesting equipment is not suited to dealing with forest biomass for energy purposes. A great variety of material must be handled, ranging from young saplings to full grown mature trees, or irregular woody material in logging debris in the forest, or on landings or sortyards. Often each situation requires a different approach. The immediate commercial market for equipment is difficult to penetrate.

Harvesting forest biomass for energy involves a much more intensive and complete removal than conventional harvesting, and could have potentially serious adverse effects on nutrient cycling, soil stability, wildlife habitat, and other components of the forest ecosystem. These impacts have been studied. Considerable effort has been devoted to the development, calibration, and application of the FORCYTE computer simulation model, designed to evaluate the long-term effects of intensive biomass harvesting on soil fertility and biomass production. FORCYTE also simulates the effects of most other forest management practices, so this bioenergy research effort also provides benefits in other fields of forestry research.

Potential

The gross potential in Canada of forest biomass available for energy use is at least 26 billion oven-dry tonnes, equivalent to 82 billion barrels of oil, or enough to meet all of the country's energy needs for 55 years. However, it is necessary to be more realistic and factor in other biomass (wood) demands - those needs principally of the lumber and pulp and paper industries. Of the available biomass, even if only the nonmerchantable portion of merchantable size trees growing on productive, accessible forest land is included, there is 4 billion tonnes available. This could supply about 25 percent of Canada's annual energy requirements on a sustained basis. Bioenergy (including spent pulping liquors) provides about 7 percent of the country's total energy needs, double what it was 10 years ago.

Surveys of biomass supply and use have been conducted in several regions. For example, a 1985 survey showed that 7.5 million cubic metres of hog fuel were produced that year in the south coastal region of British Columbia, most of it being used for production of steam or power.[15] Studies have been conducted on the costs of harvesting non-commercial hardwood stands for energy.[16] Though this could be done more cheaply than conventional timber harvesting, it is still questionable economically, given historical (ie. low) oil prices.

Trials in eastern Canada of integrated harvesting of traditional forest products, particularly pulpwood, and biomass for energy have met with considerable success. These integrated systems probably offer the greatest potential for immediate future expansion of biomass use. A number of pulp and paper companies now routinely use harvesting residues for production of process steam or energy in their mills.

5.5.2 Biomass Combustion[17]

Definition

The direct combustion of biomass is the thermal conversion of the biofuel into heat which can be readily used to produce highly practical forms of energy such as steam or electricity.

Status

In Canada:

The direct combustion of biomass for the generation of thermal and electrical energy is the major component of the traditional bioenergy sector. Systems have operated successfully in the industrial sectors for many years. There are over 8000 industrial, commercial and institutional establishments utilizing solid biomass as a source of energy. The current contribution to the national energy scene is about 540 PJ which represents 17% of the industrial energy demand. This contribution is composed of solid wood wastes (120 PJ), residential wood use (170 PJ) and spent pulping liquor (250 PJ) and includes 2000 MW of electrical cogeneration.

Hog fuel power boilers in the pulp & paper mills provide a significant bioenergy component. These integral boilers burn hog fuel, clarifier sludge and other wood derived mill residues with a minimal amount of fuel preparation. The technology has recently evolved into a variety of new applications such as circulating fluidized bed combustion for improved thermal efficiency and environmental performance.

Smaller systems are also found in sawmills and in the full range of secondary wood industries. These systems use primarily on-site generated biomass residues that in many cases would otherwise represent a disposal cost. Similar applications of this same basic technology has been expanded into non-forest industry related installations.

Another large scale traditional technology is the mass burning of municipal solid wastes (MSW). While the primary objective is volume reduction, energy as a significant by-product helps pay for the installation cost.

By far the greatest number of combustion systems are the stoves and furnaces in the residential sector. These installations burn primarily firewood for the space heating of homes, garages, farm buildings and stores. The use of wood chips as a fuel is becoming important in eastern Canada. Current estimates are that there are over 2 million residences depending on wood energy either as a primary source or supplementary source of heat.

The traditional boxstove has been replaced by controlled draft units with catalytic converters for high efficiency, low emission operations. The natural draft furnaces have been replaced by automatically regulated high-efficiency furnaces and hot water boilers operating on solid firewood or by particulate fuelled systems with fully automated fuel feeding.

Development of Canadian performance emission standards for both residential wood-burning appliances and large field erected systems are almost complete. A high-efficiency, low emission design for chip fired heating systems is now being produced commercially in P.E.I., with 90% Canadian components. In general, the thermal efficiency of small & commercial sized systems has been raised from just over 50% to over 70% with the corresponding reduction in particulate emissions of over 95%.

Combustion of biomass, including black liquor, currently represents 95% of the renewable energy use in Canada.

Worldwide:

Canada has traditionally been a world leader in biomass combustion. However, during the last decade, Scandinavian countries such as Sweden and Norway have achieved greater national uses of solid fuels by integrating bioenergy plants with district heating, densifying wood waste and producing refuse derived fuels. Sweden in particular has succeeded in developing a strong manufacturing base to commercialize and export the technologies associated with solid biofuels.

Canadian Strengths/Weaknesses - Barriers/Problems:

Strengths include an abundant supply of biomass and an established network of well over two hundred consultants and manufacturers experienced in all facets of bioenergy project engineering and equipment manufacturing. As well, there is a growing number of industries which are beginning to use biomass in a more complete fashion (eg. the pulp and paper industry, a principal user of wood biomass, uses the wood waste component as well).

Barriers include technological complacency, no real industry cohesiveness, market fragmentation and infrastructural problems in some regions.

The tightening of environmental regulations may result in the requirement for more costly emission measuring and control technologies.

There is a double environmental advantage which characterizes this technology area. In most instances, waste biomass feedstock are utilized which would otherwise require disposal and most applications displace conventional fossil fuel.

A waste disposal problem is alleviated and gaseous emissions associated with fossil fuel combustion are reduced. There is a lesser degree of acidification of the environment, a positive contribution to the carbon cycle and minimization of greenhouse gases. For example, 1000 PJ of input energy supplied by green waste wood rather than heavy fuel oil would reduce the net amount of CO_2 emissions in Canada by 55-60 million tonnes annually.

Biofuel production can be an integral part of enhanced forest management programs and job creation schemes at the regional level. Locally, there are the added advantages of less particulate emissions because of the elimination of smoke producing Tee Pee incinerators for waste wood disposal and avoidance of toxic substances leaching as a result of disposal by landfilling.

In the case of municipal solid wastes, combustion represents the only cost-competitive alternative to landfilling. MSW combustion is presently cost-effective, but with more stringent regulatory controls for emissions of particulate and chlorinated compounds, this option may eventually become too costly for all but large installations.

Potential

There is still much that can be technically improved involving current technology which could potentially increase its energy contribution by over 100%. Further technical and infrastructural developments can potentially add as much or more to the current solid wood waste contribution of 120 PJ.

On a national scale, it has been estimated that biomass could supply 25% of Canada's energy requirements, with the lions' share of this energy contribution coming from the increased application of current and novel combustion technologies. For instance, combustion of solid biomass was already accounting for 14% of the total P.E.I. energy consumption in 1987 (primarily in the form of wood chips and MSW).

5.5.3 Biochemical Conversion Technologies[18]

Definition

Biochemical conversion involves the use of microbiological systems such as microorganisms and enzymes, usually in combination with thermochemical pretreatment, to convert abundant, low cost, lignocellulosic materials (biomass and organic wastes) to fuel ethanol, methane, and other chemical byproducts. Their conversion to liquid fuels requires a number of basic unit operations: pretreatment, enzyme production, hydrolysis, fermentation and ethanol recovery.

Status

In Canada:

One of the most currently attractive technologies involves subjecting the pretreated lignocellulosic material to enzymatic hydrolysis, yielding soluble monomer hexose and pentose sugars.[19] These sugars can be subsequently fermented into a variety of fuels and chemicals such as ethanol, and the product recovered using conventional distillation technology or other recovery extraction technologies.[20]

Efforts in the latter are directed toward the problem of ethanol toxicity and the energy intensive product recovery technologies. An extractive fermentation system has been developed at Queen's University, a process by which ethanol is continuously removed from fermentation broths. Reductions in end-product inhibition and energy requirements (as compared to conventional distillation) translate into a notable reduction in the cost of fermentation ethanol.

A 30% gain in enzyme productivity has been achieved and further improvements are anticipated to result from the application of synthetic inducers and advanced fermenter and process design.

Of note, is the trend toward substitution of energy-yielding technologies in place of traditional waste treatment technologies. These treatment alternatives offer the advantage of yielding higher value by-products such as ethanol and fibre (for paper making). The low (or in some cases negative) feedstock costs result in favourable overall process economics. For example, waste sulphite pulping liquors that increasingly contain greater amounts of fermentable pentose sugars (from the greater use of hardwoods in the pulp and paper industry) can now be fermented to ethanol thereby reducing COD loads. This new technology (development initiated in 1982) is being developed by Tembec and Forintek. As well, other waste streams (from the pulp and paper and food processing industries) can now be effectively digested anaerobically to address those specific environmental impacts and at the same time produce methane (usually used as a fuel in the waste treatment process).

Using the most advanced Canadian technology, the present cost estimate for ethanol from biomass is 50-60 cents/L without subsidy. A recent study of the technical and economic limits for ethanol from biomass suggested that with continued improvements in technology, ethanol fuel could be produced at a cost of 24¢/L ± 5¢. This is based on best current laboratory results, and zero credit for lignin.

The cost of ethanol from a "mature" ethanol from biomass process is likely to be roughly 30¢/L. If lignin can be converted to a liquid fuel (likely via a thermochemical process), it would reduce ethanol costs a further 4¢/L. Much also depends on the cost of feedstock which currently ranges from a credit of $20-30/tonne for landfilled waste paper to a cost of $40/tonne for standing timber or conservative estimates for short rotation intensive culture of hybrid poplar at 10t/ha/yr. Reported results in recent years of willow productivity for example are 25 tonnes/ha/yr.

Worldwide:

Although Canada has a lead in conversion of lignocellulosics technology, the U.S.A. and Brazil are major users of ethanol fuels from grain and sugarcane respectively. Approximately 8% of all U.S. gasoline contains a 10% ethanol blend. All of Brazil's transportation fuel is near neat ethanol or a 20% ethanol blend with gasoline. Current fuel ethanol production is 23 million L/year in Canada, 3.2 billion L/year in the U.S. and 14 billion L/year in Brazil.

Many countries have been working on the conversion of lignocellulosics to ethanol and the Iogen Corporation (Canada) is considered a technical leader in enzyme hydrolysis. Sweden has proposed to scale-up the acid-based Biohol process in cooperation with Canada. Although the long-term prospects for further cost reduction are not as dramatic as the enzyme route, there is less technical and cost uncertainty in this scale-up.

Ethanol, when added as a 10% blend to gasoline, has been shown to reduce emissions of CO_2 and CO. Use of such blends has been mandated in some U.S. urban areas where specific geographical and seasonal factors create recurrent air quality problems.

Theoretically, ethanol fuel from biomass is the only environmentally sustainable liquid transportation fuel that does not contribute to the Greenhouse effect. In the short term, blends of ethanol or the production of ethyl tertiary butyl ether (ETBE) can help move towards reducing net CO_2 emissions to the atmosphere as well as significantly lower CO emissions from gasoline as has been shown in CO non-attainment areas of the U.S. (where the use of oxygenated fuels has been mandated).

Canadian Strengths/Weaknesses - Barriers/Problem:

A major technological difficulty in enzymatic hydrolysis is the limitations on enzyme longevity under use conditions which occur as a result of end-product inhibition and inactivation. This is a focus of R&D attention as well as enzyme inactivation and inhibition.[21]

Gains have been made in the areas of enzyme productivity, fermentation, and ethanol recovery. The sum of these unit improvements is a significant movement toward the realization of a commercial biochemical process for the conversion of biomass to liquid fuels and chemicals.

Canada is considered a world technical leader in wood conversion to ethanol via enzymatic hydrolysis. It is also a leader in acid hydrolysis through the Biohol joint venture, although, at 43¢/L without by-product credit, this does not have the long term promise of enzymatic routes.

It is no simple matter for fuel alcohol, either ethanol or methanol, to compete with gasoline. Market entry of E85 (85% ethanol blend) has the same market entry problems of M85 (85% methanol blend). A flexible fuel vehicle is probably required to establish a market for both alternative transportation fuels[22].

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Potential

There are many variables to consider in the introduction of an alternative fuel to the existing, well integrated and mature, transportation fuels industry infrastructure.

Assuming that ethanol from biomass costs are reduced through R&D efforts as expected, the economic impact could be significant and include:

- reduction in subsidies to the agriculture sector through diversification of land use patterns to energy crops such as short rotation intensive forestry or fast growing

grasses;
- reduced internal combustion emissions and their impacts on the environment;
- creation of jobs in agri-forestry, ethanol plant construction and operation; and
- economic activity (regionally and locally throughout Canada) resulting from direct sales of fuel grade ethanol and concurrent multiplier effects.

Increased production of forests on agricultural land would provide an added CO_2 sink as actively growing forests are more effective in this regard than are traditional agriculture practices.

Canada's total ethanol production for transportation use (as a blend) is currently about 10 million litres per year (produced by Mohawk Oil in Manitoba). Pound-Maker Feedlots in Saskatchewan is planning to produce another 10 million litres per year. About 1500 PJ of energy are used in the transportation sector. At a 10% blend, ethanol could provide 150 PJ of this total.

5.5.4 Thermochemical Conversion Technologies[23]

Definition

Thermochemical conversion is the pyrolysis and gasification of biomass and wastes (e.g. used tyres) to produce liquids (usually requiring further refining) useful as transportation fuels, and gases for electrical generation and process heat applications.

Thermochemical processes are also found to yield a variety of high value specialty chemicals (e.g. flavours, aromas) and commodity chemicals (e.g. ethylene, polyolefins, carbon black, activated charcoal) that could be extracted/recovered as byproducts.

Status

In Canada:

A gasification industry did not develop as quickly in Canada as it did in the U.S. during the 1970's. There has only been moderate efforts to improve gasification technology in Canada.

Except for a very old slow pyrolysis industry geared specifically to producing charcoal, there is essentially no industry established in Canada based on the advanced fast pyrolysis technologies[24] that minimize char production and maximize liquid and gas production. Developments in the laboratory initiated less than ten years ago, have progressed to the process development unit (PDU) scale (i.e. 3-10 kg/hr).[25]

Current efforts in this area are to develop commercially exploitable technologies[26] that can thermochemically convert biomass into liquid and gaseous fuels and chemicals for transportation fuels, electricity generation, refinery feedstocks and process heat.

Because a principal objective of the thermochemical technologies is to provide transportation fuels in the long term (beyond 20 years), the research on upgrading is currently at the laboratory scale research level. The current effort in R&D is concentrating predominantly on chemicals production,[27] a more attractive option for industry involvement, and evaluation of the processes on industrial and municipal wastes as environmentally superior alternatives to combustion and landfill. These efforts include the optimization and scale-up of processes proven at the pilot stage, the improvement of fractionation and isolation processes and the development of new methods to upgrade the oils and gases to industrial chemicals.

One area of great interest but which requires further confirmation of fuel stability, engine test specifications and refinery compatibility, is the production of 100 cetane diesel fuel from low quality vegetable oils and waste organic oils (e.g. tall oil from Kraft pulp plants). The technology, if proven in a refinery, has potentially huge impacts. With diesel fuel quality steadily deteriorating and environmental regulations for particulate emissions tightening up, a commercial opportunity could develop over the next ten years and dramatically expand markets for Canadian oilseeds.

Canada has developed one of the world's leading technologies for pressurized fluidized-bed, oxygen-fed gasification of biomass, peat or wastes to synthesis gas. Further processing of the syn gas can produce methanol, other transportation fuels (including gasoline through the Mobil MTG process) and chemicals or ammonia.

In 1885, the Biosyn technology was scaled up to 10 tons/hr before being closed down (1986) due to decreasing energy prices; the near-term opportunity for synthesis gas had disappeared. However, the versatility of the Biosyn technology allows it to operate as an atmospheric, air-fed gasifier that possibly has more near term biomass applications in developing countries and in close-coupled gasification/electricity generation from municipal solid wastes in developed countries. The technology is not yet competitive with synthesis gas from coal technologies.

Worldwide:

Pyrolysis liquids can be deoxygenated in dedicated facilities directly to conventional high octane gasoline blending stock via zeolite catalysis or hydro-treating. This is a mid to long-term option. Some pyrolysis oils however, for example oil from used tires, can be fed directly to refineries in the near term.

Air-fed gasification technology is more mature than pyrolysis technologies worldwide, but has suffered a bad reputation in the late 70's and early 80's when the U.S. public and private sector financed a number of premature commercial projects of immature technology that ultimately failed for technical or economic reasons.

Canadian oxygen-fed gasification technology is rivalled by only one recently constructed plant in Finland. This 24 ton/hr facility is designed to produce synthesis gas from peat for the production of ammonia, but the technology could be used for methanol fuel production ultimately.

Subsidies in Europe will likely help finance the scale-up of pyrolysis processes for electricity from biomass applications there.

Canadian Strengths/Weaknesses - Barriers/Problems:

Efforts are shifting to the pyrolysis of industrial and municipal wastes (including used tires) and the production of chemicals from biomass to capture the advantages of environmental benefits and higher value products respectively. In the near to mid-term, it is possible that these special market situations will help finance the development costs of scale-up in Canada.

Air-fed gasification has minimal need for R&D to dramatically improve the technology. If commercial opportunities are found in the area of cleanly disposing of wastes, R&D in technical support to industry would be required. Weakness may remain in hot gas clean-up in the air fed mode for application to diesel or gas turbine generation.

Wood gasifiers are not at an advanced stage of development; tars and particulate matter generated in the gasification stage pose a challenge in the synthesis gas purification. The economics from methanol from biomass are not advantageous, for example, at the Biosyn site, the estimated cost of methanol from biomass was 18 cents/litre as compared to the equivalent price of 13 cents/litre for methanol from a natural gas plant. Methanol production from biomass is a developing technology, the successful solution of which seems to be hinging on the development of a hot gas clean-up system.[28]

The use of biomass and/or waste derived fuels and chemicals theoretically represents (at this point in time) an environmentally sustainable energy resource with zero net contribution of CO_2 or other radiative gases to the environment. As well, it offers a superior waste management tool to present disposal methods[29].

Potential

The greatest overall improvement in the financial attractiveness and environmental benefit to society of thermochemical processes ultimately will be through R&D efforts that treat biomass as a crude feedstock, analogous to petroleum, where the basic chemical components of biomass (i.e. cellulose, hemicellulose, and lignin) are refined to a range of hydrocarbon products. This strategy encompasses a wide range of process options, not all of which can be immediately explored, but many of which can be studied comparatively inexpensively at laboratory or PDU scale.

The timeframe for widespread market introduction as electrical generation fuels, commodity and specialty chemicals, and transportation fuels might depend as much on the environmental value with which these processes are credited with as on their competitiveness with $20/bbl oil. Otherwise market penetration is limited by oil prices in the scenarios currently envisaged to the year 2000. Total energy impact over the long-term (ie. beyond 20 years) depends on many factors and could range from 0-2200 PJ. Blending of hydrocarbons from biomass and wastes would increase linearly as oil prices increase, or as tax or other environmental penalties are applied to fossil sources.

The energy impact of a high cetane fuel from vegetable oils has not been assessed. The economics indicate rapid uptake of the technology once a major process vendor (e.g. U.O.P., Imperial Oil/Exxon) could be licensed and the technical uncertainties resolved. The option will become more attractive if diesel fuel price rises relative to gasoline due to environmental regulation of emissions. The rate of impact would represent a linear increase as a blending stock with diesel fuel while diesel quality from petroleum deteriorates.

Most of the near term economic impact will be a function of the market penetration of thermochemical conversion of biomass and wastes. This is assumed to be an incremental penetration depending largely upon the availability of other environmentally acceptable alternatives to disposing of wastes such as used tires, unrecyclable plastics, MSW, wood wastes.

The major economic impact (i.e. thousands of jobs, many hundreds of millions of dollars) in the electricity and transportation sectors is likely beyond 20 years, except in special situations such as high value specialty and commodity chemicals recovery. It is noteworthy that special situations are desirable market hooks that help finance the high-costs of scale-up.

It is technically meaningless to simplify a time-frame estimate to a marketable technology when thermochemical feedstock/process/product options are so broad. There are possibly hundreds of unique and specific market applications depending on the resource, the varieties of process configurations possible, and the range of marketable products derived.

The first market application will likely be pyrolysis of used tires within the next two to five years, regardless of energy prices. The marketability depends largely on the success of current on-going negotiations within a recently formed industrial consortium. Within two to three years pyrolysis of peat in Newfoundland may open a small market. Except for potentially large markets for Canadian technology in Europe, Canadian market introduction, except in special situations, is limited (private sector financing of scale-up costs would be incremental).

Its impact as a clean alternative, will likely be felt more as a result of environmental restrictions on combustion of wastes and decreasing availability of landfill sites for municipal solid wastes.

5.5.5 Biofuel Handling/Preparation[30]

Definition

The broad activity of fuel preparation and materials handling pertains to the generation, manipulation and preparation of biofuels. This activity is common to all of the conversion technologies.

Biomass handling includes all physical movement of materials excluding those which significantly alter the material characteristics. It is comprised of several processes including: translocation, transportation, storage, measurement, metering, feeding, mixing, segregation, comminution, drying, compacting, and densification.

Status

In Canada:

Historically, materials handling of biomass has been dealt with commercially using traditional, industrial practices. These practices included the implementation of over-designed systems which were far from optimal. Canadian efforts have provided significant advancement in several areas of biomass materials handling technology and significant developments have been realized.

Specific R&D activities include: collection of fundamental data on solid biofuel handling properties including flow, moisture content, temperature and consolidation parameters; development of effective equipment for on-line continuous measurement of biofuel mass, volume, moisture content, and fuel value; evaluation of low quality feedstocks such as forest industry sort yard debris, demolition wood and municipal solid waste (MSW); and development of equipment to effectively improve biofuel quality, eg. moisture content reduction and comminution.

Improved storage and handling equipment designed specifically for biofuels, have been developed by BC Research Inc. in conjunction with UKAF Industries Inc. (their unique, low powered bin and silo non-consolidating feeder which eliminates uneven bin discharge is now being manufactured and sold). BC Research is currently involved in other developments including: a vacuum drum separator to remove inorganic contaminants from biofuel, and a low powered, dense phase pneumatic biofuel conveyor for translocation.

A rotary ring press developed by the Centre de Recherche Industrielle du Québec and licensed to Kamyr Canada Inc. has been successfully tested for mechanical dewatering of pulp mill classifier sludge. Industrial trials of the ring press by Abitibi Price have established that moisture content can be consistently reduced to 55% and the dewatered sludge then burned in a power boiler yielding a net energy output approaching that of wet hog fuel.

A novel system has been developed by Forintek Canada Corp. for measuring the moisture content of hog fuel. A prototype system is being evaluated under industrial conditions at MacMillan Bloedels' Marmac mill.

The Szego grinding mill has been developed by General Comminution Inc. and found capable of grinding a number of biomass materials with substantially less energy requirements and lower capital costs than other grinding processes.

Studies in peat bog preparation and bearing capacity to develop the peat resources of Newfoundland have shown positive results. Newfoundland Light and Power Co. Ltd. is interested in investigating the feasibility of locating a peat fired electrical generation facility on the Burin Peninsula.

Worldwide:

Systems for biomass handling and preparation are developed in response to the specific needs of the biofuel industry. Therefore, their status worldwide is reflected by the status of the conversion technology for which they have been developed. For instance, in the area of combustion where Canada has taken a leading role, advanced materials handling equipment has been developed which has generated much interest internationally. However, in the area of MSW, where Canada is only now starting to follow the lead of European countries, Canadian materials handing technologies are not as advanced.

Canadian Strengths/Weaknesses - Barriers/Problems:

Biofuels typically exhibit some of the most undesirable characteristics in a fuel material: low energy density, high moisture content, high impurity levels, and unpredictable, extremely varied physical and chemical behaviour. As a result, addressing materials handling difficulties has the potential to dramatically affect the economic viability of bioenergy from the point of view of feed-stock costs.

The interest in reducing feedstock costs has increased the pressure to utilize lower quality biofuels. This has a diminishing effect upon conversion efficiencies and emission performance which in turn puts greater emphasis on the need for cost effective materials handling equipment and practices. Two major problem areas have been identified: fuel quality, and instrumentation.

Potential

Biomass currently supplies about seven percent of Canada's primary energy demand. It has made major contributions in both the industrial (17%) and residential (14%) sectors. Having identified fuel quality and instrumentation as the two major barriers to the further acceptance of biofuels, it is believed that efforts in these areas will have the greatest potential to increase its use. Most of the R&D conducted to date in fuels preparation and materials handling has been near term and its impact on subsequent conversion processes has been immediate. It is anticipated that future R&D activities will progress in the same manner following the changing needs of a growing industry.

Biofuel quality can be upgraded during practically every stage of preparation and handling. For instance, optimization of densification practices is predicted to have a compounding impact on subsequent handling properties, which, in turn will increase convenience and economics. Continued improvements in dewatering and drying of feedstocks will significantly enhance energy density, especially in the area of combustion where moisture reduction not only has a direct effect on burn efficiency but also reduces toxic emissions. Increased efforts in the development of equipment for grinding, shredding, screening and comminution will increase the homogeneity of existing feedstocks and increase the availability of new feedstocks such as MSW and used tires.

Advanced instrumentation and control systems have been proven to increase the efficiency of most traditional industrial practices and their importance in the biofuel industry is now just being realized. The development of more accurate control systems, specifically designed for the unique qualities of biofuels will make a direct impact on biofuel quality.

5.6 Wind[31]

Definition

Wind energy is the kinetic energy in a moving stream of atmospheric air. A wind energy conversion system (WECS) is an aerodynamic device used to convert this kinetic energy into mechanical and/or electrical energy.

A typical WECS consists of a rotor, associated drive train, a generator (where applicable), a tower, foundation work and electrical or mechanical controls. Such a system can generally be classified into one of two groups according to the axis of the rotor: horizontal axis wind turbine (HAWT) or vertical axis wind turbine (VAWT). That a wind turbine is horizontal or vertical does not limit its possible uses. In fact, both types can often be used to address the same needs.

The power output of a WECS can vary from a few watts to several megawatts, and its physical size, from a few metres to over 100 metres high. WECS have the advantage of short construction lead times when a utility wishes to install additional capacity. As well, supply capacity can more closely match load growth.

Status

In Canada:

The use of wind energy to pump water for domestic and agricultural uses dates back to the early 1600's and small windmills to produce electricity to the late 1800's. The sale and installation of windmills peaked in the early 1930's but declined rapidly from the early 40's due to the introduction of rural electrification that reached far into remote farm areas.

Today, there are about 800 water pumping wind turbines operating in Canada. As well, there are about 500 small and medium sized wind turbines across Canada which are used for electricity production. Collectively, these represent a capacity of about 1.5 MW. Another 6 MW of wind energy capacity including project ÉOLE and medium sized wind systems (25 kW to 500 kW) exist in Canada, for a total 7.5 MW.

The Canadian wind industry is composed of a dozen relatively small companies employing about 100 people. Half of them are manufacturing wind turbines for water pumping applications and are mainly located in the Prairies. The second half is manufacturing wind generators of various sizes, capacity and design. The most important companies (Indal Technologies, Adecon, Lavalin) are located in central Canada. Several companies act as distributors for wind systems built in the U.S. and Europe.

Present R&D activities, focussed on the vertical axis wind turbine design (for wind farm applications) and wind/diesel hybrid configurations (for remote communities), include some basic technology research, product development, material research, industry support activities (resource assessment, monitoring, standards, maintaining testing sites, field trials, market research) information and technology transfer activities (seminars, workshops, socio-economic studies, etc.).

Environmental concerns related to wind energy are of a localized nature and have substantially been reduced over the years. Today, noise and electromagnetic interference have been reduced to a negligible level. The visual impact of wind turbines needs to be addressed at the time of siting a wind farm and can be substantially minimized.

Canada has testing facilities for the WECS manufacturer, one at the Atlantic Wind Test Site (AWTS) in P.E.I. and another in Lethbridge, Alberta, the latter for waterpumping testing. These facilities are useful in the development of systems suitable to Canadian applications and to help manufacturers better address the export market.

Standards have also been developed relating to safety, performance, siting guidelines and interconnection with the electrical utilities.

Canada has designed, built and is presently evaluating the worlds largest VAWT - a 4 MW (rated 2.7 MW) prototype called ÉOLE located at Cap Chat, Québec and operated by LavalinTech. As well, through federal support, the Atlantic Wind Test Site (AWTS) on the northern tip of Prince Edward Island operates as a research facility for experimenting and testing prototype and commercial WECS for electrical generation.

In western Canada, a research test station for wind powered water pumps in Lethbridge, Alberta exists under the sponsorship of the Alberta/Canada Energy Research Fund. The site is used for testing and demonstrating the technical feasibility of WECS for this application.

Wind energy systems have been demonstrated in real-life conditions frequently with electric utility involvement. Many of the demonstration projects have been targeted in Canada's remote regions to undertake field trials addressing off-grid power needs.[32]

Support to Hydro-Québec has helped develop a high penetration control system for wind/diesel power plants for off-grid systems. The construction of ÉOLE-D in Germany is also a direct outcome of the joint federal-Lavalin R&D activities in the field of VAWT development.

Worldwide:

Wind energy systems have been used for centuries throughout the world to operate grain mills, water pumps and other machinery. Today, almost all industrialized countries have embarked on wind energy programs with varying degrees of commitment.

It is estimated that more than 2000 MW of wind electric capacity has been installed worldwide. In the U.S. a capacity of 1500 MW, mainly installed in California, is presently providing more than 1% of California's electricity requirement.[33] Another 190 MW of capacity is installed in Denmark and in 1988 produced 290 GWh which was also 1% of the Danish electrical consumption. More than $130 M (U.S.) is spent yearly in R&D activities within the IEA countries where the installed capacity goal for the year 2000 is just below 3500 MW.

National targets (outlined in Table 5) for installed wind capacity established in 1986, show the importance given worldwide to wind energy as an alternative energy source.

Table 5

Some National Targets for Installed Wind Energy Capacity

Netherlands	150 MW by 1992 1000 MW by 2000
Denmark	1000 MW by 1991
China	100-200 MW by 2000
India	250-300 MW by 1991 5000 MW by 2000
Germany	200 MW by 1995

In 1991, Germany is expected to bring in legislation enabling buy-back rates at 90% of the retail rate.

Canadian Strengths/Weaknesses - Barriers/Problems:

Wind energy is an intermittent source of energy and is site sensitive. In Canada the best locations are in East coast regions, in much of the North and in the southern prairies of Alberta and Saskatchewan.

The cost of wind energy generation, although reduced substantially during the past decade, is still higher than the buy-back rates offered by major utilities, even in Alberta where it is supported by legislation. The exception is in remote regions where the cost of fuel for conventional (diesel) power plants is unusually high.

The Canadian wind energy industry is a small and under-capitalized industry. Wind derived energy cannot compete with more conventional energy resources within the present energy pricing situation except in remote regions.

The success of the LavalinTech operation of the large ÉOLE turbine has contributed to a joint venture between LavalinTech and Dornier of West Germany to develop a similar machine in that country. However, from another point of view this may signal the loss of the Canadian "edge" in this technology.

Potential

Canada's remote communities offer utility buy-back rates that make them attractive as a major domestic market for wind energy systems. In these areas, typical fuel costs from diesel-generation can range from 50¢ to 75¢/kWh and in some instances exceed $1.00/kWh. Many of these sites have good to moderate wind regimes.

Because the Canadian remote community market has the most immediate potential for cost-effectiveness, the wind/diesel area has been a top priority for the Canadian wind energy program. However, it is now apparent that grid connected wind farm applications represent the most significant market. Financial barriers need to be addressed before wide scale development can take place.

Wind turbines represent one possible option for sustainable development. Even with vigorously applied demand side management by electric utilities, new sources of electricity will be required and hence all forms of emission free generation are likely to be encouraged. If the electricity produced by wind turbines replace that from coal-fired generation, for every MWh of wind generation, 1000 kg of atmospheric CO_2 would be avoided. (1 kWh = 1 kg CO_2).

It is estimated that the technical potential of wind energy in Canada, when incorporated into the provincial electrical grids, is 24 000 MW of capacity for a 25 year time frame, at which time 44 MWh/yr or 9% of national consumption, would be generated. With a buy-back rate of 7¢/kWh (1990) the capacity would be 4000 MW, providing 2% of national electricity. This represents a capital cost of $6 billion and 85,000 person years of employment. Wind energy can provide for a decentralized industry and promotes regional development.

5.7 Geothermal[34]

Definition

Geothermal energy is the heat in the earth's crust principally derived from radioactive decay and secondarily from conduction from the planet's core. There are four types of geothermal resource: hydrothermal, geopressured, hot dry rock and magma. The rule of thumb is that temperature increases by 3°C for every 100 metres down.

In the strictest sense, geothermal resources are not renewable on a human time scale; reservoirs can be depleted in a matter of decades and hence require proper management strategies. However, this resource does not share the intermittency characteristic of other renewable energy resources and can deliver energy as needed.

Depending on the thermodynamic properties of the extracted fluid, resources can be classified as low-enthalpy systems (30°-150°C) or high-enthalpy systems (above 150°C). The former is used for direct heat, the latter primarily for electricity production. To be commercially viable, the geothermal resource must be concentrated in a restricted volume at accessible depths, and temperatures must fall within a usable range.

Status

In Canada:

The technology is not being actively developed in Canada. Since the early 1980's, there have been no major players involved in the technology. A Geothermal Energy Association exists with about 40 members. In the past, B.C. Hydro spent about $20M in an attempt to develop a major geothermal site at Meager Creek, B.C., a site with potential for over 100 MW of electrical production. However, falling energy prices caused them to drop the program in the early 1980's. With the recent change in the utility's interest in independent power producers (IPP), the site may be reconsidered.

R&D efforts over the last few years have been of a "watching brief" nature focussed on limited resource assessment and feasibility studies. Most recently (October 1990), R&D efforts in this area were eliminated for the time being. There are a few isolated Canadian sites where warm water is used for space heating. There is currently little geothermal energy being used in Canada.

Worldwide:

Geothermal energy technology is a tried and proven technology available "off the shelf". There are a number of countries (17 in total), the principals being the U.S., Soviet Union, Iceland, Japan, Mexico, Italy and New Zealand, exploiting their extensive geothermal energy resources. At the end of 1984, the total installed capacity for direct use of geothermal energy (hydrothermal direct heat) was 7 100 MW_{th} which provided 24 000 GWh of energy. Geothermal electric capacity amounted to approximately 4 800 MW_e in 1985 and is experiencing a growth rate of about 16%/year. The application of this technology in these countries has been helped significantly by a close "resource availability to load demand" relationship.

Canadian Strengths/Weaknesses - Barriers/Problems:

The effort in this area is small due to a weak "resource availability to load demand" relationship. Canada's large land mass and relatively small dispersed population works against the application of this technology. As well, the availability of higher value "electricity producing geothermal energy" is not as great as that resource available for lower valued lower grade geothermal heat.

The environmental impacts associated with this technology can be serious and include airborne emissions, liquid effluents, noise, induced seismicity and subsidence. Since geothermal reservoirs can have a range of characteristics, the incidence, type and severity of environmental impacts from geothermal development are very site specific as well as process specific. The positive side to this problem is that the technology essentially exists "off the shelf" to deal with these problems.

At current energy prices and conditions, the costs are very high to develop the principal type of Canadian geothermal resource (low grade heat).

Potential

Geothermal energy exists everywhere in Canada. The issue is how deep does one need to drill (and incur this significant expense) to obtain usable energy. As economics are a principal factor in this energy source's potential, the opportunity at this time is very limited (also for reasons outlined above). However, there are possible site specific opportunities, principally in British Columbia, which might offer development possibilities. Depending on electricity pricing (it needs to rise), a site like Meager Creek (100 MW generating capacity) could become cost-effective.

6. The Renewable Energy Industry

Firms in the renewable energy industry are engaged primarily in manufacturing, distributing or retailing products which are used to produce energy from renewable energy sources. A first attempt by EMR was made to better understand the nature of this industry in 1990. The data is limited and one must draw observations with care.

According to response rates from a recent survey[1] of firms in the energy conservation and renewable energy industries, 316 firms reported that the majority of their sales in 1987 pertained to renewable energy. In addition, these survey respondents indicated that total industry employment doubled between 1985 and 1987 to exceed 9000 (full-time equivalent) people. However, firms also suggested that during the same period (i.e. 1985 - 1987), the renewable energy industry experienced only a moderate growth in total sales. Reported figures for the passive solar industry likely under represent this area as it has traditionally had definitional problems with energy conservation.

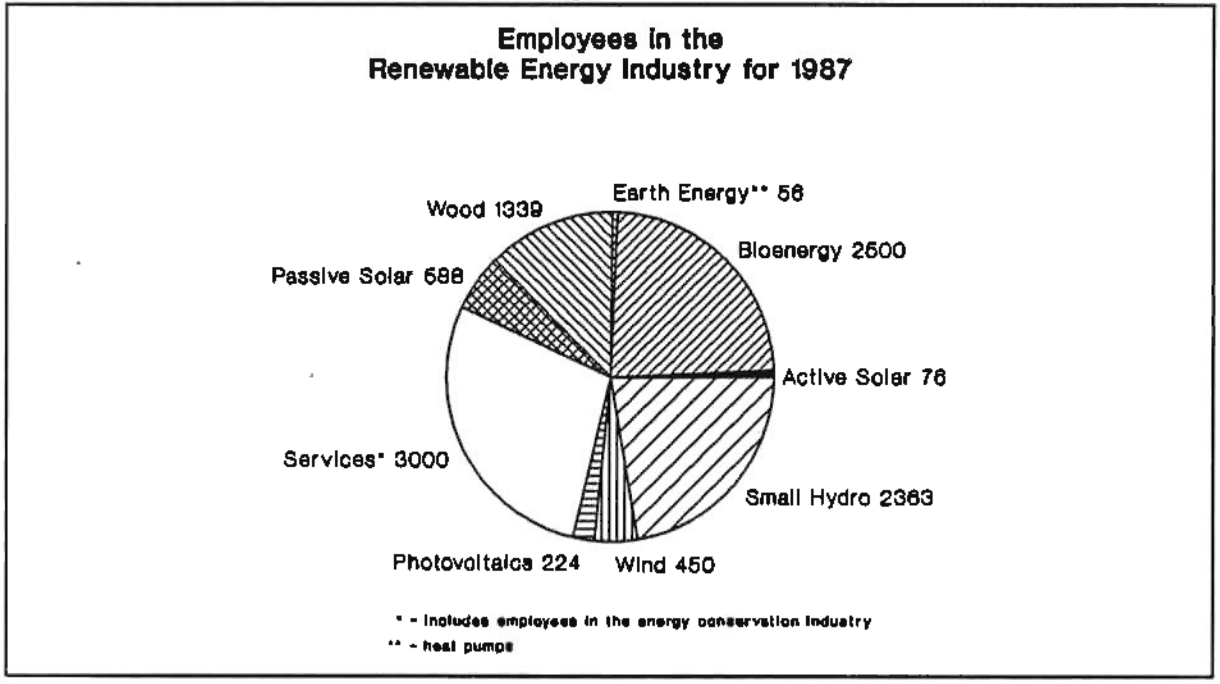
6.1 Employment

Figure 6 illustrates the distribution of employment by sector for the Canadian renewable energy industry in 1987. It appears that in 1987 the majority of employment occurred in the services sector (i.e. services ranging from consulting engineering to project assembly and integration). However, included in this figure is employment associated with the services sector of the energy conservation industry.

In terms of technologies, the bioenergy sector is the largest of the renewable energy employers, mainly because of its link to the pulp and paper industry and other large-scale manufacturing industries. Manufacturers typically produce large industrial wood waste burners for the pulp and paper industry, and small boilers for institutions, or alcohol transportation fuels from biomass sources. Employment in the small hydro sector was second to bioenergy. The majority of this employment is associated with the manufacture or assembly of small hydro generating sites and equipment or related services.

Figure 6 also indicates significant employment in the wood (stove)[2] and passive solar sectors. Nevertheless, firms in wind energy employed less than 500 people in 1987, and firms in photovoltaics, active solar and earth energy accounted for only a small share of total industry employment.

Figure 6[1]



Employees in the Renewable Energy Industry for 1987

* - Includes employees in the energy conservation industry
** - heat pumps

Although it would seem that firms in the active solar sector account for only a small proportion of total industry employment, it is important to note that during the early 1980's a strong manufacturing capability developed from which Canadian products achieved world-wide recognition for their design features and cost-competitiveness. However, as indicated through survey responses, this sector had fallen on difficult times during the latter part of the 1980's as a result of declining energy prices and reduced government support.

6.2 Annual Sales

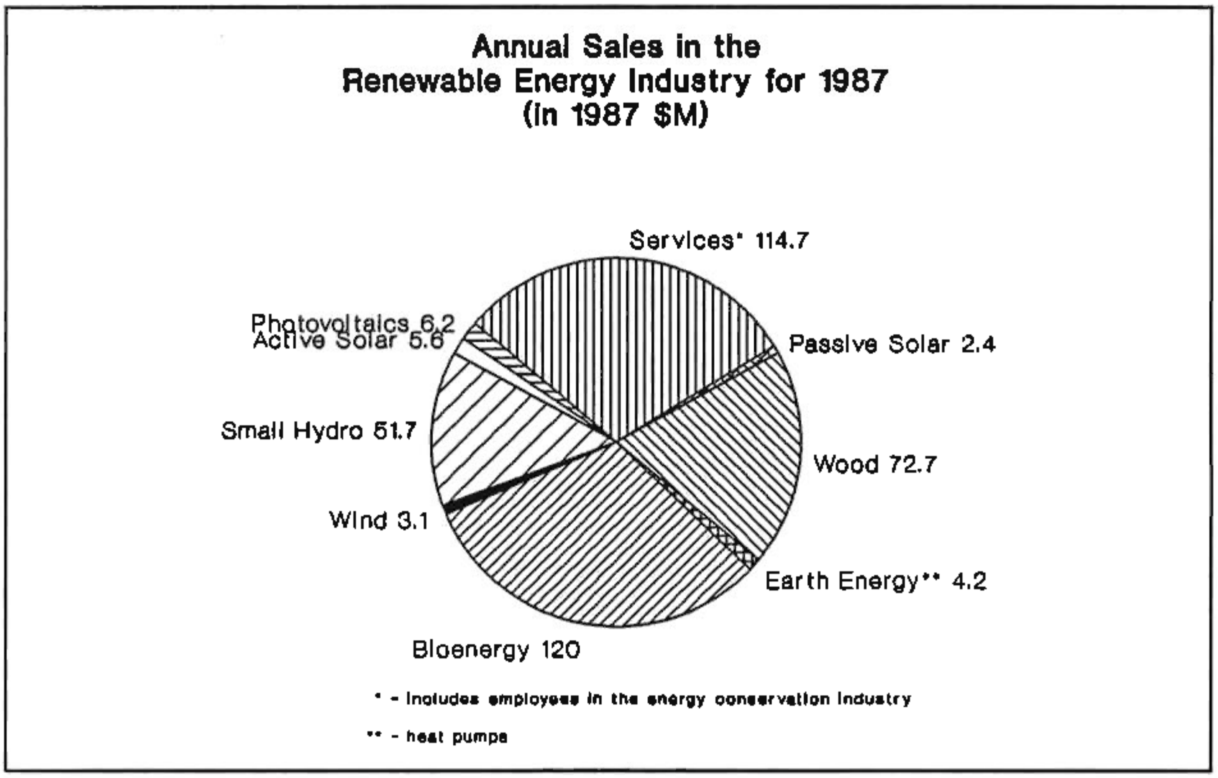
Figure 7 shows the annual sales by sector for the renewable energy industry in 1987. In general, most firms realized sales of less than one million dollars. The bioenergy sector, however, was the exception as 40% of the respondents achieved sales of greater than one million dollars. Total sales in the bioenergy sector amounted to $120 million in 1987 of which $100 million were generated from manufacturing activities.

Although firms in the (energy conservation and renewable energy) services sector reported sales of $114.7 million in 1987, sales by individual firms were consistent with the industry as a whole (i.e.

80% of firms reported sales of less than one million dollars).

Other sectors which achieved significant sales in 1987 included the wood (stove) and small hydro sectors. Sales in the wood (stove) sector amounted to over $72 million. Although firms in the small hydro sector reported sales of $51.7 million, one firm alone indicated sales of greater than $30 million.

Figure 7[1]



Annual Sales in the Renewable Energy Industry for 1987 (in 1987 $M)

* - includes employees in the energy conservation industry

** - heat pumps

Sales in each of the remaining sectors of the renewable energy industry, including wind, photovoltaics, active solar, passive solar and earth energy, were less than 10 million dollars in 1987.

6.3 Research and Development

In terms of expenditures on R&D, firms in some sectors indicated that a lack of government support for R&D has made it difficult to compete on an international basis. However, R&D expenditures by firms in the wind energy, small hydro and bioenergy sectors amounted to significant proportions of annual sales (i.e. an average of 32% for respondents in the wind energy sector in 1987).

In general, reported expenditures on research and development in the renewable energy industry seem to represent only a small share of annual sales. However, most firms that responded to the survey listed technology and quality of product as their key strengths. In bioenergy, for example, Canada is considered to be on the leading edge of technology.

7. Achievements[1]

A diverse array of renewable energy technologies are available today to meet a variety of energy end use demands. Some technologies are commercially available and accepted while others face non-economic barriers to achieving commercial acceptance. Other technologies are relatively mature in a technical sense but not economically competitive in Canadian energy markets except in isolated market niches such as remote communities. Other technologies are at earlier stages in the development cycle and require further technical development.

During the short time the federal government has been involved in renewable energy R&D, enormous strides and successes have been made. Fundamental work on resource assessment techniques, system modelling techniques, establishment of key laboratory and testing facilities, and the development of world-class technologies have each contributed to the advancement of the renewables industry. The establishment of this technical infrastructure is one of the most significant, yet less tangible, accomplishments of federal R&D support. A few examples will help illustrate this key role:

(a) Canada is now considered a world leader in wood gasification, liquefaction, and biomass to ethanol conversion technologies, active solar systems, and large-scale vertical axis wind turbines;

(b) testing and laboratory facilities are now well established to assist the renewable industry in developing and testing new products. The Atlantic Wind Test Site (P.E.I.), the Lethbridge Waterpump Test Site (Alberta), the National Solar Test Facility (Ontario), the Institute national de la recherche scientifique - énergie (INRS) and centres of expertise based out of universities are providing industry with valuable technical expertise.

Characterization of the nature, quantity and distribution of the various renewable energy resources in Canada, such as solar flux, wind intensity, biomass availability, small-hydro sites, geothermal occurrences and peat inventory, is essentially complete and requires only a minimum level of ongoing support.

Wood combustion in the forest industry and, to a lesser degree, in the residential sector, now satisfies about 7% of Canada's primary energy demand. Almost all of this current contribution is through wood waste and spent pulping liquor use in the pulp and paper industry and wood for space heating appliances in the residential sector. This 7% is in addition to the 12 percent contribution made by other renewable energy technologies, mainly hydroelectricity.

In economic terms, the forest products industry saves more than $500 million a year by burning wood and wood wastes rather than oil and other purchased energy. Further, the value of goods, products and services connected with renewable energy sources, excluding conventional hydroelectricity, amount to about an additional $500 million a year. Forest products industries offer significant regional growth potential in both domestic and export markets.[2]

Perhaps one of the more significant program roles in commercially ready technologies has been to show the economic, technical, and in some cases the environmental benefits of using bioenergy conversion technologies in the non-forest industry sector. The use of biomass and municipal wastes to meet process heating requirements has been successfully applied to the health care sector, schools, light industries, municipalities and agricultural businesses. The FIRE program, and the more recent Alternate Energy Development Program for P.E.I. have been critical in the development of new markets for this technology.

Another key accomplishment has been the widespread use and consumer acceptance of residential wood heating appliances. In addition to encouraging their use, the COSP program was instrumental in encouraging the industry to sell "approved or certified" wood heating appliances. Without federal leadership in this area, appliance safety and reliability could have remained as an outstanding issue for Canada's $72 million per year (1984) wood appliance industry. The COSP program, sponsoring over 220 000 off-oil conversions, has had a lasting effect on the industry by directly addressing consumer concern's for safety.

While biomass is clearly the most important renewable energy source and a significant industrial capability exists to deliver and further develop a number of biomass technologies, considerable progress has been made in the development of other renewable energy technologies as well. An industrial capability and embryonic service infrastructure is in place for each of the technology areas, and several Canadian renewable energy companies are recognized as being on the leading edge of technology development.

Although the overall achievements to date in renewable energy have been reasonably significant, renewable energy has not as yet met the original expectations for its potential role formed during the 70's. Energy prices have not risen as quickly as expected, and technology, infrastructure and market development have taken much longer than originally expected.

To conclude with an overall observation of the existing federal RETs effort, the R&D program currently helps provide the infrastructure vital to the development of renewable energy industries, supports development of products and processes by and for these industries and as a result, helps develop world-class technologies at competitive costs. The option of technologies and services made in Canada is preserved, thus helping to create employment and maintain a positive trade balance.

8. References

4. Historical Background

4.2 Historical RETs Evolution In Canada

1) Barclay, J. CONSULTATION PAPER: Renewable Energy Opportunities for Canada. Ottawa: Renewable Energy Branch, EMR, April 1987.

Alternative Energy Technology in Canada. Ottawa: NRC, (NRC's Energy R&D Program 1975-1985), September, 1986.

2) Current university participation includes:

Hydraulics:
- Laval University
- École polytechnique de Montréal
- University of Ottawa

Active Solar:
- University of Waterloo
- Queen's University

Passive Solar:
- University of Waterloo
- Queen's University
- University of Western Ontario
- University of Acadia
- University of Moncton
- University of Guelph
- University of Calgary
- University of Saskatchewan

Photovoltaics:
- University of Ottawa
- University of Waterloo
- Carlton University
- University of Western Ontario
- Institute nationale de recherche scientifique (INRS) - Université du Québec

Bioenergy:
- Queen's University
- University of Saskatchewan
- Université de Laval
- University of Toronto
- University of British Columbia
- University of Western Ontario
- McGill University
- Université de Sherbrooke
- Technical University of Nova Scotia
- University of Waterloo

Wind: - Université de Sherbrooke

Geothermal: - none

4.3 Current Federal Renewable Energy Program

3) Plan of the Energy Research and Development Program of the Interdepartmental Panel on Energy Research and Development of the Government of Canada. Ottawa: OERD/EMR, OERD 89-03, April 1989.

4.4 Expenditures

5) Table 6

IEA Government R&D Budgets for Renewables in $M U.S.

	Canada	U.S.	Japan	U.K.	Sweden	Italy
1978	43.4	675.6	52.2	18.5	34.4	14.3
1979	48.3	915.2	67.4	32.4	68.2	13.9
1980	50.1	1000.0	164.0	28.8	58.0	26.5
1981	77.8	898.4	161.2	41.6	73.7	50.3
1982	65.0	431.4	167.6	31.2	70.7	24.7
1983	71.3	324.9	152.1	24.5	51.9	43.2
1984	55.9	265.7	140.8	27.4	48.9	86.6
1985	33.0	243.5	126.6	23.7	33.3	22.7
1986	19.2	179.6	122.9	19.0	23.1	36.9
1987	16.4	163.2	109.5	22.8	17.0	33.4
1988	15.2	128.5	121.0	23.2	19.1	47.2
1989	14.9	118.3	99.7	23.7	19.3	36.5
Total	510.5	5,344.3	1,485.0	316.8	517.6	436.2

Source: Energy Policies and Programs of IEA Countries: 1989 Review. Paris: OECD/IEA, p. 96.

6) Table 7

Historical Federal Support for Renewables
M$(PY) in dollars of the year

	PERD T4	PY	Other R&D	Demos, Grants, etc.[a]
1974/75	0	0	1	1
1975/76	0	0		
1976/77	1.150	0	3.578	
1977/78	4.950	0		
1978/79	10.236	0	4.216	
1979/80	15.427	5	3.924	3.10
1980/81	15.574	5	.564	23.09
1981/82	21.355	23	.500	54.70
1982/83	28.500	39	.600	54.78
1983/84	36.141	44		54.09
1984/85	39.680	44		51.18
1985/86	20.067	34		39
1986/87	9.871	6	2.581	22.54
1987/88	8.281	2	3.629	11.68
1988/89	9.001	3	3.800	4.188
1989/90	9.682	4	1.600	1.158
1990/91	9.366	3		
1991/92	9.366	3		
TOTAL	252.647	215	25.992	321.41

[a] - from Totals for Table 8

Figures are from best available sources, where available (PERD Database, Input Survey Data for Federal/Provincial Energy Ministers' Conference - Peter Milne, Energy Commodities Sector/EMR, February 1987 and program information collated in preparation of the EED Memorandum to

Cabinet) and are rounded off.

They include:

Science and Technology for Canada's Energy Needs: Report of the Task Force on Energy Research and Development to the Minister of Energy, Mines and Resources. Ottawa: OERD, April, 1975, pp. 44 & 53;

An Inventory of Energy R&D Supported by the Government of Canada: 1976/77. Ottawa: OERD, Report ER77-3, March 31, 1977;

An Inventory of Energy R&D Supported by the Government of Canada: 1978/80. Ottawa: OERD, Report ER80-6E, October 1, 1980;

PERD Databases:	5	(FY 83/84)
	9B	(FY 84/85)
	9D	(FY 85/86)
	10F	(FY 86/87)
	11C	(FY 87/88)
	11C	(FY 88/89)
	13B	(FY 89/90)
	13B	(FY 90/91)

Table 8 Historical Federal Non-R&D Expenditures in Renewable Energy[e]
(M$ in dollars of the year)

	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88
Biomass ERDA						5.355	11.197		
Domestic Hot Water			3.002	1.258	.079	.082			
Fed/Prov Agreements		3.888	5.723	7.375	15.036	9.793	.034		
FIRE		11.606	19.419	11.799	7.069	11.106	10.607	14.741	2.421
P.E.I.(AEDP) Agreement			1.017	1.864	.617				
SEDP					1.195	4.904	4.926	4.977	2.361
Enerdemo[a]						1	1	2	4
RCDP[b]					.432	2.173	.206	.810	2.894
PUSH[c]	1.1	5.5	12.1	17.2	14.1				
PASEM	2.0	2.1							
COSP[d]			13.440	15.283	15.561	16.767	11.034	.015	.002
TOTAL	3.10	23.09	54.70	54.78	54.09	51.18	39.00	22.54	11.68

[a] - estimates are rounded off except for FY 88/89 ($4.188M) and FY 89/90 ($1.158M) - not in table

[b] - estimated 60% of total program funds directed to Renewable Energy projects

[c] - although $125 million was the original program budget, only about $50 million was spent

[d] - estimated 10% of total program funds directed to Renewable Energy projects

[e] - information sourced from material collated in preparation of the EED Memorandum to Cabinet and <u>1982 Solar Policy Review</u>, done for the Renewable Energy Division, EMR, p. 21.

?

7)

Table 9

Renewable Energy R&D Expenditures as a Percentage of All Other Energy R&D Expenditures

	Total PERD*	Task 4 as a % of PERD	Total Energy R&D Expenditures in Canada	All Renewables R&D as a % of Canada Total
1974/75				
1975/76	.973			
1976/77	10.867	10.58	121.0	.2
1977/78	20.863	23.37	162.1	11.4
1978/79	33.568	30.49	139.2	13.3
1979/80	37.328	41.33	257.74	13.31
1980/81	39.337	39.59	293.99	17.84
1981/82	77.948	27.40	337.68	17.21
1982/83	123.134	23.15	396.18	11.5
1983/84	162.569	22.23	432.31	12.55
1984/85	168.184	23.59	376.57	6.24
1985/86	114.256	17.56	336.28	3.38
1986/87	95.237	10.36	300.71	4.16
1987/88	88.814	9.32	328.22	4.23
1988/89	89.077	10.10	352.87	4.24
1989/90	90.098	10.75		
1990/91	91.297	10.26		
1991/92	95.717	9.79		
TOTAL	894.258	28.25	3,834.85	

[*] Total PERD R&D includes: Energy Efficiency (Task 1), Coal (Task 2), Fusion (Task 3), Renewable Energy and Generic Environment (Task 4), Alternative Transportation Fuels (Task 5) and Oil, Gas and Electricity (Task 6). It does not include fission R&D which falls within the responsibilities of AECL.

How much PERD → Task 4

Source: The yearly IEA reviews entitled: Energy Policies and Programs of IEA Countries. Paris: OECD/IEA; and Databases identified in 1) above.

8) Table 10

Distribution of Task 4 R&D Funds by Technology[6]

($K (PY) of that year)

	Hydraulics	PY	Active Solar	PY	Passive Solar	PY	PV	PY
1975/76								
1976/77								
1977/78								
1978/79							660	
1979/80							650	
1980/81							900	
1981/82							1100	
1982/83							1600	
1983/84	1685	2	6878	13	2803	3	1985	3
1984/85	1684	2	6657	12	2786	3	2695	4
1985/86	325	0	3844	11	552	3	502	3
1986/87	536	0	1000	0	900	0	850	0
1987/88	500	0	927	0	850	0	850	0
1988/89	500	0	1291	0	600	0	600	0
1989/90	500	0	1291	0	600	0	600	0
1990/91	425	0	875	0	1066	0	600	0
1991/92	425	0	875	0	1066	0	600	0
Total	6,580	4	23,638	36	11,223	9	14,192	10

Note: Data in the earlier years are difficult to disaggregate due to the nature of the record keeping at that time.

Table 10(cont'd)

Distribution of Task 4 R&D Funds by Technology
($K (PY) of that year)

	Bioenergy	PY	Wind	PY	Geo-thermal	PY	Coordon-ation	PY
1975/76								
1976/77								
1977/78								
1978/79								
1979/80								
1980/81								
1981/82								
1982/83								
1983/84	13274	9	8029	7	1063	1	424	6
1984/85	13895	9	10278	7	1260	1	425	6
1985/86	7239	7	5599	4	397	1	1609	5
1986/87	4383	1	1928	2	65	0	209	3
1987/88	4115	1	897	0	82	0	60	1
1988/89	5073	2	747	0	129	0	61	1
1989/90	5754	3	747	0	129	0	61	1
1990/91	5433	2	772	0	129	0	66	1
1991/92	5433	2	772	0	129	0	66	1
Total	64,599	36	29,769	20	3,383	3	2,981	25

Note: Bioenergy includes earlier program efforts in Peat. As well, data in the earlier years are difficult to disaggregate due to the nature of the record keeping at that time.

5. Technical Background

5.1 Hydraulics

1) Small Hydro and Tidal Power. Ottawa: EMR, Renewable Energy Projects Digest, 1985-88, October 1988.

ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, New Energy Supply Technologies, Small and Low Head Hydro.

Small Hydro Critical Assessment. Ottawa: EMR-CANMET, First Draft, September 1990.

"Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

Renewable Sources of Energy. Paris: International Energy Agency, 1987.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

5.2 Active Solar

2) ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, New Energy Supply Technologies, Active Solar.

"Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

Active Solar Heating in Canada To The Year 2010. Waterloo: Enermodal Engineering Ltd., prepared for EAETB, CANMET/EMR, April 1990.

Renewable Sources of Energy. Paris: International Energy Agency, 1987.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

3) The most cost effective residential application of active solar technology is the heating of swimming pools offering paybacks from 3 to 5 years. The sale of swimming pool collectors is a mature and well-established market. Solar swimming pool systems are reliable, and are being installed without government subsidy. Seasonal pool heating systems in Canada delivery between 280 and 420 kWh per square metre depending among other factors on the length of the pool season. Over 15 000 solar heated pools have been installed in Canada.

5.3 Passive Solar

4) "Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

Passive Solar. Ottawa: EMR, Renewable Energy Projects Digest, 1985-88, October 1988.

Passive Solar Potential In Canada: 1990-2010. Ottawa: Scanada Consultants Ltd., prepared for EAETB, CANMET/EMR, March 1990.

Renewable Sources of Energy. Paris: International Energy Agency, 1987.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

5) EMR works closely with the Canadian window industry as represented by the Canadian Window and Door Manufacturers Association (CWDMA) and the Insulating Glass Manufacturers Association of Canada (IGMAC) in developing the energy labelling procedure. EMR has a Technical Advisory Committee made up of representatives of private sector consultants, university researchers, NRC, window industry and others. EMR also has a close working relationship with the U.S. advanced window program under the Department of Energy to achieve consistent standards and procedures and to share R&D results.

6) Their research lead to the development of simple calculation guidelines, used in computer programs such as HOTCAN (also known as HOT-2000), now used by the R-2000 program. Contracted-out research focussed on specific design issues,

and resulted in the development of Canadian expertise in a range of private companies from coast to coast.

NRC's Passive Solar Test Facility was used for intensive Level A performance monitoring, minute-by-minute for five years. This sophisticated facility provided the data for the International Energy Agency to validate its member countries' computer design tools.

During 1983-1986, over 20 solar houses were subjected to a simpler Level B monitoring procedure. The results showed an average solar contribution of 28 percent - a significant increase over the 12 percent contribution typical for conventional housing. This NRC research led to the following rules-of-thumb for achieving a 20-25 percent solar contribution at no additional cost:

(i) 8-10% of floor area in south-facing windows;
(ii) 15 degrees east or west of south incurs little penalty;
(iii) forced-air heating systems distribute solar gains;
(iv) conventional building materials provide thermal storage; and
(v) low-energy construction techniques.

7) The VISION program, from the University of Waterloo (similar to WINDOW-3 from Lawrence Berkeley Laboratory in the U.S.), allows manufacturers to explore innovative glazing strategies.

A companion program, FRAME, analyzes the effect of spacer and frame design. FRAME shows that improved frame and spacer design can improve a window's thermal performance by up to 43%. NRC is currently testing windows to validate the results of this analysis. The preliminary results have been presented to ASHRAE, who may incorporate the findings in their Handbook of Fundamentals.

8) A window energy labelling program, being developed with the assistance of the window and glass trade associations, the Canadian Electrical and Gas Associations, Ontario Hydro, some provincial representation, CMHC, NRC, the home builders and architectural associations, will be integrated into the existing CSA A440 window standard. Testing and development continues in collaboration with the U.S. DOE to refine and validate procedures.

5.4 Photovoltaics

9) "Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, New Energy Supply Technologies, Photovoltaics.

Photovoltaics. Ottawa: EMR, Renewable Energy Projects Digest, 1985-88, October 1988.

Royer, J. Canadian Photovoltaic Energy Status. Ottawa: EMR, speaking notes prepared for a PV conference (Rome, October 5-6, 1989), September 1989.

Analysis of Commercial Activity in Photovoltaics. Ottawa: Peat Marwick Consulting Group, August 1989.

PV Critical Assessment. Ottawa: EMR-CANMET, First Draft, August 1990.

Renewable Sources of Energy. Paris: International Energy Agency, 1987.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

10) Table 11

Estimate of All Annual Commercial Activity in The Canadian Photovoltaic Industry for 1987-88 ($M)**

Estimate	Manufacturing	Assembling	Distribution	Other	Total
Total	2.3	2.8	7 to 8	0.9	13 to 14
Export	1 to 1.5	1 to 1.5	4 to 5.6	0.5	6.5 to 8.0
For Use in Canada*	0.8 to 1.3	1.3 to 1.8	3 to 3.5	0.4	6.0 to 6.5

** - based on activities reported by respondents and extrapolated to the Canadian industry from the Peat Marwick Study

* - obtained by subtracting export dollar estimates from total

dollar estimates

11) Vikis, A.C., et al. Critical Review of Photovoltaic Research and Development. Pinawa, Manitoba: Whiteshell Nuclear Research Establishment, AECL, August 1987.

5.5 Bioenergy

5.5.1 Biomass Production

12) Richardson, J. "The ENFOR Program of Forestry Canada". Hull, Quebec: Science Directorate, Forestry Canada, prepared for BIOFOR meeting in Edmonton, Alberta, August 27-31, 1989.

Richardson, J. "Bioenergy Research in Forestry Canada". Hull, Quebec: Science Directorate, Forestry Canada, contribution to Forestry Canada Annual Report on Progress in Research, 1988-89.

Strategic Plan for Bioenergy Research: 1987-1992. Ottawa: Canadian Forestry Service.

Bonnor, G.M. Inventory of Forest Biomass in Canada. Petawawa: Petawawa National Forestry Institute, Canadian Forestry Service, 1985.

13) Mycorrhizae are symbiotic relationships of fungi with plant roots which make the plant better able to absorb and utilize nutrients.

14) In short-rotation forestry emphasis is focussed primarily on willows and alders to complement the work with hybrid poplars by other agencies in Canada (Ontario Ministry of Natural Resources, the University of Toronto, Ministère de l'Énergie et des Ressources du Québec) and by the IEA. It will be particularly important to ensure that complete systems for short-rotation management are developed and tested, from clone selection, genetic improvement, and site preparation to harvesting and transportation.

15) Appleby, P.W. Hog Fuel Availability In The South Coastal Region of British Columbia. Forestry Canada Information Report BC-X-297, 1988.

16) McDaniels, T.L. and G.H. Manning. Estimation of the Supply of Forest Biomass For Energy Conversion in British Columbia. Forestry Canada Information Report BC-X-294, 1987.

5.5.2 Biomass Combustion

17) ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, Bioenergy Supply Technologies, Biomass Combustion.

"Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

5.5.3 Biochemical Conversion

18) ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, Bioenergy Supply Technologies, Biochemical Conversion Technologies.

"Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

19) Advantages in enzymatic hydrolysis include: the mild reaction conditions employed, the potential for recovery and reuse of the cellulase enzymes, and the reaction specificity and associated product purity.

20) In Canada, there are 2 small plants (plus one under construction) that convert grain to ethanol for use in 5 and 10% blends of ethanol with gasoline in some 300 retail stations. Generally this technology application is not financially attractive without provincial subsidy and has little room for technology/cost improvements. However, Canada has shown world leadership in technology developments over the past five years in the conversion of low value lignocellulosics to ethanol. Because of lower feedstock costs than grain conversion and a large magnitude in scope for technical improvements in conversion costs, this technology may well be competitive with gasoline within ten years.

21) To the extent possible, process modifications such as the application of simultaneous saccharification and fermentation (SSF) systems are being used to alleviate these problems. More basic studies, employing state-of-the-art techniques (genetic engineering, protein engineering) are being considered as having potential longer term impacts in the area.

22) Blends of ethanol and ETBE in the short term would help establish a market for ethanol and stimulate the production of ethanol plants. The cost of ethanol from wood is expected to be competitive with the rack price of gasoline in five to ten years assuming current and anticipated laboratory results are successfully demonstrated at pilot and pre-commercial demonstration scales.

5.5.4 Thermochemical Conversion Technologies

23) ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, Bioenergy Supply Technologies, Thermochemical Conversion Technologies.

"Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

The Potential of Renewable Energy: An Interlaboratory Paper. Golden, Colorado: SERI, prepared for the Office of Policy, Planning and Analysis, U.S. DOE, SERI/TP-260-3674, March 1990.

24) This technology, generically referred to as fast pyrolysis, has been developed in Canada using three general approaches: a shallow, blow through fluidized bed (University of Waterloo); a multi-hearth vacuum reactor (University of Laval); and a transport reactor employing solid particulate heat carrier (University of Western Ontario/Ensyn Engineering).

25) The Waterloo Fast Pyrolysis Process is currently being scaled up to 100 kg/hr for a special application in Newfoundland on peat to produce fuel oil and adsorbents. Ensyn Engineering is currently designing a 100 kg/hr facility for a U.S. client, based on their R&D experience with Rapid Thermal Processing of biomass. The Laval University vacuum pyrolysis process has been successfully scaled up to 200 kg/hr for a special application with used

tires to provide a refinery crude feedstock for Ultramar and carbon black for a rubber company.

26) Canadian developed laboratory and PDU processes are recognized by the I.E.A. and C.E.C. (European Community) as the leaders in advanced fast pyrolysis technologies. One large Spanish utility has recently signed a research and licensing agreement with the University of Waterloo to scale up their process to demonstration and eventually commercial scale. A number of other European companies are actively trying to negotiate license agreements with Laval University and Ensyn Engineering.

27) Thermochemical processes are also found to yield a variety of high value specialty chemicals (e.g. flavours, aromas) and commodity chemicals (ethylene, polyolefins, carbon black, activated charcoal) that could be extracted/recovered as byproducts.

28) Production of Alcohols and Other Oxygenates From Fossil Fuels and Renewables. Ottawa: EMR, OERD, Final Report, June 1990, pp.17 & 26.

29) Left unconverted to useful energy or other products, wastes ultimately degrade aerobically to CO_2, or anaerobically to CO_2 and CH_4. In the meantime, their stockpiling, or landfilling can create other environmental and safety hazards. Landfilling incurs environmental disbenefits of leaching toxic effluent into ground water, explosion hazards, and the emission of radiative gases, of which, methane is twenty times more powerful, molecule for molecule, than carbon dioxide.

5.5.5 Biofuel Handling/Preparation

30) ADM YEAR-END REVIEW: 1989-90. EMR, Mineral and Energy Technology, Bioenergy Supply Technologies, Fuel Preparation and Materials Handling.

"Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

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5.6 Wind

31) "Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

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32) One of the more noteworthy projects is Canada's first windfarm installed north of the arctic circle at Cambridge Bay in the Northwest Territories, for the Northern Canada Power Commission (NCPC). The system was installed by NorWester Energy Systems of Calgary.

Other installations include:
  Fort Severn, Ontario - 65 kW
  Kujjuaq, Québec - 65 kW
  Belle Island, Newfoundland - 300 kW

A system independent of a grid has also been installed on Calvert Island in British Columbia. The hybrid system, composed of two 2 kW wind turbines, a photovoltaic array and a diesel generator, powers a telecommunications radio site operated by the British Columbia Telephone Company. The hybrid system will save the utility an estimated $18,000 per year in energy costs.

33) In the United States, wind energy has been exploited as a result of federally sponsored R&D programs, legislation enabling small power producers to sell their power to the utilities and a variety of state and federal tax credits. Suitable wind regimes near large electric power demand centres and existing utility transmission capabilities also helped foster the development of domestic and foreign

equipment. More than 95 percent of the wind energy capacity installed in the United States is in the state of California, representing about 70 percent of the worldwide energy capacity. The elimination of the state and federal tax credits has reduced the number of entrepreneurs involved in the development of wind energy projects in the United States leaving the stronger companies. However, European countries have taken the lead and are projecting increased wind capacity over the next 20 years.

5.7 Geothermal

34) "Strategic Technology Assessment Document"; internal report prepared in the Renewable Energy Branch of EMR, Fall 1989.

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2) As opposed to the bioenergy area which includes companies manufacturing and selling products which also combust wood and wood waste, the wood (stove) sector operates primarily

in the residential market.

7. Achievements

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